DEVELOPMENT OF INTELLIGENT MASTER CONTROLLER FOR HYBRIDIZED POWER POOL SYSTEM APPLICATIONS

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY OWERRI, IMO STATE, NIGERIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN CONTROL ENGINEERING

NOVEMBER, 2022

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CERTIFICATION

*This is to certify that this thesis entitled "**Development of Intelligent Master Controller for Hybridized Power Pool System Applications**" was carried out by **Kufre Esenowo Jack (20164994728)** in partial fulfillment for the requirements for the award of the degree of **Doctor of Philosophy (Ph.D) in Control Engineering**, Department of Electrical and Electronic Engineering, School of Electrical Systems Engineering Technology, Federal University of Technology Owerri, Imo State, Nigeria.*

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DEDICATION

This research report is dedicated to Almighty God whose grace and wisdom led to the realization of this piece.

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LIST OF ABBREVIATIONS

ABB	ASEA Brown Boveri
AC	Alternating Current
AF	Afikpo
AM	Amaziri
B	Biomass Power
CAPP	Central African Power Pool
CB	Circuit Breaker
CBs	Cost Benefit
CPU	Central Processing Unit
CSS	Cascading Style Sheets
DC	Direct Current
DCS	Distributed Control System
EAPP	Eastern Africa Power Pool
EEDC	Enugu Electricity Distribution Company
EN	Enohia
GEN	Generator
GUI	Graphical User Interface
H	Hydro Power
HMCI	Human Machine Control Interface
HMI	Human Machine Interface
HTML	Hypertext Markup Language
I/O	Input/Output
IDE	Integrated Development Environment
IMC	Intelligent Master Controller

IoT	Internet of Things
IR	Infrared radiation
KV	Kilowatt
LCD	Liquid Crystal Display
LED	Light Emitting Diode
NC	Normally Closed
NO	Normally Open
OZ	Oziza
PLC	Programmable logic Controller
PV	Photovoltaic
RERs	Renewable Energy Recourses
RH	Routh Hurwitz
RTU	Remote Terminal Unit
S	Solar Power
SCADA	Supervisory Control and Data Acquisition
TF	Transfer Function
TFT	Thin-film-transistor
UART	Universal Asynchronous Receiver / Transmitter
UN	Unwana
UV	Ultraviolet
W	Wind

ABSTRACT

The development of an intelligent master controller model for hybridized power pool system applications has become necessary in the contemporary society where much resources are allocated in a decentralized scenario which does not encourage high productivity. Many metropolitan cities are endowed with several scattered energy resources within its locality and when aggregated in a power pool, its energy resources aggregation for continuous energy supply in order to curtail energy wastage may likely be posed with the challenges associated with uncoordinated system. In view of this therefore, an Intelligent Master Controller (IMC) is proposed to oversee and regulate the unified energy potentials in some metropolitan cities in order to ensure efficiency, reliability, and optimal utilization. In the conceptual framework deployed in this study, Afikpo Metropolis was used as a case study to demonstrate a typical power pool architecture with the intelligent master controller. The network voltage level for the five experimented communities were used with respect to the available energy sources. Programmable Logic Controller (PLC) was adopted for the renewable energy synchronization and hybridization through virtual demonstration; the integration of their hybridized renewable energy sources with other available sources like the public power supply and the generating system were made possible through intelligent master controller. The intelligent master controller operation sequence was simulated with proteus software. The hardware was implemented with electronics components, whereas the remote monitoring and control was achieved with Hypertext Mark Language (HTML), Cascaded Style Sheet (CSS), JavaScript and Hypertext Preprocessor (PHP) design. The HTML, CSS and JavaScript provide an app for human and machine interactivity and MongoDB gives the data documentation platform, whereas the ThingSpeak gave the real time analytical scheme for the system. The result from the software simulation conformed with that of the hardware implementation which reveals that energy from metropolitans' cities could be centrally monitored and controlled using intelligent master control model. This model was demonstrated remotely through the web/Android App, and the energy generated and consumed by the pooled communities were documented in the cloud. The system performance was validated within 6hours of operation, and the system reliability prediction was carried out to ascertain the model functionalities. The developed intelligent master controller model was stable, observable and controllable from the MATLAB simulation result.

Keywords: *Intelligent Master Controller, Programmable Logic Controller, Web Application, Android Application, Remote Monitoring System, Remote Control System*

CHAPTER 1

INTRODUCTION

1.1 Background of Study

An intelligent master controller-based system is a computerized, enhanced dynamic and smart system designed to provide the overall control measures to coordinate the hybridized energy from individual generating communities with their associated storage capabilities within the pool bus. It also provides an interface for the electricity supply grid managers to access their energy markets by coordinating their response towards conditioning the electricity supply system for reliability and efficiency. The system in its design considers the combination of digital and intelligent systems. Digital systems are systems that provide discrete output signals in accordance with the system behaviour. Their input and output are in the form of binary numbers zero's (0) and one's (1). Computer is a digital system because of its digital electronic concepts. Intelligence is the ability of the system to perform its task without much human interference. Controllers are group of devices designed to predetermine the manner, behaviour and performance of a system by regulating its parameters.

The introduction of PLC in power system for the purpose of pooling is as the result of its roles in automation. A Programmable logic Controller (PLC) is a special industrial computer control system designed to constantly oversee the status of input devices and decides based on a custom program to control the state of devices output (Gupta, Giri, & Gupta, 2018) ; (Kumar, Teshome, Muluneh, & Aragaw, 2013).

Whereas SCADA are specialized computer system designed for data gathering and analysis on a real time basis (Kirti, 2014). Human machine control Interface (HMCI) also known as HMI is basically a display device in which the status of the PLC and Process is graphically visualized. The integration of a human machine control interface (HMCI) and programmable logic controller (PLC) in power system control provides a lean automation. The prime difference between SCADA and HMI is in their operational scope. Human Machine Interface is actually just a part of the larger SCADA system (Gupta *et al*, 2018).

The renewable energy resources (RERs) are considered to be an alternative to other energy generating systems in view of its hydrocarbon-based deficiencies which have shown to be unfavorable to the environment. Although availability varies from a specific geographical zone to another, some renewable energy resources such as wind, hydropower and solar depend solely on the climate. Utmost attention is given to urban residents on optimization design scheme to thoroughly harvest the electrical energy generated from the renewable energy resources (Dawoud, Lin, & Okba, 2018). Due to the high quality of generated power, RERs are allowed to distribute generated energy. Renewable energy is characterized with being clean and eco-friendly.

Despite the hybridization of renewable systems, effective and reliable operation is required and this involves the selection of components or parameters to managed the inherent weakness or inconsistency of any of these renewable energy systems as designed (Yang, Yu, Shu, Zhang, Qu, & Jiang, 2018). It is vital for communities not to perceive their available renewable energy resources as being ultimate and unrelated resources rather, a community-global energy system should be combined for higher efficiency, sustainability, effectiveness and reliability. The integration of all the community-based renewable system resources from energy generated from different geographical areas are termed power pool system (Nuño, Maule, Hahmann, Cutululis, Sørensen, & Karagali, 2018). The harmonized arrangement between different geographical areas on energy matters was studied and implemented on a larger grid (Makkonen & Lahdelma, 1999); (Nuno *et al*, 2018). With this arrangement, locally generated electricity forms a micro-grid system for communities to interchange their power outputs. This would however meet up with the energy demand for certain communities. Power pooling requires a continuous optimization system for effective usage of energy in the rural/urban communities. With these harvested renewable energy resources, more technologies for energy storage, conversion and load demand management system (economic dispatch) are required as its conveyance from one location to another may result in some losses (Baral & Kim, 2014). Optimal design and planning have become an integral part of renewable energy systems due to its combinational capabilities and potentials. Within this co-resource's concepts, minimal cost of energy supply and maximum reliability is guaranteed, though this is not a focus for this research. RERs are useful beyond the alternative projection as it is now residentially utilized considering its economic and reliability advantage. This is a positive step in resolving the rural ill-energy system problem (Mohammadi, Ghasempour, Razi-Astaraei, Ahmadi, Aligholian, & Toopshekan, 2018). The incorporation of RERs like wind, hydro, solar, biomass with other energy system enables sustainable development in community-based energy concept (Sansaniwal, Sharma, & Mathur, 2018).

This requires the development of a formidable energy integrating and regulating system, this entails that control engineering principles which include system conditioning for effective and optimal operations is required. These control system principles requires that the system block diagram be formulated; loop and feedback concept developed; the system transfer function derived and the system characteristic equation determined for system stability attainment, and state space analysis be carried out to determine the system controllability and observability. These control system concept help in the design, modelling and simulation of the physical system with the model parameters (Zhang, Zhu, Mobayen, Yan, Qiu, & Narayan, 2020).

An intelligent master controller is designed essentially to have control panels with electrical devices to enable its control actions. This provides a convenient way to operate the hybridized renewable energy resources for power pooling. These intelligent master controllers typically are capable of providing a feedback mechanism to the design system. It is capable of converting an analogue input to digital format and digital inputs to an analogue outputs format as well as initiating an overall system control, monitoring and energy management criteria. With this, a program is developed to relate the outputs and inputs information. Different communities have different renewable energy resources, when harvested, it will be individually utilized but not to its full capacity and some may be left unused and as such wasted. Some communities might not have the full potential for usage thus community with lesser energy potentials can benefit from the surplus of the neighboring community's energy resources (Osueke, & Ezugwu ,2011).

This research looks at the integration of these renewable energy resources (wind, solar and biogas etc.) combined with the conventional grid power system through an alternative energy system (generating set) to provide power to these co-located communities by energy power pooling system. This research is novel in that the pooling system has never been implemented on a community level by the formulation of this model. For simplicity and accessibility, Arduino is adopted for design integration with the HMI, SCADA design, though it is meant for smaller project implementation but will be experimented in this research work. With this design, access will be given to multiple operators with android interface to control and manage the pool system (Allafi & Iqbal, 2018).

Afikpo North Local Government Area in Ebonyi South Senatorial Zone, Ebonyi State, has abundant, dispersed, and irregular renewable resources. These include Solar, Wind, Hydro and Biomass which could be integrated with generators and public power supply for improved power supply. An analog control system is a system in which continuous time controllers are employed to control the behavior of a continuous-time plant and a digital control system includes discrete time controllers together with a continuous time plant, the interconnection between digital and analog part is typically realized through sample and hold device. The increasing complexity of power system requires the use of digital devices; they are widely spread and play an essential task in the operation of power systems (Magdy, 2016). There are many different approaches to designing discrete time controllers for a continuous-time system in a feedback configuration. Hence, this necessitates the development of an intelligent master controller for the renewable energy resources monitoring and control using energy sustainability as the thrust of this study.

1.2 Problem Statement

Many metropolitan cities in Nigeria and other sub-Saharan African countries are endowed with several scattered energy resources within its locality. These abundant, dispersed, and irregular renewable resources include Solar, Wind, Hydro and Biomass which could be integrated with public power supply and emergency power supplies in the form of generators for improved power supply. This would have served the metropolitan cities' agro-allied, small and medium-scale industries for rapid socio-economic development. Unfortunately, despite these abundant and replenishable renewable energy resources, most of these cities are still confronted with the challenges of epileptic power supply. Such poor power supply emanates from lack of unified and integrated energy scheme, absence of smart monitoring and control system to coordinate their dispersed, irregular, and abundant resources for their optimal production recovery.

A typical metropolitan city where the above scenario of abundant scattered renewable energy resources has been extensive researched on is Afikpo and its environ (Akorede, Ibrahim, Amuda, Otuoze & Olufeagba, 2017). It was revealed that no effort has been made to develop and apply smart energy management system for the study area. Other researchers Arowolo, Blechinger, Cader, & Perez, (2019) and Aerobi, Ike, & Nlewem, (2017) who have done related work did not consider Android and IoT applications which would have help aided in long distance remote monitoring and control of the system.

Above all, the inadequacies identified above are heightened by the call for the introduction of an intelligent master controller for the hybridized power pool system applications which has the propensity to centrally coordinate the collaborative energy supply from the hybridized energy system, guarantee continuous energy supply within metropolitan cities, facilitate remote monitoring and control using android devices via internet of things, thus meeting the energy regulatory demand for them in this twenty-first century. These hybrid systems form the source of energy supply to most of the local dwellers. Since their potential in each community vary with different operational conditions, this research takes a look at the already coordinated dispersed resources through a micro-smart-grid configuration for centralized monitoring and control with the use of an intelligent master controller.

The intelligent master controller design deploys full control system concept to bring about optimal operations judging from the following established research gaps: Lack of attempt to design an intelligent master controller with human machine interface (HMI) for power pool system control considering a community-based micro-grid system despite all the optimize hybrid system researched on and implemented (Tehero, 2021); previous research implemented the HMI and SCADA system design without making effort to monitor(Gupta, Kumar, Gupta, & Gupta, 2018); also the failure of one pool agent to generate and integrate its energy into the centralize pool system will not stop other agents from contributing their energy quota to serve in view of the pool design monitoring and control criteria(Dawoud, Lin, & Okba,2018),(Haines & Joyce, 2017); previous research only recommended for hybridized since some communities are energy-endowed than others with different energy potentials and pooling their energy resources provides steady, constant and efficient energy system(Baral & Kim, 2014). There was no attempt to implement the model via Internet of Things and no attempt to introduce remote monitoring and control of Integrated power pool system for community-based purpose using Android application (Sagala, Silalahi & Manurung, 2015), (Yang, Yu, Shu, Zhang, Qu, & Jiang, 2018), and finally there has not been any attempt to introduce remote multiple generators starting system for complete energy integration cycle (Kumar, 2013), (Lu & Yi, 2016). Afikpo metropolitan cities has energy resource similar to the research input as such is likened to benefit from this unified energy concept and therefore would be used for demonstration. This work is aimed at addressing the above unresolved research problems.

1.3 Objectives

The main objective of this research is to develop an intelligent master controller for hybridized power pool system applications. This primary objective will be achieved with the aid of the following specific objectives:

i. To develop an intelligent master controller architecture;

ii. To design a remote monitoring scheme interlinked with screen-touch human machine interface through android application;

iii. To develop and implement software program for the unified sequence of operation for the system;

iv. To develop the performance validation test criteria for the designed system;

v. To carryout system stability and cost benefit analysis for the system.

1.4 Justification of the Study

Standalone and hybrid energy systems integrated into a single energy bus is the pooling concept. All diverse abundant resources in Afikpo metropolis are coordinated for use, thereby curbing energy wastage. A power pool is a system where two or more electric public utilities coordinate their transmitted and generated electricity into a single common bus. This provides an integrated power transmission grid and energy market across communities. The creation and exploitation of the economics of scale in the generation, transmission and distribution of electric power is imperative considering varying energy endowment. This results positive economic spillover effects across the different communities more than that could be generated by individual communities alone (Andrews-Speed, 2011).

Proper management of the power pool system requires a formidable intelligent master controller with a soft-touch human machine control interface for remote monitoring and control (Nugraha, Abdullah & Hakim, 2016). The communities' under-study are rated high in the table of rice processing in Ebonyi south senatorial zone, this necessitates this research. A community-based power system is required for continuous operation of the rice processing plant remote monitoring and control system will enhance energy availability as individual energy resources will complement one another in the event of failure.

Inability to embrace unified power system in the location understudy has made the cost of doing business high. Rice processing which is their major occupation suffered huge set back, but with this hybridized, pooled and centralized monitoring and control system, the energy supply will readily be available for the processing of their mini-factories. Intelligent master controller regulated supply engender rice storage flexibility which foster low cost of rice outside the harvest reason.

1.5 Scope of the Study

The scope of this research covers the design, modeling, simulation and practical implementation of the intelligent master controller using electronic components. The defined scope for this study is the intelligent master controller development with the monitoring and control scheme for the integrated hybridized power pool system, the intelligent master controller uses digital control techniques. The details of the power unified modelling and integration is assumed but not covered in this research work. The research work considered the most suitable and available source of power supply for demonstration but not taking into consideration the quality, quantity (numerical strength of the energy supply) and cost. The undamped natural frequency and damping ratio for the system was assumed since the sources were connected from a known integrated and synchronized bus with same parameters. Energy storage and compensation were not covered in this study. The energy data representing each of the communities under study are assumed with a simulated model whereas remote access system for distant monitoring using Mobile and Web application from an android device with a screen soft-touch control system interface are also the focus of this work. Five communities in Afikpo North Local Government Area of Ebonyi State; Afipko, Amasiri, Enohia, Oziza and Unwana. Enohia community serves as central pool station in this design. These communities were deployed for the demonstration of this model and the design can be applied to any metropolitan city. In the conceptual framework deployed in this study, Afikpo metropolis was used as a case study to demonstrate a typical power pool architecture with the intelligent master controller. The network voltage level for the five experimented communities were used with respect to the available energy sources, however energy and load enumeration were not carried out because emphasis was on the controller development.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Information

Renewable energy, (RE), are energy resources that are naturally replaced on a human time-scale by God for the purpose of continuous illumination and other human pleasurable adventures (Bower, Gonzalez, Akhil, Kuszmaul, Sena-Henderson, David, & Schaffer, 2012). God has potentially provided Nigeria with sufficient capacity to meet the energy needs of both urban and rural communities (Shaaban & Petinirin, 2014). There are several potentials in renewable energy resources in Nigeria (Newson, 2012). These potentials can be used and reused due to their replenish-able nature. These resources are available in our local communities and are used individually either as a standalone or hybrid system. Sources of renewable energy resources are naturally derived from wind power, sunlight, hydropower, waves, Biomass, rain, tides, Hydrogen, and geothermal sources etc. (Shaaban & Petinirin, 2014); (Tiwari, 2014).

2.1.1 Solar Energy

Solar energy is derived from the radiance of light as heat from the Sun reaching the earth and it is one of the inexhaustible, free and accessible sources of renewable energy (Kabir, Kumar, Kumar, Adelodun, & Kim, 2018). The light coming from the sun provides non-vanishing renewable energy without environmental pollution and it is a noise free energy resource (Sharma, Jain, & Sharma, 2015).

Solar radiation is the energy emitted from the sun, and consists mostly of radioactive energy and light. The length path through which light that travels from the sun to the atmosphere is referred to as air mass, this air mass depends on the location of the sun. Solar radiation carries power which has the unit of measurement in watt. The solar power is known as irradiance, the more the irradiances the more the radiation and the amount of power depends on the strength of the radiation, hence there are three types of radiation: the reflected; the scattered and total global radiation.

These are harnessed using various evolving techniques which include: solar heating system, photovoltaic system, solar thermal energy system, solar architecture system, molten salt power plants system and artificial photosynthesis system.

In plate 2.1. the photovoltaic cell or solar cell (PV) is a specialized semiconductor diode designed to convert visible light into direct current (DC). Some PV are designed to convert infrared (IR) or ultraviolet (UV) radiation into direct current electricity such that when light strikes a solar cell, direct current is generated.

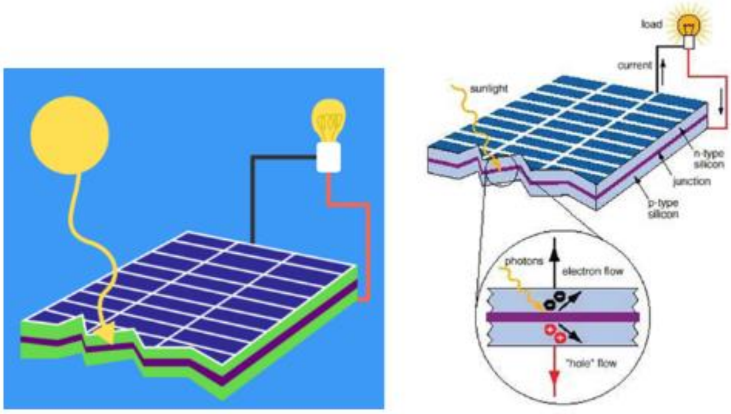


Plate 2.1 : Photovoltaic Cell or Solar Cell Array (Ranabhat, Patrikeev, Revina, Andrianov, Lapshinsky, & Sofronova,2016).

PV technique is one of the best methods of generating electric power through the usage of solar cells to convert energy source from the sun into a flow of electrons (Wasfi, 2011). The era of PV technology with crystalline has gone up to three generations: First generation considers Mono-crystalline (Mono c-Si); Polycrystalline (Poly c-Si); and Amorphous Silicon Cells; The second generation (Thin Film) was characterized by Amorphous silicon, Cadmium Telluride, Copper-Indium-Selenide and Indium-Gallium-Diselenide; and the third generation uses Dye senitised, Perovskite and Organic (OPV) (Ranabhat *et al*, 2016, Sharma *et al*, 2015).

2.1.2 Wind Energy

Wind energy is one of the fastest and growing means of generating power in Nigeria with harmless emission characteristics. Wind energy production is a process in which air in the wind are used to generate electricity (Felix, & Akinbulire , 2012). It has a turbine as a major component that aids in converting the kinetic energy from the wind into mechanical power, thus requires the service of a generator to convert that mechanically generated power to electrical energy which is electricity.

Okoro, Chikuni, & Govender, (2007) evaluated the prospects of using wind energy in Nigeria as one of the major sources of power considering its merits. The research data shows that wind speed from some towns in Nigeria are good enough to provide the required capacity for installation of wind energy system and its conversion facilities.

Ajayi, Fagbenle, Katende, Ndambuki, Omole, & Badejo, (2014) explored the potential of using wind as power source as well as analyising the energy cost in South West Nigerian. For this reason, the study was to expose the region's wind profile and characteristics for power generation. A huge Potential was found on developing wind energy system to increase its capacity to about 60 000 MW with a yearly production progression of about 100 TWh (Jaber, 2013).

The problem faced by the fast-growing population in developing countries is lack of access to electricity supply which is more common in rural areas. The challenge of creating more energy sources in an effort to meet current and future increasing electricity demands led to the development of wind power generation (Dabiri, Greer, Koseff, Moin, & Peng,2015), (Blanco, 2009) as in Plate 2.2.

Plate 2.2: Wind energy system (Dabiri et al,2015)

Royal Academy of Engineering (2014) confirmed that the increasing significance of wind energy in Great Britain gives developing countries like Nigeria favorable energy future. This is because wind would contribute up to 65% of renewable energy supply in 2025 and the potential of integrating it into the grid system is high.

Kaygusuz (2004) researched on the progress and the potentials of wind as the most common renewable energy source, the prospects of wind are high and thus, need to be widely considered. Kaldellis & Zafirakis (2011) confirmed that wind energy system has found a place in the global market in Europe since 2009.

Wind Energy has the following merits (Felix & Akinbulire, 2012): the source of its fuel is clean with absence of harmful emissions; its energy resources do not pollute the environment and its energy does not produce atmospheric emissions which may cause acid rain or greenhouse gasses. However, wind energy resources have the following demerits: It is characterized by noise which may likely damage human hearing mechanism and its turbine design is expensive.

2.1.3 Hydroelectric Energy

Hydroelectric energy generates its power from the movement of running water, in view of its mass, whenever its falls and flows downward due to gravity, it creates kinetic energy in form of motion (Muljadi, Singh, Gevorgian, Mohanpurkar, Hovsapian and Koritarov, 2015). Hydropower has contributed upto 19% of the world's electricity output and this contribution has been useful for large, medium and small power generation and is one of the most widely used renewable energy in the world (Razan, Islam, Hasan, Hasan & Islam, 2012).

This kinetic energy produces a mechanical power. Hydropower system transfers the energy from falling water to generate electricity, thus, converting the kinetic energy of falling water into mechanical energy through the use of a turbine which in turn employs the use of a generator to convert the mechanical energy from the turbine into electrical usable energy (Muljadi *et al*, 2015),(Lajqi, Lajqi , & Hamidi,2016).

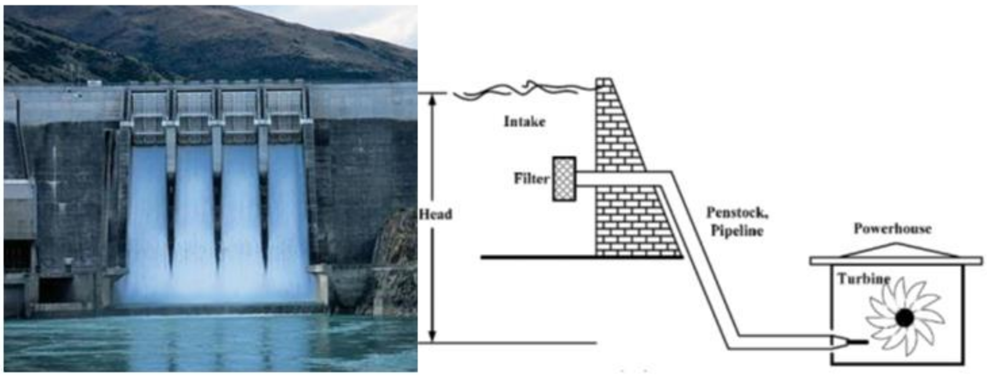


Plate 2.3: Hydro Energy System (Elbatran, Abdel-Hamed, Yaakob, Ahmed, & Arif- Ismail, 2015)

Types of hydropower system, Elbatran *et al*, (2015) are : Run-of-river hydropower, where the flow of water channel through a river canal or penstock to spin a turbine and Storage hydropower which stores water in a reservoir using a dam for its operation. Hydro Energy is known with the following merits (World Energy Resource, 2016); it is fuelled by water; thus, it has a clean fuel source. Hydroelectric power became a domestic source of energy because of allowing each state to produce their own energy without reliance on international fuel sources. Hydro energy has the following demerits (Bunea, Dan Ciocan, Oprina, Băran, & Băbutanu, 2010)**:** hydro-electric power system is likely to affect aquatic life because of its complex interaction between numerous physical and biological factors; it is expensive to construct; it may lead to droughts if not handled properly, and it has limited capacity.

2.1.4 Biomass Energy

Biomasses are organic materials derived from plants and animals' dumps (Ogwo, Dike, Mathew, & Akabuogu, 2012). As one of the important sources of renewable energy, biomass contains stored energy from the sun. These plants materials absorbed heat from the sun through the process of photosynthesis and when biomasses are burnt off, they release heat in form of chemical energy and if adequately harnessed, will help in creating more energy sources. In plate 2.4, biomass has deposits from wood chips, rice, corn, straw, manure, wood, wood waste, sugar cane, and many other by-products from various agricultural processes and some types of garbage, can be used to produce electricity (Omer,2011).

Plate 2.4: Biomass Energy system (Omer,2011) (Gavrilescu, 2008).

Biomasses are organic materials that have the capability of storing sunlight in the form of chemical energy. Biomass renewable energy source has energy released from the sun and it is suitable for community-based energy creation. Though its potential varies from country to country depending on their geographical region (Gavrilescu, 2008). *Biomass types* (Gavrilescu, 2008) includes: wood and agricultural products; solid waste; landfill gas and alcohol fuels. Biomass energy has the following merits (Patra & Sheth, 2015)**:** they are renewable; their carbon are neutral**;** they are cost-effective and they are abundant in supply. However, Biomass energy suffered the following demerits: they are expensive and always require space.

2.1.5 Kinds of Energy System for Small Scale (Community-based) Utilization

Small-scale energy system is used in supplying power to rural communities, and they are made of either standalone (off-grid power system), micro-grid or hybrid:

(a.) Standalone or Off-grid Energy Systems

The standalone energy systems are individual energy systems configured to generate energy independent of the electrical grid. Oladeji, Balogun & Aliyu (2017) explained the need to design a standalone renewable energy system to service the rural and urban area in-view of the Nigeria energy shortage. Their research proposed a low cost and efficient energy system for National Centre for Hydropower Research and Development (NACHRED) built with solar PV, which would essentially help in meeting the electrical load demand of buildings and excess energy which would be diverted to other heavy appliance like Air conditioners. Energy can be generated to accommodate the rural area as a way of helping them in the eradication of poverty using renewable energy resources within their disposal. With this, standalone home energy system was developed for houses with singular loads, and provides less expensive energy system and low-cost maintenance system using solar PV and wind energy resources (Foroogh, Hazelton, Mekhilef, & Borhanazad, 2014).

Perera (2016) states that standalone energy system is suitable for rural electrification. The system was designed and optimized with a standalone hybridize energy system it aids in reducing renewable energy wastage.

In developed countries, there is less interest in the development an off-grid renewable energy system whereas the developing countries have essential need for the off-grid renewable energy system due to lack of energy supply to their rural communities. These serve as alternative energy measures in place of grid absence in the local area (Irena, 2015).

Off-grid energy system is designed to help in supplying electricity to rural communities which do not have the support of remote infrastructure from electrical grid. It is a common practice to develop a standalone energy system for rural dweller because it is cheaper in the long run and simple to operate but it will also be pertinent to integrate other renewable sources into the standalone system configuration to enhance the electrification of the rural locations through the off-grid system (Akikur, Saidur, Ping & Ullah, 2013). The off-grid system can function on a stand-alone basis or as a mini-grids power system, their generation capacity can typically provide smaller community with energy. The encouragement to establish a standalone system was borne out of the challenges of grid system configuration (Siddique, Bin, Yadav, & Gadhauli, 2016).

Dawound *et al* (2018) forecasted that energy consumption will be raised by 35% between 2008 to 2035 as far as the energy market is continuously increasing with the increase in population and economy. Mostly the standalone power systems are used for small scale energy generation.

Belmili, Boulouma, Boualem, & Fayçal (2017) worked on the conversion and optimization techniques for PV- wind system under the standalone arrangement. In their quest to introduce an advanced way of controlling DC to DC as well as DC to AC regulatory system from PV-Wind standalone system. This is to say that standalone systems cannot be rollout simply because out of it emanates combine and hybrid system configuration, thus; this it was needless to develop a micro-grid system from it.

(b.) Micro-grid tie Power System

These are the power system arrangement that interconnect the generated renewable sources at smaller scales. Renewable energy resources are environmentally friendly means of generating and storing of electricity considering the enabling energy policy and regulations. The micro-grid systems provide a unique opportunity for the integration of renewable resources into a single distribution network (Abdar, Chakraverty, Moore, Murray, & Loparo, 2012). Micro-grid systems are small-scale types of centralized energy systems where smaller scale distributed systems and renewable energy resources like wind, solar, Biomass etc are interconnected. They are equipped with suitable energy storage facilities which provides energy closer to point of usage. Considering the impact of micro-grid system in developing countries, Tushar, Zhang, Yuen, Smith, & Hassan, (2016) developed a model for the management of the micro-grid systems, their scheme was capable of improving power quality, network efficiency, reliability and maximizes renewable resources usage in a smart grid scenario. Camacho *et al* (2011) opined that there are several benefits in embracing the smart/micro-grid energy system configuration.

Abdelkader, Meriem, Ilhami, & Korhan (2017) developed a smart grid system with renewable energy resources to be used in Algeria; this was as a result of increasing demand for electricity due to the geometric increase in their population. The smart system also helps in monitoring and controlling the renewable energy utilization; solar energy system finds its usage in electrical grid application in Florida (Bower *et al*, 2012).

(c.) Hybridized Renewable Energy Systems

The combination of several energy sources that are above two in order to meet up the load requirement for a particular community is the concept of energy hybridization (Dawound *et al*, 2018). In this scenario, any shortcoming from one energy source will be complemented by another natural source. Hybridized energy systems are combination of several renewable energy sources to form a single integrated, efficient, sustainable and reliable power source. Hybridizing (combining more than two renewable energy sources) these resources for the efficient generation of energy in power system is rapidly increasing in the present time. A few examples of renewable energy resources are wind energy, solar energy, hydro energy, tidal energy, geothermal energy etc. Among these renewable energy resources, solar or photovoltaic (PV) and wind turbines have low environmental impact and ease of generation. With these, the system which consists of two or more renewable energy sources are combined to provide increased system efficiency and larger balance in energy supply (Pranav, Afsal, & Krishnan, 2017). It is becoming increasingly interesting that energy efficiency has improved as the hybridized renewable system design evolves. The hybrid renewable energy systems technology finds its vast application in power generation though mostly associated with issues and challenges in its design stage (Ibrahim, Khair, & Ansari, 2015).

The following are combination of hybridized renewable energy systems:

(i.) Hybridization of Wind and Solar Energy System

This hybrid energy system combines wind and solar energy technology for the production of electric energy, these hybrid systems have several merits. When operated individually, that is solar energy system alone and wind energy system alone there are many limitations. During dry season, the wind speeds are low but the sun shines brightly and for longer durations, but during the rainy season, wind speed will be high and intensity of sunlight will be less. That is the peak operating time for wind and solar system occur at different times of the day and the year. Hybrid systems have a likelihood to produce power when needed (Pranav *et al,* 2017). Wind and solar energy are the most widespread inexhaustible sources of energy. Wind is a free source of energy that generates power exponentially, but it is irregular and random. On the other hand, availability of solar radiation cannot be determined due to various climatic changes. They are intermittent and unpredictable and hence, hardly used for generating base load power. On the contrary, their nature of complementing each other and world-wide availability supports their hybridization (Bhattacharjee, & Acharya, 2016).

(ii.) Hybridization of Wind Solar and Diesel Energy

Numerous hybrid systems, which operate off grid, are not connected to electrical distribution systems. At times when neither solar nor wind system generates electrical energy, these power systems provide a backup supply through diesel generating system, which is powered with non-conventional fuels such as diesel. When the power generated by the renewables sources is low and does not meet the energy demand, the engine generator produces power and thus provides the continuous energy supply. Integrating an engine generator makes the system more complex, but modern controllers can operate these systems automatically (Pranav *et al,* 2017). An engine generator also reduces the bulk of the components needed for the system.

(iii.) Other Hybrid Energy Systems

The design of a system or the choice of energy system depends on several considerations such as the cost of hybrid technology and availability of natural resources. The different systems combined and made to work as hybrid system are such as wind-hydropower system, solar-hydropower system, solar-wind-geothermal systems etc.

Although the combination of just two or three of these hybrid systems work efficiently, it is still not satisfactory to be used, since it is not intelligent enough to know when to use one source instead of the other. This research designs a system model that gathers electrical power from all these hybridized sources, integrate them, control, analyze and further redistributes the total power generated to each community regardless of the amount of power contributed by each individual source, this is referred to as Power Pooling. The system also uses micro-controller technology to effectively manage and control the switching operations hence toggling from one power source to the other to make the system economical.

(iv.) Afikpo Renewable Energy Potentials

In North local government Area in Ebonyi State, Afikpo and Unwana were one of the identified non electrified cluster communities. The survey carried out reveals that with the population of 20,940 and the renewable energy potentials available can provide the communities with about 28,621 load KWhrs/day from its renewable energy resources and suggested a pathway to energy harvest and management (Arowolo et al., 2019). Similarly, Afikpo North was listed among the local communities in Nigeria that has the capacity potentials to providing upto 20MV for its dweller from hydro-electric energy system (Akorede et al., 2017). Energy situation in Ebonyi state was also carried out and analysis shows that the status of renewable energy available for utilization is plenteous with its maximum solar irradiance ranges from 895.70 W/m^2 to 1043.83 W/m^2 if harnessed and manage effectively can provide sufficient energy supply can generate sufficient electricity for both domestic and industrial use (Nwofe and Ekpe, 2014). More so, Anerobi et al. (2017) carried renewable energy impact assessment in Afikpo Metropolitan city and the research results shows if these available resources are integrated it would provide sufficient energy to compliment the effort Enugu Electricity Distribution Company of Nigeria (EEDC) in the area. Their survey uses an artificial neural intelligent agent for its simulation and modelling analysis. Similar pool concept was developed and modelled by Ezugwu, Dike, Okozi, Olubiwe & Paulinus-Nwammuo(2019) for collocated bank application in Owerri but without enabling controller to manage their energy resources. Tehero (2021) opined that access to electricity in west African countries could only be achieved with the introduction of power pool system and validates that despite the existence of many sources of primary energy in our locality, there are still no access to electricity.

2.1.6 Issues and Problems of the Hybrid Energy Systems

1. Hybrid energy systems require efficient storage devices such as batteries, and these batteries are needed for continuous monitoring.
2. The problem of optimum power dispatch is one of the major issues in hybrid energy system.
3. Most of the hybrid energy systems are weather dependent.
4. Stability is another problem faced by hybrid energy systems, since power are generated from different sources, as such sudden change in the output power from any of the sources is likely to significantly affect the system stability.
5. Load sharing among other numerous factors decides the power allocation within a particular area. These includes the reliability of the source; economy of use and the switching require between the sources etc.

2.1.7 Hybrid Optimization Model for Electric Renewable (HOMER) Design

National Renewable Energy Laboratory in the United States developed HOMER software for the design of hybrid energy systems. The systems handle and evaluate both technical and financial issues emanating from off-grid and on-grid power systems remotely. It is also serves the stand-alone and distributed generation applications, this is one of the example of HOMER design for the hybridized power system with simulation result in fig. 2.1.

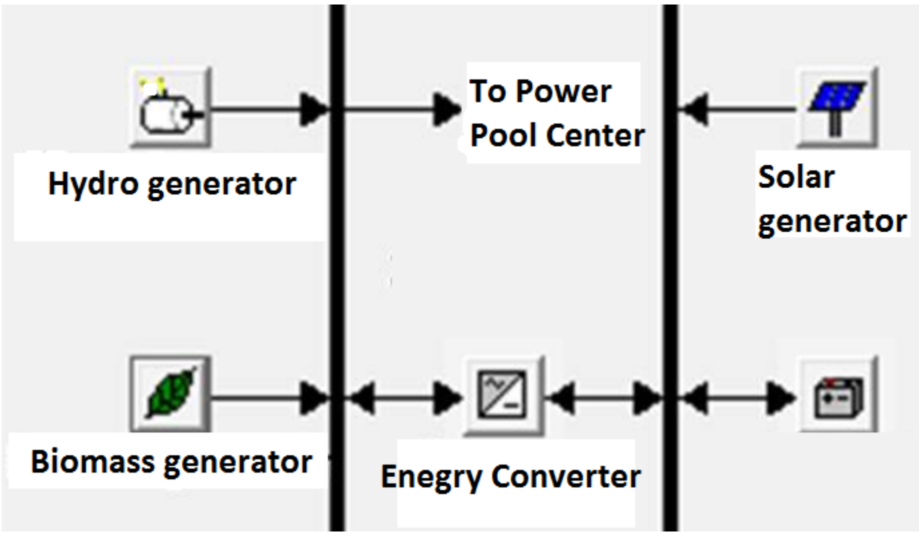


Fig. 2.1: Diagram of Hybrid System representing the Pool Contributors Model (Dawound et al, 2018)

2.2 Energy Power Pool System

The power pools operation were analyzed and optimized with different kinds of system model to realize the desired output. Several policies aimed at allocating common resources to the benefits of a power pool member were looked into which lead to the development of a new algorithm and this new algorithm would be helpful in balancing the pool system. These were the cases of Northern European countries: Finland, Sweden and Norway (Makkonen & Lahdelma, 1999); (Igbinovia & Josef, 2014) as in fig.2.2. The regional power interconnectivity was proven to be one of the major solutions to energy demand. The market simulations for the aforementioned countries were carryout. The traditional and current markets were simulated and analyzed. Model was developed for short, medium and long-term market Implementation including the pool sharing and benefits distribution among members. The model was based on the commercial **EHTO** (Energy and Heat Trade

Optimization) energy optimization. The analyzed data were based on real time life example. Pool members were classified according to the following:

(a.) **Producers' Pools:** These are pools that help in optimising members' production with central management without undue start-up or shutdown systems.

(b.) **Consumers' Pools:** These pool classifications are based on the economy of scale; the diversity of load curves; increased market power, and centralised demand side management.

(c.) **Distributors' Pools:** This classification takes a look at the combinational benefits that exist between the producers' and consumers' pools.

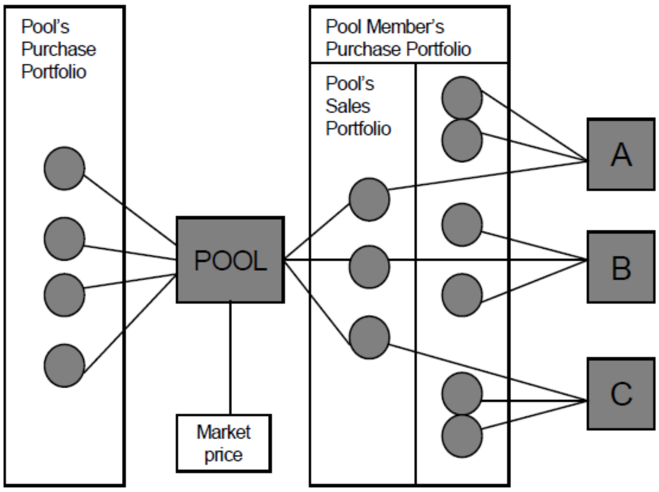


Fig. 2.2: Power Pool System arrangement adopted from (Makkonen & Lahdelma, 1999)

Igbinovia & Josef (2014) named the existing power pools agencies in Regional Economic Communities to include: The Central Africa Power Pool (CAPP); the ComitéMaghrébin de l'Electricité (COMELEC); the Eastern Africa Power Pool (EAPP); the Southern Africa Power Pool (SAPP) and the West Africa Power Pool

(WAPP). For years, the power distributing control center at all levels in our country has slowly established a practical dispatching automation system, which plays an important role in guaranteeing the dispatching and production to the power grid. Nonetheless, there is a big gap with the new requirements for the continuous development and reform of the power grid, mainly in the given aspects:

(a.) The operation characteristics of the power grid are increasingly complex, and the difficulty of security control is constantly increasing;

(b.) Economic dispatch requirements of energy saving and lean management are increasing, and the optimization level of power grid operation needs to be improved;

(c.) Natural disasters have caused frequent impact of the super defense failure, and the security line needs to be expanded continuously;

(d.) The technical support system has begun to take shape, but the ability to evaluate and manage the credit risk needs to be improved (Wang, Ge, Ge, Wang, & Li, 2018).

In order to solve the above problems, this research employs a system called power pooling using a computer-based control system technique. As one or more power transmission system operators physically connect their power transmission equipment, they form an interconnection (Zimba, Nyamutswa, & Chikova, 2017), this integration of different system operators is the Power pool system. Such system was developed for use in West Africa to provide sustainable strategy to diversify from hydro and gas regional projects and invest in solar PV in order to improve electricity supply and reduce the high electricity prices in the region (Adeoye & Spataru, 2018) as in plate 2.5. This design adopts similar concept but in a micro form.

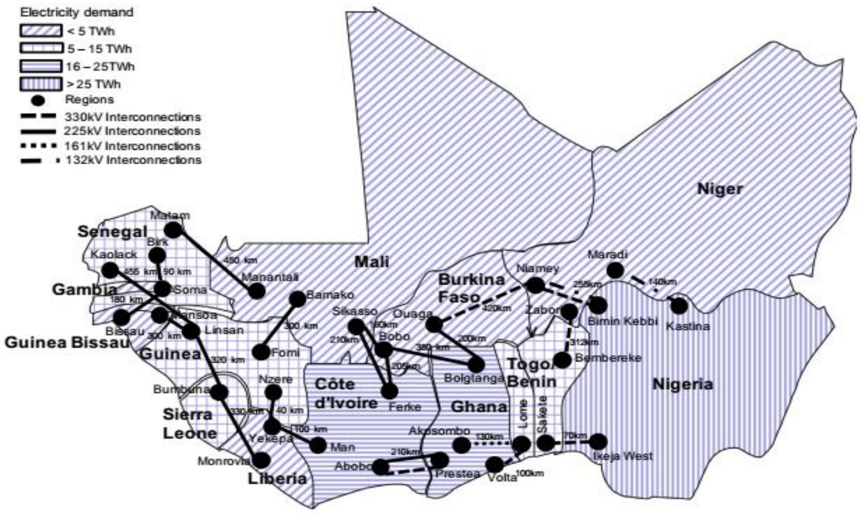


Plate 2.5: West Africa Integrated Power Pool System ((Adeoye & Spataru, 2018)).

This research limits its scope to five co-located communities all having hybridized sources of electricity. These power pool systems have to be implemented in a more optimized setting with a computerized control system. This computerized system has a soft-touch remote control, monitoring capability, Human Machine Interface (HMI) and mobile application for operator flexible accessibility.

2.2.1 Power System Control and Management

In some remote areas, power supply through grid extension seems to be exorbitant and not feasible to manage. As such, alternative energy sources such as solar, wind, hydro and biomass, are easily managed and very much needed to solve rural power problems. Because of cost and effectiveness, a hybrid renewable energy system is widely adopted as today's private energy system. The hybridized system as compared to single energy system requires a proper management scheme. Although it is very much dependent on the weather conditions but its interconnections help in providing constant and efficient power, because weather condition in one zone effecting the supply may not be the same in another zone. The weather dependent nature for the renewable sources leads to power supply instability, thus energy control and management play important roles to meet the demand and supply targets in order to minimize energy system instability. Wang *et al*, (2018) provides easy power management of the hybrid renewable system where supplying good and quality power to the various communities is made possible. The research described a power management and control system as developed based on a rule-based power distribution strategy for a hybrid system. In addition, the power distribution strategy is integrated into the host controller.

2.2.2 Selected Communities for Energy Pooling Experimentation in Ebonyi South Zone

From the thirteen communities in Afikpo North Local Government Area, five communities were selected for the experimentation of this Model. These five communities were selected based on the following: Renewable Energy Resources Availability; Available energy record via its load demands, Business energy demand and the level of their proximity to each other. These communities are: Enohia-Itim; Oziza; Afikpo; Amaziri and Unwana. Research findings show that their population and the type of business they do with diverse natural resources, energy co-ordination is required. These in turn necessitates a specialized controller for efficient energy management.

2.3 Human Machine Interface (HMI)

A human-machine interface is any platform that allows transfer of information and commands from the user to the machine or control device. It is needed for effective control and information transfer in a system. In this research, an HMI is used to automatically control switching of various sources and monitor the power output and input levels of the system. For this design, soft and hard-touch HMI is used. The soft-touch is implemented by a mobile application on an android device, while the hard-touch HMI is implemented using switches and buttons on the hardware design panel. A human machine interface is a software application which presents the system information to an operator (user) showing the state of a process and provides the user the opportunity to accept and implement operator regulated directives. In another machine language, the human machine interface is likened to the traditional Graphical User Interface (GUI). Human Machine Interface is commonly used in manufacturing industries to visually mediate between the user and device in order to regulate the system behavior for optimal efficiency. HMI is the user interface that relates the operators command to the regulatory mechanism of the system. HMI is not a standalone system; it incorporates other embedded and non-embedded systems such as PLC, SCADA etc. For this reason, human machine interface (HMI) and its counterpart programmable logic controller (PLC) are integrated to provides clear solution to automation technology. HMI interface are both software and hardware driven (Deshpande, Vibhute, Choure, & Smitha, 2016). In many situations, HMI provides a window-based communication link between the user and the machine.

Human-machine interface (HMI) is a device that is capable of handling human and machine interactions, since its interface are made of hardware and software components, it enables the user inputs and translate the information to the machine understandable signals (Gupta *et al*, 2018).

2.3.1 Human Machine Interface Operators Panels

This is the description of the general housing that accommodates all the power pool control and monitoring interfaces. It also shows discrete devices as well as simulate panels showing all the hidden process lines on the hybrid community-based power pool system. This platform permits the interaction between users which is the power pool operators and the interconnected automation power pool equipment. In this design, provision is made for numerous communication ports for fast communication, expedient control of diverse range of machines, systems facilities and low LED indicators for the design.

Plate 2.6: A Simple HMI terminal panel with touch screen panel display (Gupta et al, 2018).

Plate 2.6 shows the touch screen panel with the display of the control switches, this touch screen graphical interface allows humans and machines to interact. The human machine interface panel basically comprises the followings: Switches /pushbutton; virtual wires; metering devices; lighting/indicator and alarm/trip systems.

(a.) Switches & Push buttons

These include the **ON & OFF** power system gear/button on the pool virtual dashboard of the final product. Push button switch is a switching device with small sealed mechanism that when the circuit is completed by pressing the contact, an electric current pass through it. At ON stage its small metal spring inside makes contact with two wires, allows the flow of current. There are of two types: the normally open (NO) and the normally close (NC). The NO contacts are closed when it is energized and NC contacts opens when the switch is actuated.

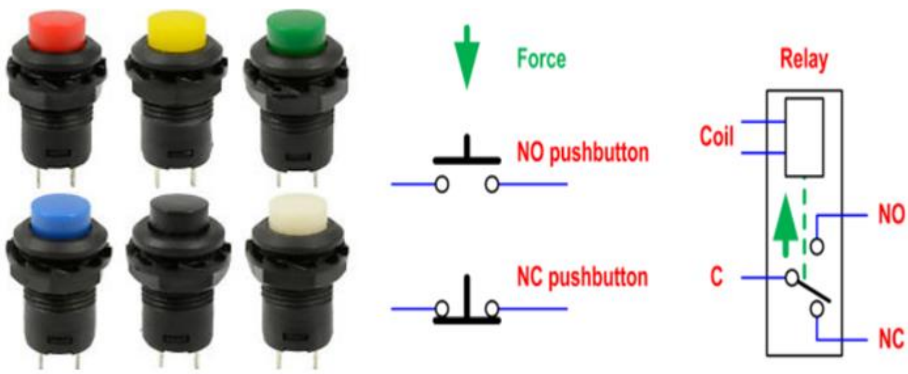


Plate 2. 7: The ON/OFF Push Button Switch with (NO & NC) Contacts (Gupta et al, 2018).

Plate 2.7 shows the 12V ON/OFF Latching push button switch for the power pool Dashboard. This push button switch controls the inlet and the outlet of each of the pool contributed energy.

(b.) Virtual wires

This traces how the visible and invisible interconnections of the power system and pool devices are linked. In a virtual wire deployment, the installation of a firewall transparently is made on a network segment by binding two firewall ports (interfaces) together. This is achieved such that each virtual wire interface directly connects to a Layer 2 or Layer 3 network device or host. With this the virtual wire interfaces have no Layer 2 or Layer 3 addresses.

(c.) Metering devices

These show the levels of various energy utilization and indicates the frequencies in which each pool operates upon. The metering device can either be digital or analogue.

Plate 2.8: Metering device on the HMI Operators panel (Gupta et al, 2018).

(d.) The Light and Alarm Panel

These designs are made with discrete panels that light or blink with each alarm in accordance with the power operation from the pool contributor and buttons are used to acknowledge each alarm point for each pool agent. Safety instrumented system (SIS) alarm and trip strip system are connected together. The alarm alerts the operator when the system is malfunctioning whereas the trip system turn the system OFF when the alarm has completed it preset time.

Plate 2.9: Virtual Alarm and trip configuration in Human Machine Interface (Gupta et al, 2018).

(e.) Trend

Trend functions as a database that records previous power pool system operational information for future applications.

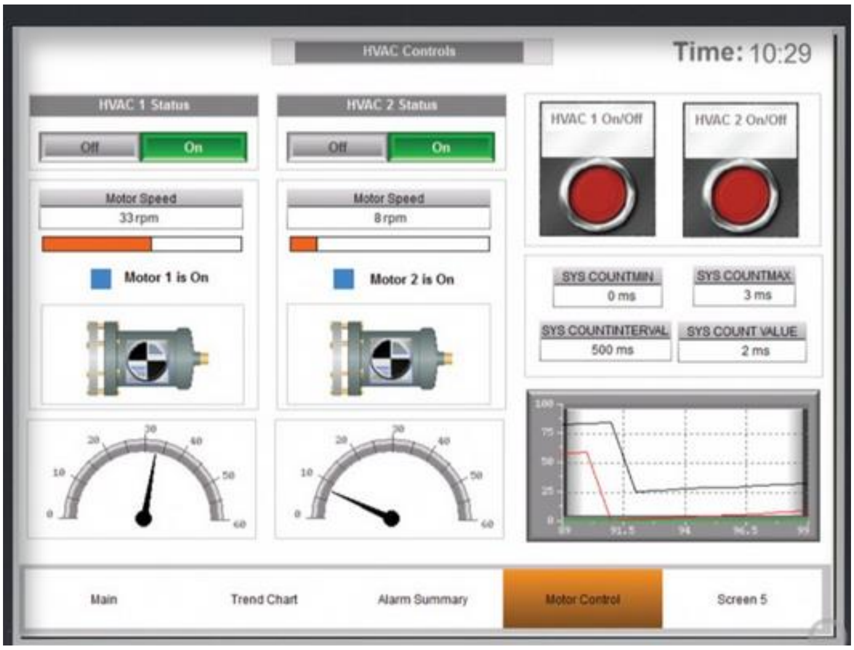


Plate 2.10: Trend in Human Machine interface (Gupta et al, 2018).

The trends are the graphical expression of the behaviour of the plant. they are of two types:

i. Real-time trend displays only the present state of the process with graph.

ii. Historical trends display the present and the state of the process with graph.

The basic information requirements for the HMI are as followings:

1. Input signal device (Human)
2. Process and translate signal(interface)
3. Output Signal (Regulated Machine operation sequence)

Plate 2.11: Human machine Interface with feedback configuration (Normanyo, Husinu, & Agyare, 2014)

(f.)Applications of Human Machine Interface (Ardi & Ardyansyah, 2018)

1. They are used in automation industries
2. They are used in pharmaceutical and food industries
3. They are used in Process industries

    a) Oil and Gas

    b) Mining

c) Power and Energy

4. Building/Home automation
5. Digital signage
6. Vending machine
7. Medical
8. Education
9. Manufacturing
10. Transportation

A user interface with dashboard that connects a user to a machine, system, or device is referred to as a Human-Machine Interface (HMI). Technically it is a screen that allows person to interact with a device. It is commonly used in industrial settings (Pradhan & Priyadarsini, 2018).

Plate 2.12: Screen Touch HMI (OFF/ON) with trends (Lagari, Nasiakou, Fainti, Mao, Tsoukalas, Bean, & Alamaniotis, 2016)

In industrial scenarios, HMIs can be used to (Lagari *et al*, 2016):

i. To display data visually
ii. To track the production time, trends, and tags
iii. To monitor machine operational inputs and outputs

(g.) Various forms of HMIs

i. Built-in screens on machines
ii. Computer Monitors
iii. Tablets

2.3.2 Types of Human Machine Interface

(a.) **The Pushbutton Replacer HMI**: In pushbutton replacer HMI the button are centrally arranged to one location from each of the functions. The pushbutton replacer replaces the conventional mechanical device that performs a control function such as LEDs, ON/ OFF buttons, switch gears etc. This innovation introduces LCD screen to replace the conventional mechanical devices.

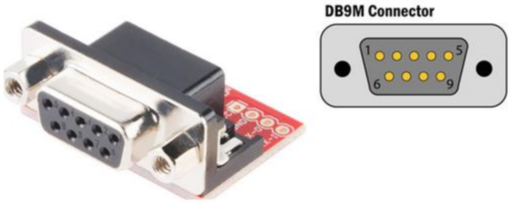
(b.) **The Data Handler HMI**: This HMI is capable of accommodating functions like recipes; data trending; data logging and alarm handling/logging etc. Data handler also ensures visual representations of data in form of graph in an organized screen visible enough for assessment. Data handler is efficient because its applications always give constant feedback from the system and data handler is required for an application that needs constant feedback and assessment.

(c.) **The Overseer HMI**: This HMI is always useful when SCADA are involved and is exceptionally beneficial because it runs on Windows and has numerous Ethernet ports. These HMI are made of central systems for the monitoring and control of the entire system including large and complex systems or those spread over large process areas. This HMI are normally connected to the SCADA system's database with a software program. It also provide trend of the process with ability to diagnose data and manage the system information.

2.3.3 Communication Protocols applicable to Human Machine Interface line

(a.) RS232

This is a standard communication protocol and is used for connecting computer and its peripheral devices. These connections allow serial data exchange and the maximum cable length for RS232 which approximately transmits about 1Mbps within the distance of 50 feet with capacitance of about 2500 pF.



RS232 Pin Out

Pin #	Signal
1	DCD
2	RX
3	TX
4	DTR
5	GND
6	DSR
7	RTS
8	CTS
9	RI

Plate 2.13: RS232 with pin configuration (He, Wu, Deng, Zhen, & Liu, 2018) ;(Sonnenberg, 2018)

(b.) RS422

RS422 are improved versions of RS232 and they are made of two pair of cable that aids in reducing the noise and encourage signal balancing. It transmits data for longer distance with faster rates, with up to 10 Mpbs at 50 feet or 100 Kbps at 4000 feet.

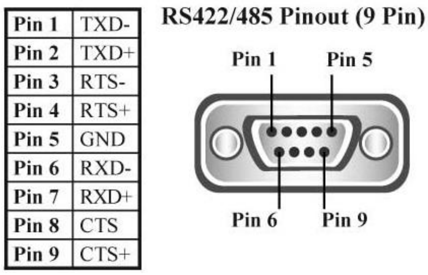


Plate 2.14: RS 422 with pin configuration (He et al, 2018) ;(Sonnenberg, 2018)

(c.) RJ-45

These types of connector are normally used for Ethernet networking and has 8-pin/8-position plug or jack. This Ethernet cable run for 100 meters length.

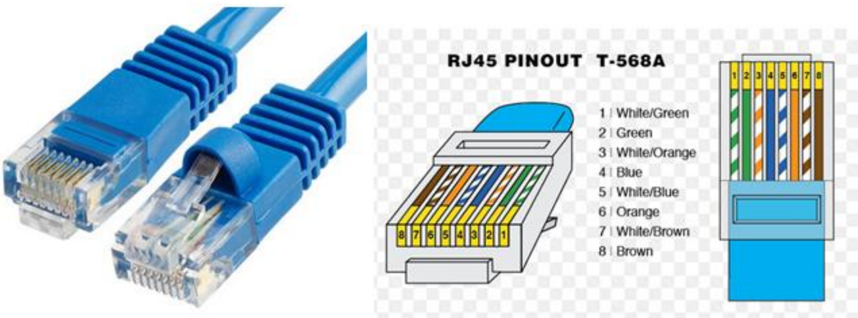


Plate 2.15: RJ-45 with pin configuration (He et al, 2018) ;(Sonnenberg, 2018)

2.3.4 Trends in Human Machine Interface (HMI) Technology development

(a.) High-Performance HMIs

These trends facilitate fast and efficient interaction and have simple and clean graphical control system quality colour and size.

(b.) Touch Screens and Mobile Devices

These are two advanced technologies that have emerged with the introduction of smartphones. Touch screens have replaced the buttons and switches in the modern HMIs. Operators can quickly tap or touch the physical screen to access the command on the phone. The advantages of the touch screen to operators, include the instant access to human machine interface information with remote monitoring capacities.

(c.) Remote Monitoring

This is flexible and accessible for the system operators and managers in monitoring setting which makes the HMI mobile-friendly because it eliminates onsite supervision at intervals.

(d.) Cloud and Edge-of-Network HMIs:

These HMIs allow the system operators to access field data and also visualize the device from the field. It is now common to send data from local HMIs to the cloud which makes it easy to access and analyze remotely.

(e.) THINGSPEAK

ThingSpeak is an analytical platform that provide several Internet of Thing services that allows one visualize, aggregate, and analyze live data in the cloud. Acquire data are send to ThingSpeak from the desire devices for it to create an instant visual mode of the that data are analyzed and send to any desire's platform on a real time basis. ThingSpeck work perfectly with ESP WIFI module in receiving and analyzing information on web for smart health monitoring services (Islam, Rahaman, & Islam, 2020). Similarly, Smart community, Energy and home monitoring and control system was demonstrated to validates ThingSpeak capability in real time IoT data management with Arduino mega and ESP 8200 series (Razali, Kassim, Sulaiman, N. & Saaidin, 2020), (Patil & Tapaskar, 2017), (Nettikadan and Raj 2018), (Prashant -Hiwale, Sudam-Gaikwad, Dongare & Mhatre, 2018).

Pasha (2016) opines that Thingspeak is capable of sensing and monitoring any System that is IoT enable and can also Analysis that system with its embedded MATLAB software remotely.

2.3.5 Merits of Human Machine Interface (Ponsa, 2011); (Somra, 2016)

i. User-friendly
ii. Interface flexibility
iii. Convenience
iv. Ease to wire
v. Ease to troubleshoot

2.3.6 Recent advancement in Human Machine Interface

Normanyo *et al.* (2014) the advancement in Human Machine interface for industrial application leds to the design of an automated systems using siemens Simatic WinCC.

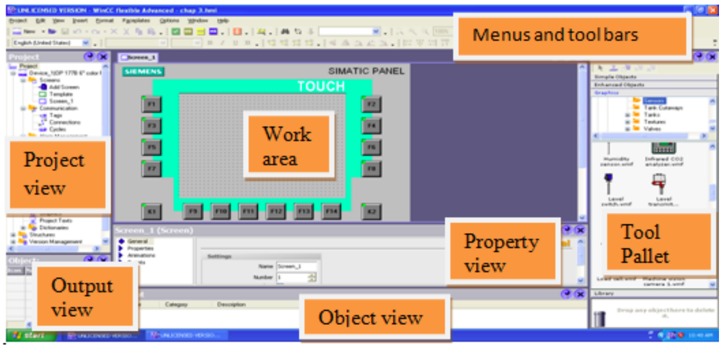


Plate 2.16: Siemens Simatic WinCC Flexible User Interface (Normanyo et al. 2014)

2.4 Supervisory Control and Data Acquisition (SCADA) System

2.4.1 Fundamental of SCADA System

Supervisory control and data acquisition (SCADA) system are made of software and hardware elements. These software and hardware element allow for the following operations:

(a.) Control of industrial processes locally and from remote locations;

(b.) Monitoring, gathering and processing of real-time data from the system;

(c.) Facilitates direct interaction with devices (switches, sensors, valves, pumps, motors, and more through human-machine interface (HMI) software);

(d.) Documents and records events in a log file.

SCADA systems are essential in industrial control because they help to process data for smarter decisions, maintain efficiency, and communicate system issues to help mitigate downtime (Kirti, 2014)

The following configurations are the reason why SCADA system design is required:

i. Human-machine interface (HMI): This is an input to the output device that presents the processed data to be controlled by the user.
ii. Supervisory system: This is used as server to communicate between the equipment of the SCADA system (RTUs, PLCs and sensors); via the HMI software used in the central control workstations.
iii. Remote terminal unit (RTU): These are used to transmit data to the supervisory unit. They receive messages from the master device for the control of the connected target.
iv. Programmable Logic Controller: These are connected to sensors to detect the output data to be collected for onward conversion into desired digital data. This is because PLCs are flexible, ease to configure, versatile and affordable.
v. Communication infrastructural interface: standard Communication protocols are recognized by SCADA vendors (RS 232, 422 and RJ-45).
vi. SCADA Program: Its programming language or C languages are used. Maps and diagrams created give important situational information on the plant event.

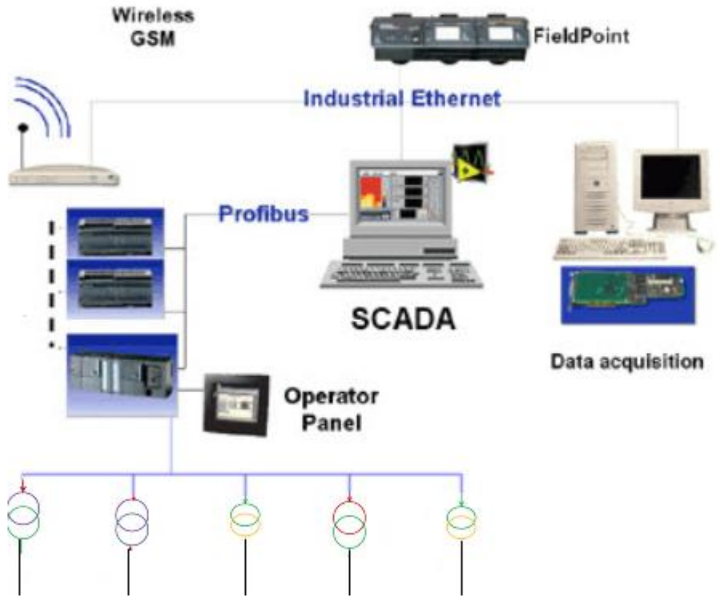


Plate 2.17 :The Supervisory Control and Data Acquisition (SCADA) System for power system application (Berg & Stamp, 2005).

PLC can control the entire system solely but lack the capability of remote-control system, for this reason SCADA plays a vital role in remote access control and monitoring. The SCADA software used for this design is Wonderware InTouch 2012R2 because of the following characteristics:

i. It has access name: Intouch uses access name concept for continuous communication of the dynamic data exchange (DDE)

ii. It has a dynamic data exchange (DDE)

iii. It has an alarm system

iv. It has the trend

v. It has the scripts

2.4.2 The Basic SCADA Architecture

The simplest SCADA architecture traces its origin from programmable logic controllers (PLCs) or remote terminal units (RTUs). PLCs and RTUs are microcomputers and they are designed to communicate with an array of objects. These objects include factory machines, Human Machine Interfaces, sensors, and output devices. The processed information from these objects are routed to the computers with SCADA software. The SCADA software processes, distributes, and displays the data. This helps the operators and others to analyzed the data and make important decisions out of it (Berg & Stamp, 2005).

2.4.3 Functions of SCADA Systems

1. Supervisory Control
2. Data Acquisition
3. Real Time Database
4. Graphical Operator Interface
5. Alarm Processing
6. Data Historian/Strip Chart Trending
7. Map-board Interface

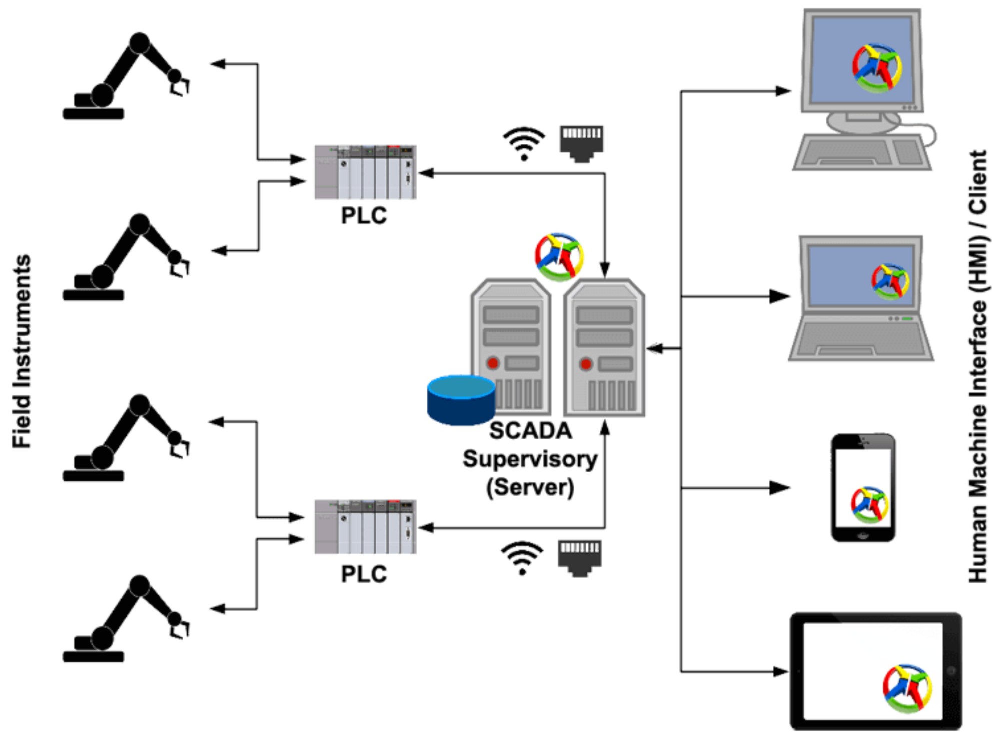


Plate 2.18: SCADA System Architecture (Shalini et al ,2013)

2.4.4 Elements/ Components of the SCADA System (Shalini et al ,2013)

(a.) A supervisory (computer) system: This is where the data are gathered (acquired) from the process and commands are sent (control) back to the process.

(b.) Sensors and Actuators

(c.) RTUs: These are the connecting device to the sensors in the process that enable the conversion of the sensors signals to digital data that are sent to the supervisory system.

(d.) PLCs: These are used as field devices because they are more economical, versatile, flexible, and configurable than special-purpose RTUs.

(e.) Communication: Communication infrastructure connects the supervisory system to the remote terminal units.

(f.) Front end process

(g.) SCADA server

(h.) Historical /Redundant/ Safety server

(i.) HMI computer: This is the apparatus that presents the process data to a human which is the operator, and through this device, the human operator monitors and controls the desired process

(j.) HMI software

2.4.5 Application of SCADA systems (Tim, 2008)

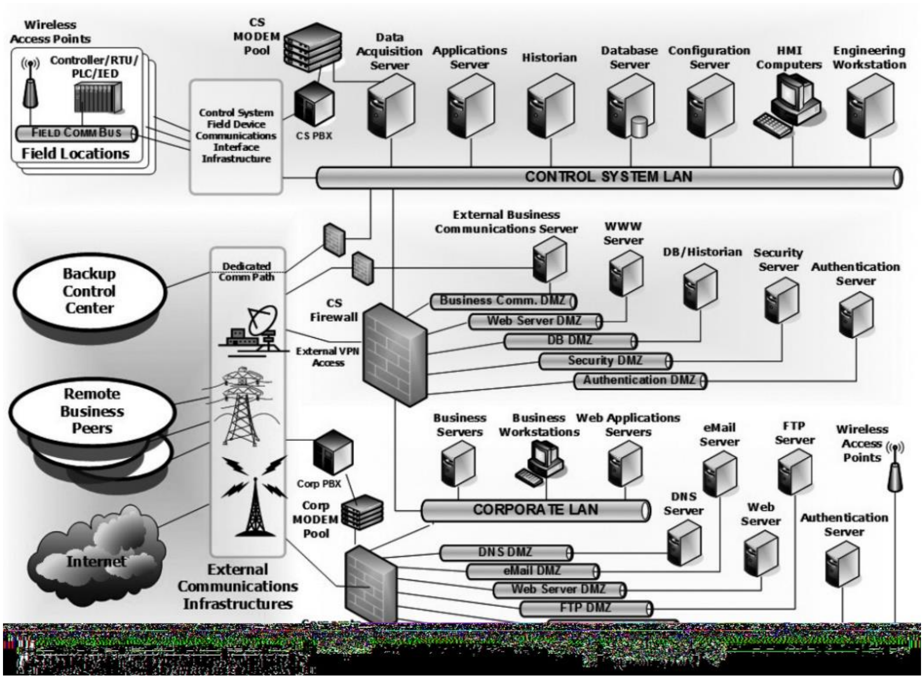


Plate 2.19: Application and future Advancement in SCADA System Technology (TIM, 2008)

These are backbones of many modern industries and serve in the following capacities:

(a.) Energy and Power sector

(b.) Food and beverage

(c.) Building Automation

(d.) Manufacturing production

(e.) Oil and gas

(f.) Recycling

(g.) Transportation

(h.) Waste Water Treatment & Management

2.4.5 Benefits of SCADA Systems (Berg & Stamp, 2005)

(a.) It helps in improving operation of the plant or process due to its optimized level;

(b.) It increases productivity of the personnel;

(c.) It improves the safety of the system because of its better information presentation and improved control level;

(d.) It protects the plant and equipment;

(e.) Its Safeguards the environment from the failure of the system.

(f.) It improves energy savings due to optimized operation in the plant.

(g.) It improves and speedup the receipt of data for clients to be invoiced more quickly and accurately.

2.4.7 SCADA Hardware

A SCADA Hardware System consists of a number of Remote Terminal Units (RTUs). The function of the RTU is to collect field data and then send the data back to a master station via a communication system and the master station displays the gathered data and also gives the operator room to perform remote control tasks.

The field analog and digital sensors situated at each remote site are interfaced by RTU. Five essential levels or hierarchies in complex SCADA system are:

(a.) Field level instrumentation and control devices

(b.) Marshal terminals and RTUs

(c.) Communications system

(d.) The master station(s)

(e.) The commercial data processing department computer system

The RTU gives an interface to the field analog and digital sensors situated at each remote site.

2.4.8 SCADA Software

The SCADA software are two types

(a.) **Proprietary *type***: These are developed by companies to help communicate to their hardware.

(b.) **Open *type***: This software is developed with inter-operational capability and have gained wider acceptance because of its inter-operability to systems. Inter-operability is the ability for its software to relate with different manufacturers equipment within the same system.

2.4.9 Features of SCADA Software (Kumar *et al*, 2013)

(a.) User Interface

(b.) Graphics displays

(c.) Alarms

(d.) Trends

(e.) RTU (and PLC) Interface

(f.) Scalability

(g.) Access to Data

(h.) Database

(i.) Networking

(j.) Fault Tolerance and Redundancy

(k.) Client/Server Distributed Processing

2.4.10 Types of SCADA Systems

(a.) Basic SCADA: These are designed for one machine process and one RTU and MTU (Master Terminal Unit) operations.

(b.) Integrated SCADA: These are designed for the Multiple RTUs (MRTU) and Distributed Control System (DCS).

(c.) Network SCADA. This is designed for the Multiple RTUs only.

2.4.11 Manufacturers of Hardware SCADA System

The following are some of the SCADA hardware manufacturing firms:

(a.) Schneider Electric

(b.) Emerson

(c.) General Electric

(d.) Rockwell Allen Bradley

2.4.12 Manufacturer OF Software SCADA System

The following are some of the SCADA software manufacturing firms:

(a.) Invensys: Wonder ware In touch

(b.) Honey well

(c.) General Electric: Intellution fix

The choice of hardware or software in system development is dependent on individual applications.

2.4.13 Recent Advancement in SCADA for Automation

SCADA system was designed in order to automate the power distribution companies' network. The results show that most of the control actions were performed automatically by Remote Terminal Units (Shalini *et al*, 2013).

Vignesh & Kirubakaran (2015) developed a PLC & SCADA for the smart monitoring and control of power transmission Station to ease Power management. The control and monitoring were made easy with the optimized hardware and software devices with the help of PLC ladder logic system and SCADA was used. The constraint was used to monitor and control the power grid system without human effort. The breakers were managed with the computer SCADA system installed and this facilitated monitoring and control of the system should problem arise in the plant, and with the PLC self-diagnosis algorithm, it identifies which part to disconnect from the grid easily. In another development, SCADA and PLC-based control system were implemented for power distribution system, this provided management criteria for the power distribution system with real-time data presentation. The production operations were more efficient, better control, cost reduction with improved plant and personnel safety. In automation, switch and control using PLC & SCADA has gained wide acceptance as it was experimented in electrical distribution system substation in a view of phasing out or transforming the manual control system to automated system. The four main tasks in SCADA based system for electrical distribution system were deployed. These are the automated control system, interfacing units, monitoring system and networking system. The PLC ladder diagram for the automated distribution system were developed and analyzed for a secured, reliable and convenient management of power distribution system (Zaw & Tun, 2014).

Osunbor, Ezechukwu, & Alumona, (2017) worked on the descriptive analysis of automated system developed with SCADA-based monitoring and remote-control techniques and adopt these techniques for the control of circuit breakers. The system were developed in two phases; the hardware and the Software. In the hardware design, the circuit breaker, the monitor, the personal computer and the Global Positioning System clock receiver was developed and used. The circuit breaker was developed with an intelligent electronic device located at the breaker cabinet in the switch-yard whereas the global positioning system receiver and the personal computer concentrator were located in the control house. Proteus 8.6 Intelligent Schematic Input and System (ISIS); Program Description Language (PDL) and MATLAB were used for their design.

Zhang & Zho (2012) configured an intelligent power distribution monitoring system with PLC and SCADA. The PLC system was designed to collect various intelligent Electrical parameters and the monitored system data was uploaded through the serial server. The Fame-View software was used to configure the design and the data was displayed on real-time bases showing the status of the field equipment. The results revealed that the systems were capable of integrating query historical data from of the database, present the curves, perform the alarm function and read the remote metering system. Mathew, Srinath & Jyothi (2015) applied the use of PLC and SCADA in setting up an intelligent Electrical Power Distribution System (EPDS). The main objective was to reduce the man power required for the EPDS and to raise the safety levels.

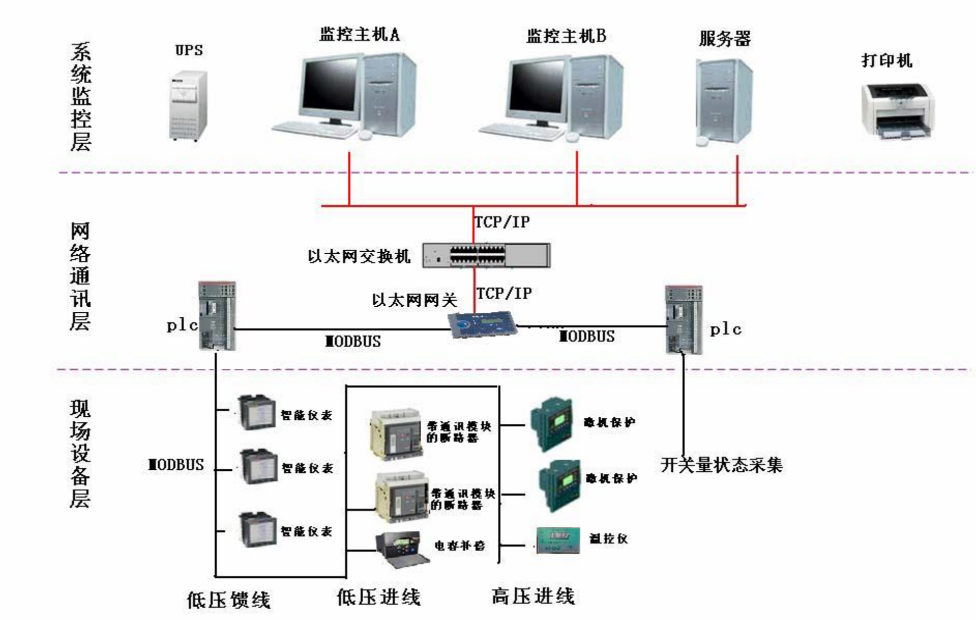


Fig. 2.3: SCADA & PLC design for the power Distribution Monitoring System (Zhang & Zho, 2012)

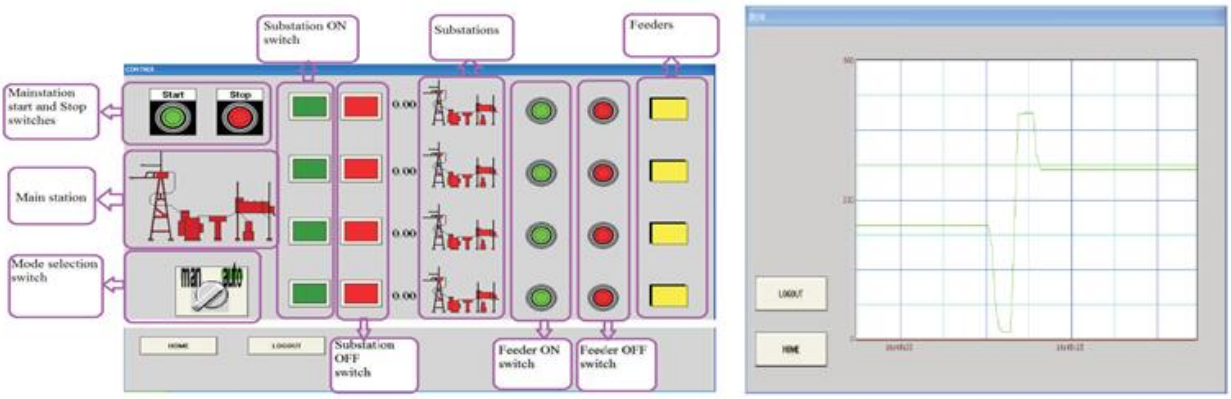


Fig. 2.4: PLC and SCADA Automation of Electrical Power Distribution System with the trends (Mathew et al, 2015)

The Fig. 2.4 show the graphical representation of the monitored system trend produced from real-time voltage, current, temperature parameters in the automated electrical Power distribution system and the human machine interface from the design. The design was simple, flexible and reliable and the method adopted ensures safe fast transmission and distribution of power.

Kadam *et al* (2008) developed a Micro-SCADA & PLC system because of space constraint Autoclave Automation is described briefly.

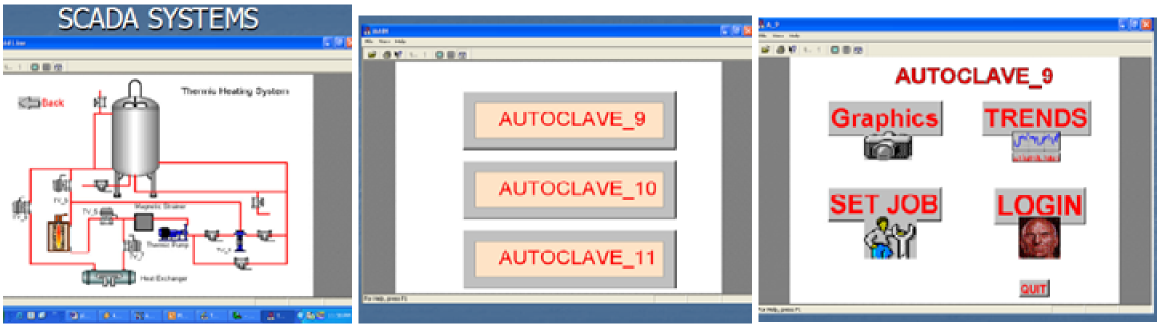


Plate 2.20: Micro-SCADA & PLC system design for Autoclave Automation (Kadam, Sonwnae, Landge, Dhote, & Thorat, 2008)

Plate 2.20 shows the various interfaces of the Cimplicity SCADA software used in developing the SCADA systems for Autoclave Automation. The design Comprises numerous graphical screens which the operator can visualize and initiate any activities to facilitate adequate monitoring and control of the system.

Belekar, Desai, & Parit, (2014) considers replacing the electromechanical device with PLC & SCADA for most efficient means of monitoring and controlling electrical distribution in automotive system in case of fault situation and established that a personal computer can be used to determine the actual fault zone through control action and data acquisition was one of their priorities. The PLC unit mediated between electrical system and Personal Computer for SCADA through input and output data.

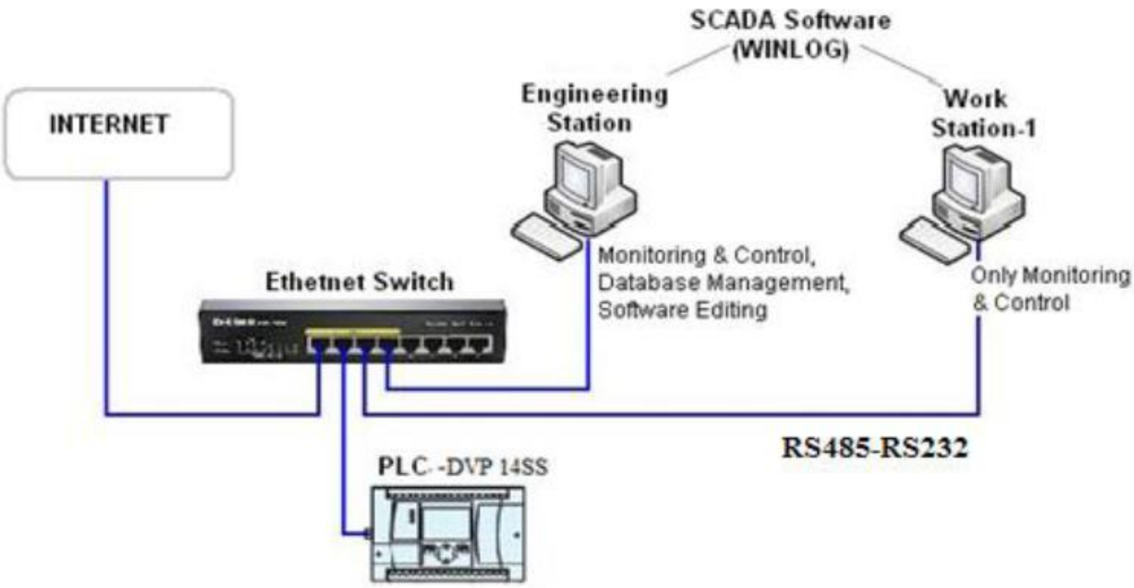


Plate 2.21: Interfacing of PLC with SCADA for the Automotive Electrical Distribution System (Belekar et al, 2014)

Plate 2.21 shows the automatic electrical distribution systems developed using (SCADA) system, the developed system was one of the most cost-effective design as it improves the system reliability, increase utilization, increase efficiency and saves costs.

Lakhoua (2010) unraveled the potentials of SCADA systems in thermal power plants management. It considers three basic items to be managed: its ability in performing counting on the natural gas product; the supervision of pumps vibrations in the plant and the supervision of heavy fuel oil by floating level system in the plant.

The developed SCADA system was capable of monitoring and controlling industrial processes remotely and allows the operators to adjust the set point changes on remote controllers by opening /closing of the valves or switches. It aids in monitoring the alarms systems and the instrument information was also gathered.

Rukhsar (2014) compares the result from the SCADA design on transmission line parameters to that of the manual reading captured directly from the line. The result shows that the direct data usually contain 25% to 30% error as against values measured by the SCADA system. This research attributed incorrect billing due to error that emanated from wrong economic dispatch of energy supply. SCADA system demonstrated its ability to monitor and control the Load Dispatch Centre so that the operators can keep the account of quantity of electricity transmitted through a grid adequately. With this, the data acquisition, power system supervision and power Systems control were ultimately achieved.

Jose, Varghese, Abraham, Joy & Koilraj (2017) developed a Sub-station Automation System with SCADA for Energy monitoring and Control purposes. This was designed to replace manual monitoring and control of power grid with the use of internet. The SCADA system substation automation enable accurate fault location which prevents false tripping thereby minimizing the area affected by the fault since the system is intelligently monitored.

Ozdemir & Canbolat (2016) explored the potential of SCADA System in the construction industry where chemicals plant for manufacturing were designed. These medium sizes chemical plant was designed and managed using PLC and SCADA. ABB PLC was adopted for the design of the control system operations with its ladder diagram whereas SCADA design was made possible through the use of Reliance 4.

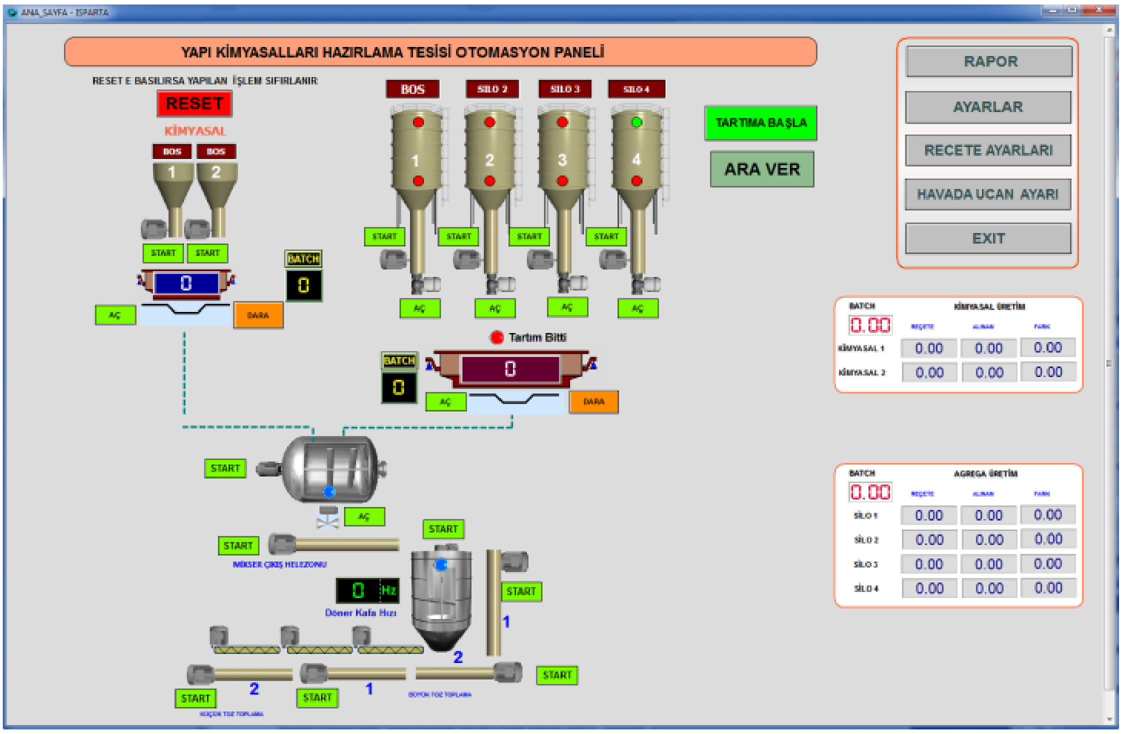


Plate 2.22: SCADA Screen for the Constructed Chemicals Manufacturing Plant (Ozdemir & Canbolat, 2016)

Plate 2.22 demonstrates the important application of SCADA and PLC in chemical production plants. The plants are made of the electromechanical systems with giant silos, conveyors, mixers, rotating heads, dust absorption units and packaging units.

In load security and allies' systems, PLC & SCADA still find their applications and the PLC and SCADA design underwent a Power-based Distribution Monitoring where electrical parameters: voltage, current and power factor were monitored on the computer (PC) using SCADA Software. The PLC mediates between low tension power distribution system and PC providing the system data from electrical power continuously at real time bases (Yusufjai, Vekariya, Joshi & Desai, 2017); (Berg & Stamp, 2010).

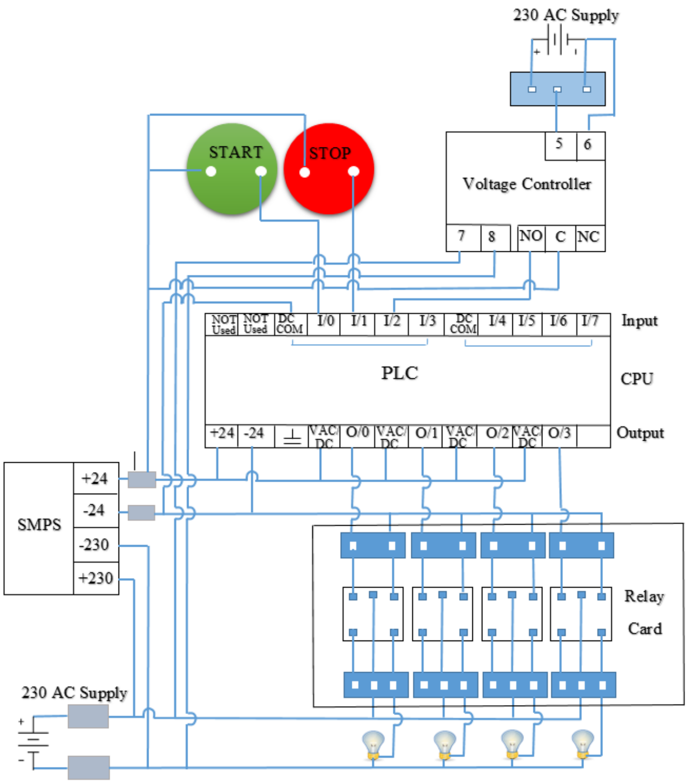


Fig. 2. 5: Block diagram of the load security system (Yusufjai et al, 2017)

Distribution transformers are one of the key equipment in power system network and its performance over a wide area in power systems requires data acquisition system, condition monitoring and automatic control. The design and actualization of smart control with PLC and SCADA aids monitoring as well as faults diagnosis in the transformation system. The load currents, transformer temperatures and voltages require constant monitoring and regulation. The suitable approach was an on-line monitoring system which was integrated through the use of a solid-state device called PLC (programmable logic controllers) and sensor packages. The PLC monitoring system helps in detecting the internal and external fault in the transformer and diagnosing of these faults. The desired range of parameters was the strength of their design as developed by programmer (Behera, Masand, & Shukla, 2014).

The acceptability of SCADA system in the integration of several technologies was presented in modern buildings as it was used in controlling the ventilation, temperature, water network, Gas network, Computer network and illumination in the building (Figueiredo & Costa, 2012).

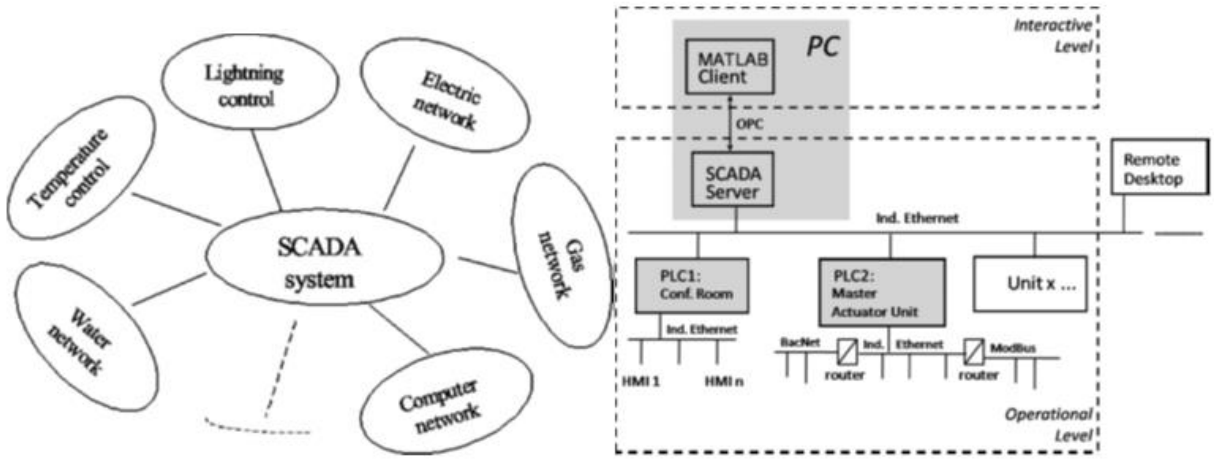


Plate 2.23: SCADA system architecture for Building Automation Systems (Figueiredo & Costa, 2012)

Furthermore, Desai, Mahale, Desai, & Karamchnadani (2014) developed a smart SCADA system for the automation of Power Plants. This SCADA system was designed with central terminal serving several kilometers away from the site of operations with several remote sensor terminals close to the operational site. The sensor units send the system acquired data to the central terminal for monitoring and management. The communication devices via the user interface and the software aids in completing the SCADA system cycle. RTU and GPS receivers were made to synchronously interact with the Smart grid system.

PLC & SCADA has contributed in no or little measure to the monitoring and control of system for reliable performance. This design gives acceptable level of flexibility and efficiency as it helps in monitoring system operation of an induction motor using online/offline mode (Pampashree & Ansari, 2014). The forward and the reverse operation were monitored as seen in figure 2.24.

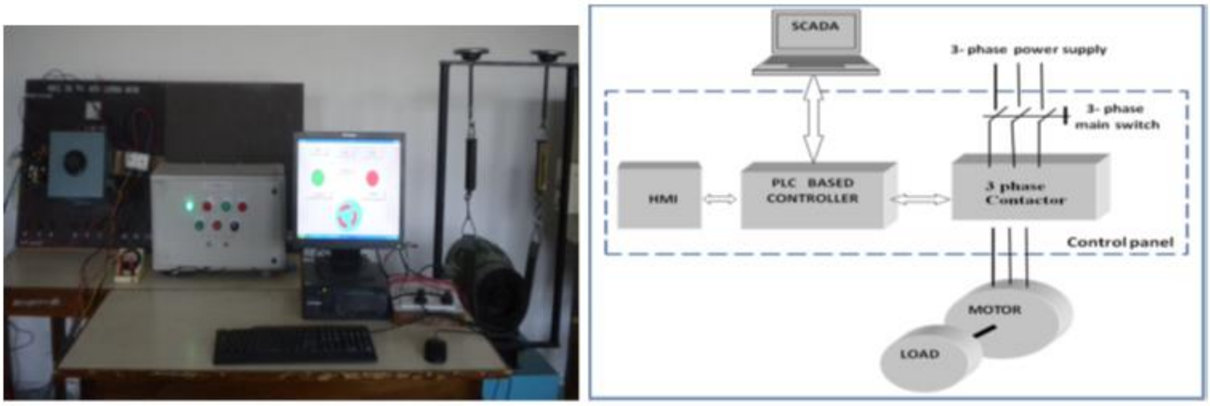


Plate 2.24 :The Experimental HMI diagram and experimental setup block diagram (Pampashree & Ansari, 2014)

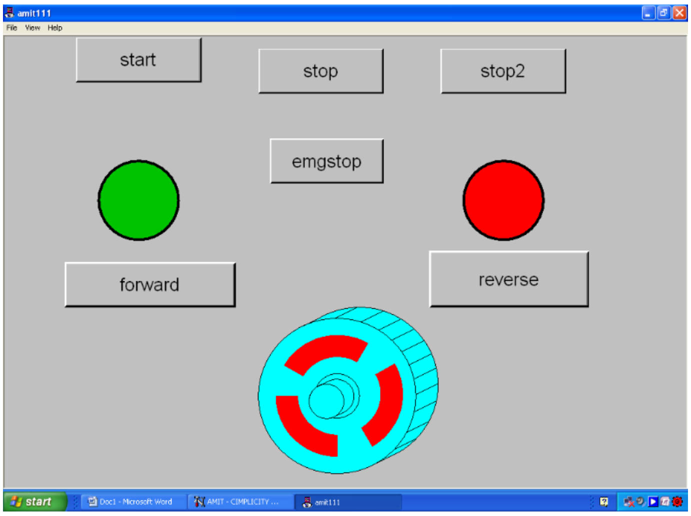


Plate 2.25: Forward and Reverse operation of the induction (Pampashree & Ansari, 2014)

Kalaivani & Jagadeeswari (2015) developed PLC & SCADA for effective automation for boiler scheme in a thermal power plant system. Boilers are the most important utility device in thermal power plants. Continuous monitoring and inspection is necessary for their effective operation and the measurement of parameters manually introduces error. In order to maintain its operational efficiency and reliability, Programmable Logic Controller & Supervisory Control and Data Acquisition system were introduced. The design put together the functionalities of PLC and SCADA interfaced through communication cables. SCADA was designed to monitor the boiler temperature, pressure and fluid level in the system with the help of sensors.

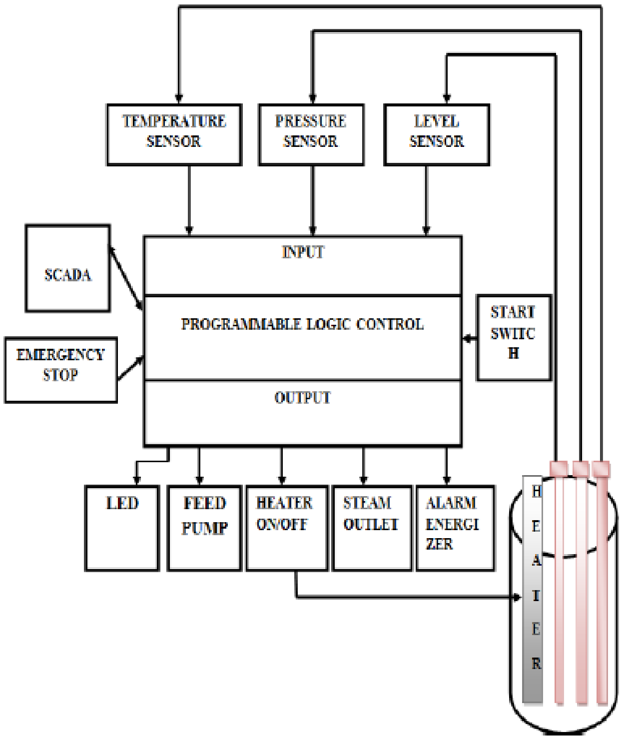


Plate 2.26: The Automated Boiler System (Kalaivani & Jagadeeswari, 2015).

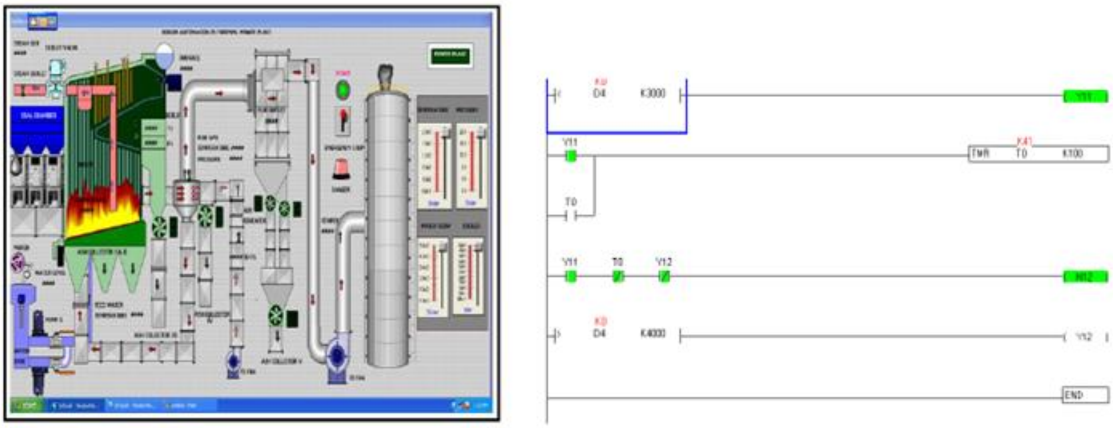


Plate 2.27: SCADA and Ladder Diagram of the Automated Boiler System (Kalaivani & Jagadeeswari, 2015).

Plate 2.27 shows that the output was fed to the PLC which in turn controls the boiler temperature, pressure and fluid level such that when the temperature and pressure in the boiler exceed calibrated values, then the entire system automatically shuts down. Boiler automation was achieved using PLC ladder diagram designed with WPL soft and SCADA using Intouch Wonderware.

An intelligent means of monitoring and controlling the power flow with PLC, SCADA and Arduino-UNO was proposed, and data in the order of KVA, KVAR, KW as well as power factor were effectively computed using Microcontroller. The system was designed such that whenever the threshold value is exceeded, the micro-processor speedily generates a control signals to actuate the relays responsible for operation to trip-off the connected loads in an hierarchical manner (John, Karthikeyan, Mathivathani, Preethi, & Vivekenandhan, 2016).

Similar to that of the boiling system, was the design of an automatic chilling plant system using PLC, SCADA and Microcontroller (Vairavel, Ikram, & Ijaz, 2017). These were designed to relief the vendors from the problem of the conventional chilling system which has been high power consumption; noise due to the incorporated fan and that of maintenance.

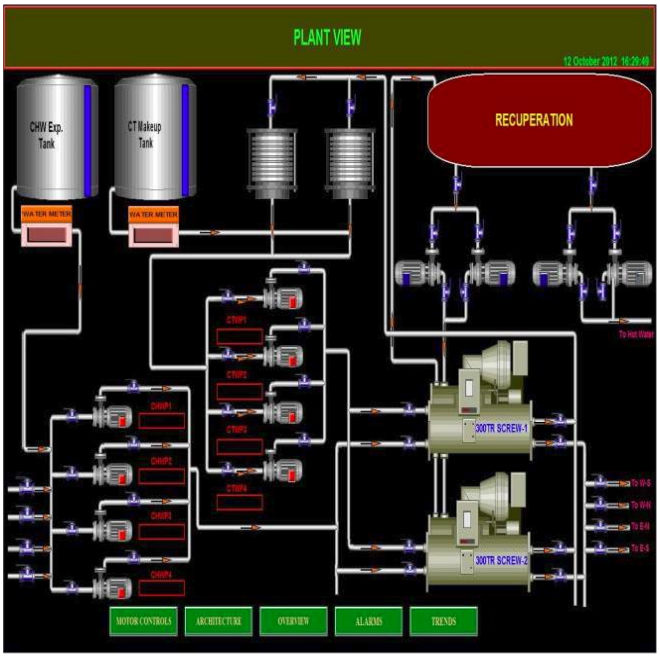


Plate 2.28: The Automated Chilling Plant System (Vairavel et al, 2017)

Plate 2.28 shows the SCADA representation of the automated chilling system and has a control interlock developed and loaded in PLC using MICRO LOGIC 5000 software which aids the power consumption reduction to about 50% daily with lesser human involvement (Vairavel *et al*, 2017).

2.5 Programmable Logic Controller (PLC) system

2.5.1 Concept and details of the Programmable Logic Controller (PLC)

The Programmable logic controlled provides the program logic for the system parameter to be control or regulated. This is implemented through the use of logic ladder and the modular PLC were adopted in-view of the fact that it is expandable. The brand of PLC adopted for the design was Keyence because it has both the PLC and SCADA package; AB PLC has three software embedded into one: RS-logix 500 was used for the ladder diagram design, RS-logix emulate 500 was used for the ladder simulation and the RS-linx classic was used for communication. The primary function of the PLC program was for program control. The Communication port RS22 was selected; the operating voltage for the selected PLC was 24v for both sink and source.

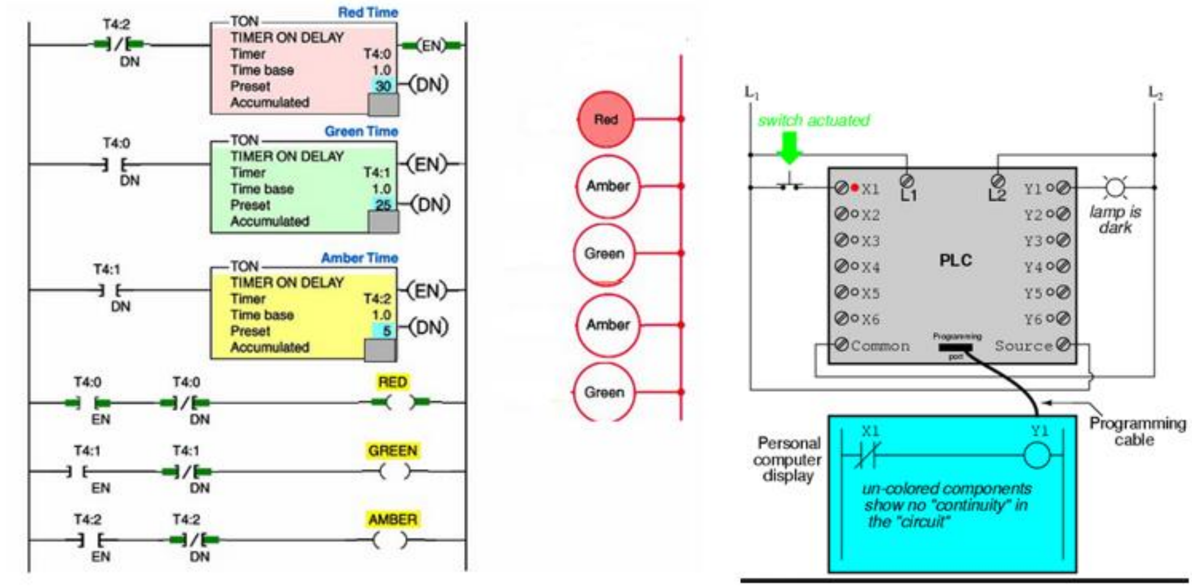


Fig. 2 6: PLC Ladder diagram in Human Machine interface design (Petruzella, 2011)

The Programmable Logic Controller (PLC) is a member of a specialized computer and solid-state device which control machine operations and processes based on the input of the program given to the controller. Also, it is basically an assemblage of solid-state digital logic elements which are designed to make logical decision and provides an output that aids the manipulation of system devices (Petruzella, 2011). Programmable Logic Controller uses a microprocessor-based Programming technique and this helps in many industrial process task accomplishments.

Programmable Logic Controller operates in a similar manner to the ordinary controller though with PLC different operations are performed by software.

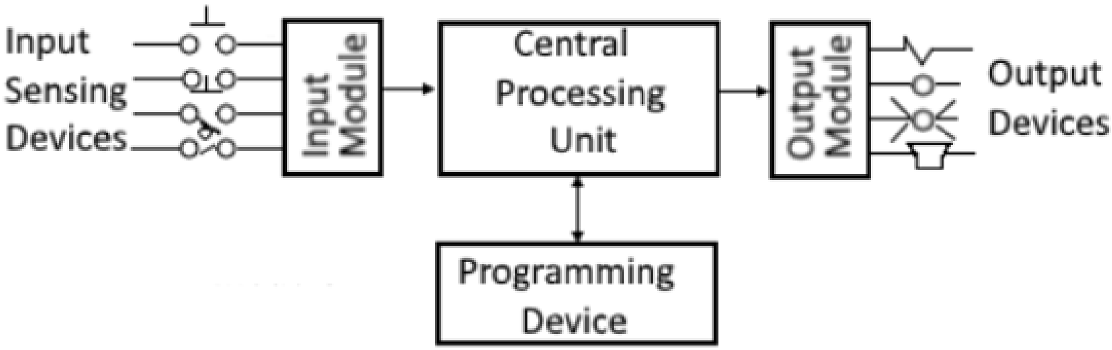


Fig. 2.7: Diagram and common parts of the Programmable Logic Controller (Petruzella, 2011)

The generalized Programmable Logic Controller architecture:

(a.) It has the **Central Processing Unit** (CPU) which contains an internal program that tells the PLC how to perform the following functions:

i. Execute the control instructions contained in the User's Programs. This program is stored in "nonvolatile" memory, thereby translating to no loss of program if power is removed.

ii. Communicate with other devices, which can include input/output (I/O) devices, programming devices, networks, and even other PLCs.

iii. Perform housekeeping activities such as communications, internal fault detection and diagnosing etc.

(b.) **Inputs Modules**: These contain the set of ladder instruction given to the PLC using ladder logic and are connected to input sensing devices.

(c.) **Output Modules:** These are devices like motors solenoid valve, motor starters, light indicators. These are hardwired and connected to the output module.

(d.) **Programming Devices**: These are computer systems with other accessories.

The advantages of Programmable Logic Controller (PLC)

i. It has easy programming languages

ii. It is easy to troubleshoot

iii. It is easy to modify its logic

iv. It is easy to increase or decrease its input and output devices thus permit future adjustment.

v. It is fast and easy to install

vi. It is easy to maintain

The operating voltage for PLC is 24v DC and this is common to all brands of PLC but with little tolerable range of variation depending on the brand and model and PLCs can be remotely controlled through the use of SCADA.

2.5.2 Types of Programmable Logic Controller (PLC) (Yusufjai *et al*, 2017)

(a.) Fixed Programmable Logic Controller

These are type of PLCs used in small scale industries. It is usually small with little memory and has a limited number of inputs and outputs of about 208 and it has no room for expansion.

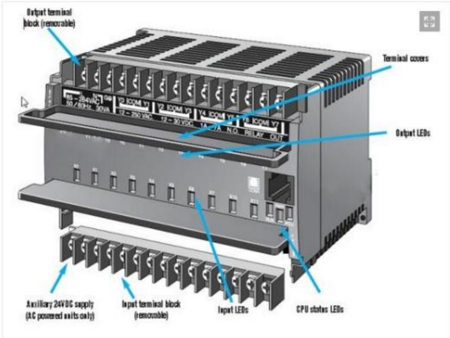


Plate 2.29: Fixed Programmable Logic Controller Architecture (Petruzella, 2011); (Foster, Hammerquist, & Melendy, 2010); (Rakshe, 2017) ;(Yusufjai *et al*, 2017)

Features of Fixed Programmable Logic Controller

(i.) It has Memory

(ii.) It has I/O Modules

(iii.) It has No Room for Expansion

(iv.) Troubleshooting and downtime cost more

(b.) Modular Programmable Logic Controller

Modular PLCs are used for medium scale industries and they are expandable. It has adaptive features; it can be changed easily and simply. They are made of a chassis, rail, or back plane. This permits the connection of any modules to build up and interface with any system. The prime advantage of a modular PLC architecture is that it has an ability to choose individual specifications. As such, the quantity and type of I/O modules can be selected. It has options that accommodate network interface cards. The maximum input and output that modular PLC can accommodates is about 2048.

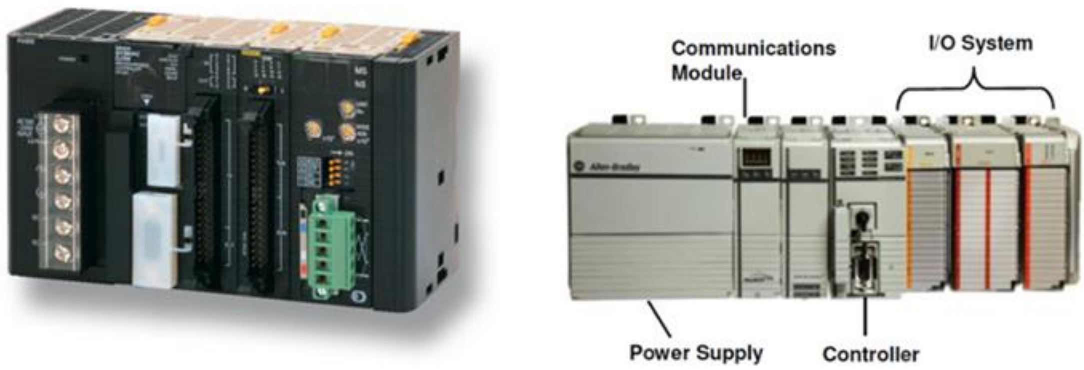


Plate 2.30 :Modular Programmable Logic Controller Architecture (Petruzella, 2011); (Foster *et al*, 2010); (Rakshe, 2017); (Yusufjai *et al*, 2017)

Features of Modular Programmable Logic Controller

(i.) It has far more Memory and is capable of storing a higher volume of information.

(ii.) It has greater number of available I/O modules

(iii.) There is room for expansion

(iv.) Easier to troubleshoot, Less downtime

(v.) Mix and match is possible

(c.) Rack Programmable Logic Controller

Rack PLC are used for large industrial operations, and they are expandable with the maximum input and output of about 16000 and is arranged in parallel such that if one rack is bad, other racks can still be functional.

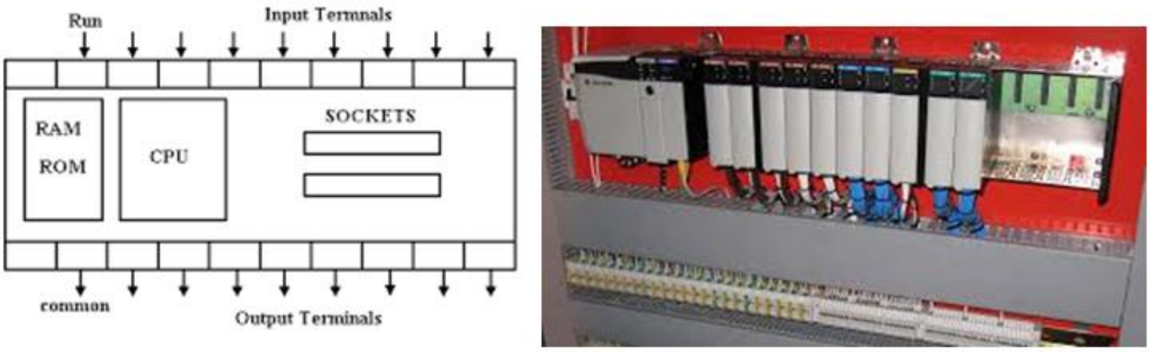


Plate 2.31: Rack Programmable Logic Controller Architecture (Petruzella, 2011) ; (Foster *et al*, 2010); (Rakshe, 2017) ;(Yusufjai et al, 2017)

Features of Rack Programmable Logic Controller

(i.) Its ultimate performance allows for optimization of processing time and accuracy.

(ii.) It Instructions fit several applications

(iii.) It permits integrated development environment and middleware

(iv.) It permits seamless networking

(v.) It has inheritance and maintenance capability

(vi.) It is an expandable System

2.5.3 Programmable Logic Controller (PLC) Programming Languages

(Foster *et al*, 2010); (Rakshe, 2017) ;(Yusufjai *et al*, 2017)

(a.) ***Ladder Diagram Language [LD]***

This language is commonly used for graphical interpretation of a process with rungs of logic. This is similar to that of the relay ladder logic schemes and ladder diagram

(LD). It translates the traditional logic symbols into a programming language. These are initially programmed with simple contacts that simulate the opening and closing of relays. Ladder logic programming can accommodate other functions such as counters, timers, shift registers, and mathematical operations

(b.) ***Functional Block Diagram [FBD]***

These are graphical instruction used for the control of a process illustrated using simple and complex building blocks. It can utilize analog I/O to carryout closed-loop control algorithms and diagnostics.

(c.) ***Sequential Function or flow Chat [SFC]Language***

Flowchart gives the system steps (one or more actions) for a given transactions (defined condition before passing to the next step). This is the method use in programming complex control systems at a more highly structured level. A SFC program gives an overview of the control system, in which the basic building blocks are the entire program files. Each program file is created with the aid of the other types of programming languages and the SFC approach organizes large complicated programming tasks into smaller and more manageable tasks.

(d.) ***Instruction List [IL]***

Instruction list uses microcontroller program: assembler-type, text-based language for building small application or optimizing complex systems. A low level "assemble language like" with similar instructions list languages is found in a wide range of today's PLCs.

(e.) ***Structural Text [ST]***

In structural text, C language is developed to provide high-level syntax using if and then statement, and this method of programming complex control systems uses more highly structured level language and this high-level text language encourages structured programming. It has a language structure (syntax) that strongly resembles PASCAL and supports a wide range of standard functions and operations.

2.5.4 Brands of Programmable Logic Controllers

(a.) AB - Allen Bradley

(b.) ABB - Asea Brown Boveri

(c.) SIEMENS

(d.) MITSUBISHI

(e.) SCHNEIDER

(f.) GSM: Global System Mobile

(g.) KEYENCE

(h.) OMRON

(i.) GE-FANUC: General Electric Factory Automation Numerical and Coding Control

(j.) MESSUNG PLC

(k.) TOSHIBA

(l.) TELEMICAQUE

2.5.5 Recent advancement in Programmable Logic Controllers (PLC) Applications

Husin, Ngahdiman, Hashim, Yusop, & Ja'afar (2013) adopted PLC for domestic use; home electrical appliances were made smart by implementing home appliances switching ON and OFF automated system. Similarly, Bingol *et al* (2014) implemented a web-page smart automation *using Delta DVP28SV model PLC (Programmable Logic Controller).* The Smart homes were designed to serve four purposes:

(a.) to manage the physical structure of the building;

(b.) to handle control systems in terms of security, air conditioning, and power control;

(c.) to manage internet and communication services;

(d.) to manage the energy, illumination and irrigation in the premises.

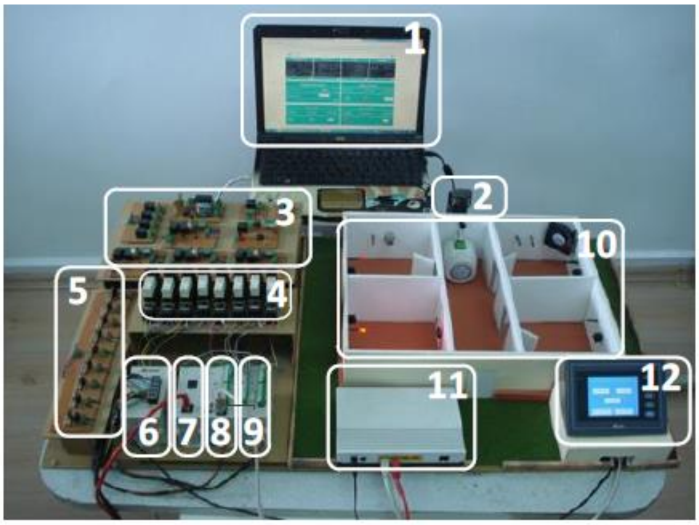


Plate 2.32: Automated Home Electrical Systems (Bingol & Tasdelen, 2014)

In another development, web-based remote-control system was developed for electrical power in building with microcontroller and PLC. Monitoring and remote control was made easy with the help of the designed SCADA system. The programmable logic controller (PLC) was able to access and control the devices directly with the help of RS-232 and RS-485 serial communicators. The SCADA system was built directly into the hypertext markup language (HTML) and HTML5. It runs on the web server which allowing access from a PC or smart-phone web browser (Chen, Liu, Kuo, & Yang 2017) .Haines & Joyce (2017) developed graphic users interface for remote monitoring without android app using python software.

Process control which is the heart of automation also witnessed a vast application of PLC due to its flexibility. Programmable Logic Controllers in-conjunction with power electronic devices was put together in controlling electrical machineries. PLC was interfaced with power converters via PC and other electric equipment to provide industrial electric drive systems with more accurate and efficient capability (Pawar & Bhasme, 2016).

Devi & Kanimozhi (2016) modeled and fabricated an intelligent food packaging system using PLC for industrial purposes. This was to explore the usage of PLC in automation with a simple HMI design to present the system operational output. The possibilities of using PLC and SCADA in energy monitoring system was explored. Intouch and Allen Bradley software were used for the design and the energy meter was designed to measure and display the amount of electric energy consumed by residential and business operators with the help of SCADA, PLC and DCS. Serial communication was connected to facilitate communication between the designed PLCs system and computer (Thamarai & Amudhevalli, 2014).

Mamodiya & Sharma (2014) carried out review on major technique used in industrial automation and control. The use of PLC and it wider application was one of the technology found to be very effective and also aids in improving product quantity and quality.

Programmable Logic Controller (PLC) has stood out as one of the standards in industrial control and automation. It provides a simple and robust method of controlling manufacturing and dynamic processes. The ability for the PLC to be adaptable in most of the processes reliably makes it useful in most common control mechanism. In educational applications PLC with associated logic and programming language makes the study of automation simple and easy (Foster *et al*, 2010).

Rakshe (2017) designed heating, ventilation and air conditioning system with PLC. The system demonstrated its ability to provide heating and cooling service to buildings in industries. The result from that research is as shown in plate 2.33.

Plate 2.33: PLC Panel and HMI (Rakshe, 2017)

On the other hand, power communication line transmission parameters were simulated with PLC, the analysis from the experimentation was evaluated and the results reveal that the PLC generator and simulators are suitable for investigating commutation line parameters. Some sub-channels with deep fading conditions were also traced, results show that some sub-channels are unsuitable for data transmission

(Mlynek, Misurec, Koutny, Fujdiak, & Jedlicka, 2015). The control application of PLCs in factory automation are unique because of the ease in its integration, small size and safety isolation. PLC also finds it use in transformer protection and fault detection system (Gupta, 2015).

2.5.6 Supervisory Control & Data Acquisition (SCADA), Distributed Control System (DSC), Human Machine Interface (HMI) and Programmable Logic Controller (PLC)

(a.) Human-Machine Interface is a part of the SCADA system while SCADA is a complete control system;

(b.) HMI is what the human operator sees and works with. HMI is visible for human to interact with whereas SCADA is the generality of the system that is involved in the control and monitoring of the plant operations; of the plant;

(c.) PLC controls the machine data through its logical reasoning and RTU is used in connecting PLC to SCADA system;

(d.) DCS are process oriented systems and SCADA are data acquisition-oriented systems;

(e.) DCS are process state driven systems and SCADA is event driven systems;

(f.) DCS handles operations on a single locality and SCADA operations are spread over a wide geographical location;

(g.) DCS operator stations are connected to its Input/output whereas SCADA operate notwithstanding failure of field communications;

2.5.7 Programmable Logic Controller (PLC), Supervisory Control & Data Acquisition (SCADA) and Human Machine Interface (HMI) System

Automation technology is dominating today's domestic and industrial organization because of operational convenience offered by remote monitoring and control as well as the provision of the screened display system capable of comparing the input power and the output power visibly to the user through its interface called Human Machine Interface (HMI). Primarily, HMI is deployed for visual control interface between the machine and the operator but the Human Machine Interface (HMI) is used in monitoring and control systems (Chen *et al*, 2017). In the context of power system pooling, SCADA aids in energy conservation without wastage and with the assurance of power system control balancing. These three words HMI, PLC and SCADA describe a complete system. Human Machine Interface is micro-computers systems used as an interfacing medium between the utility operating staff and SCADA system. A Programmable Logic Controller (PLC) are industrial computer control systems designed to continuously monitor the status of input devices and decide based on a custom program to control the state of output devices.

Supervisory Control and Data Acquisition (SCADA) is a term that refers to an entire industrial control system that consists of instrumentation, communications, PLC automation equipment, and human machine interface (HMI) computer systems. Tag is a name within a SCADA database that uniquely defines data used by the SCADA system. A tag has a number of attributes that together completely define the tag. Human Machine interface helps in providing sufficient level of details which enable the operator to determine what is happening in the system and what is going to happen next in the process sequence (Gupta *et al*, 2018).

In Power system, PLC find its application in control stations and substations. Primarily, PLC is used in substation level to view communication protocol in substation automation technology. Typically, IEC 60870–5–104 is the protocol used in controlling multiple numbers of substations from only one control center and this protocol works on TCP /Network. More so, IEC60870–5–103 is another protocol used in Protection device for communication with PLC and relays. MODBUS is another protocol which works on serial communication between PLC and Energy meters. *Supervisory control and data acquisition (SCADA)* are used in monitoring and control of substation from one control center to another. Power system requires the use of PLC for energy management system and it is mainly used for calculating supply and demand of power required to run the system.

2.5.8 Relevant of Programmable Logic Controller (PLC), Supervisory Control & Data Acquisition (SCADA) and Human Machine Interface (HMI) system in hybridized Power Pool System.

PLC & SCADA has a prime role to play in the development of integrated power pool monitoring and control scheme with human machine interface. The automation of these hybridization system for co-located communities become imperative.

The combination of a human machine interface and programmable logic controller brought to bear the long-awaited automation expectation. It has complemented the manufacturing sector with boosted efficiencies in production processes. Supervisory control and data acquisition; controls the system architecture that uses computers, networked data communications and human machine interfaces for high-level process and supervisory management.

(a.) SCADA Systems Generations

There are four different generations of SCADA Systems with different Architectures: first generation is known as the monolithic or early SCADA systems; second generation: is known as the distributed SCADA systems; third generation: is known as the networked SCADA systems and fourth generation: is known as the Internet of things technology SCADA systems.

(i.) Monolithic or Early SCADA Systems

Before now, minicomputers were used for configuring the SCADA systems because of the absence of the common network service.

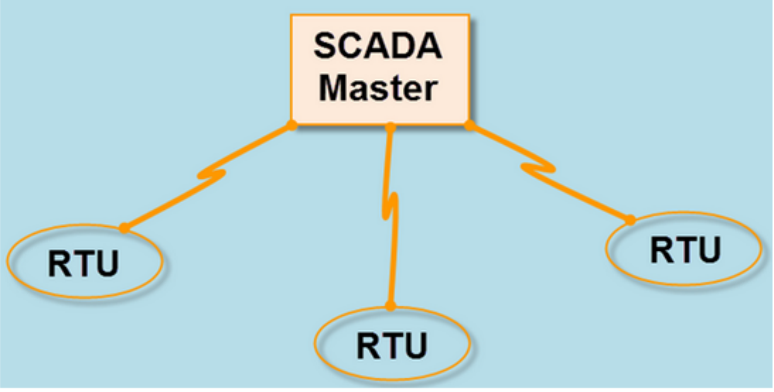


Plate 2.34: Monolithic or Early SCADA Systems (Ujvarosi, 2016), (Koushik & BS, 2016).

In monolithic SCADA, functions of the systems were restricted to monitoring sensors in the system and flagging any operations in case of exceeding programmed alarm levels.

(ii.) Distributed SCADA Systems

The sharing of control functions was an innovation in the second-generation SCADA. The control functions were distributed across the several systems, these were connected to each other with Local Area Network (LAN). This led to the term distributed SCADA systems. These have a distinct station which shares real-time information and command processing in order to perform control tasks. The trip of the alarm system problems was mitigated.

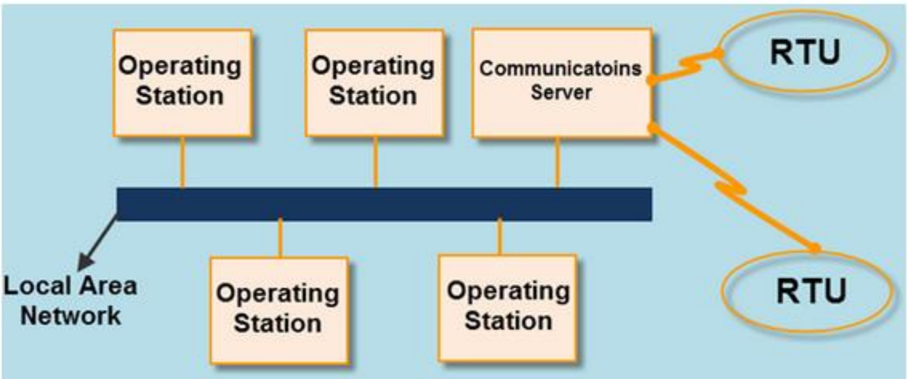


Plate 2.35: Distributed SCADA Systems (Ujvarosi, 2016), (Koushik & BS, 2016).

The distributed SCADA system was of reduced cost with considerable size compared to the first-generation system.

(iii.) Networked SCADA Systems

The present SCADA systems are usually networked and communicated with Wide Area Network (WAN) Systems over data lines. They make use of Ethernet or Fiber Optic Connections to transmit data between the nodes often. Network SCADA systems use Programmable Logic Controllers (PLC) to monitor and control the routine flagging operations.

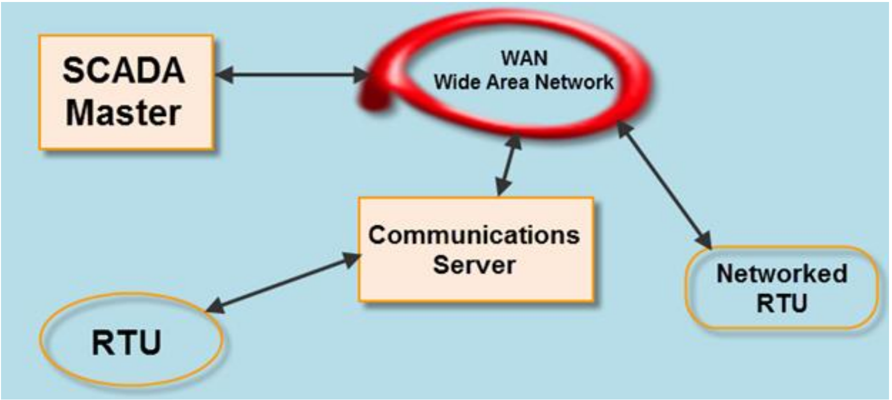


Plate 2.36: Networked SCADA Systems (Ujvarosi, 2016), (Koushik & BS, 2016).

The deficiencies of both the first- and second-generation SCADA systems were restricted to single site networks whereas network SCADA has numerous parallel working distributed SCADA systems under a sole administrator network architecture.

(iv.) SCADA with Internet of Things

In fourth generation, the cost of the SCADA systems was lowered because of the internet of things technology. Also, the commercially applied SCADA system were available in cloud computing edges and these facilitate ease of maintenance and integration compared to the third generation of SCADA systems.

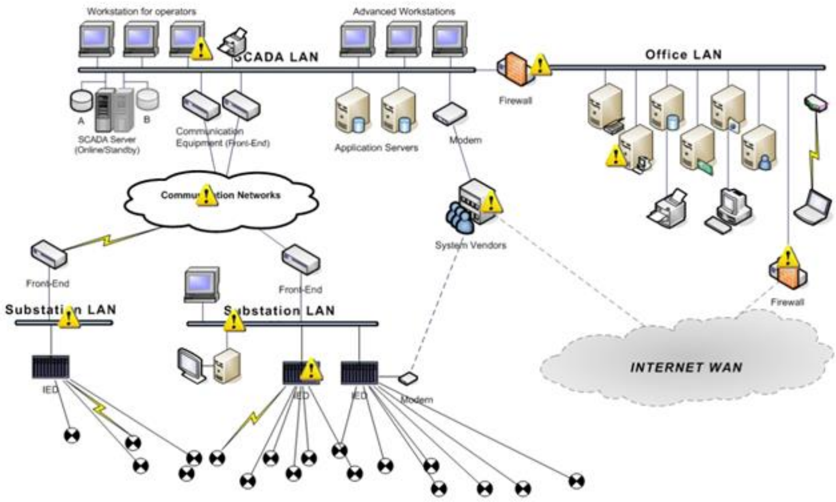


Fig. 2.8: Internet of Things SCADA System (Koushik & BS, 2016).

These SCADA systems were capable of presenting the performance and behaviors of systems on real time with the horizontal scale from the cloud figuring facility. A complex control algorithm is implemented with sufficient practical concepts compared to the traditional PLCs. Sagala, Silalahi & Manurung (2015) developed a secure network communication module with HMI and controller without android and WIFI device.

2.6 Android Application and Internet of Things

An android application developed using android studio software interfaces between the user and the hardware components. This enables the system to intelligently switch between power sources with consideration to the most economic source at that moment and this is after smart scanning of the power control system. Monitoring and managing the energy supplied to different communities lies on the sensitivity of the developed system. With this, similar usage was demonstrated with smart power system to monitor and control the flow of current with different light intensities (Gupta *et al*, 2017).

Hidayatullah, Kurniawan, & Kalam, *(2018*) concluded that IoT network supports integration, exchange and communication. Some of these networks have a sensing device with internet enabled accessories like radio frequency identification device, global positioning system (GPS), infrared sensors and LASER scanner through secure gateway protocol. When these systems are interfaced with a power pool system, a complete monitor and control system could be achieved through its remote operation. Similarly, Sahat, Tantya, Bandung, Subekti, & Tanjung (2019) developed an IoT-based system for home energy management (monitoring and control) with android application interface. These IoT systems for monitoring the home environment and managing power provides the users with effective and efficient energy utilization. An IoT based investigation of smart power utilization service system was carried out. A wireless sensor network, power line carrier communications, optical fibre communications and other hybrid network technologies were proposed. Their design developed an intelligent power network service-based system with two-way interaction services for intelligent home appliance control, home security, the ability to collect user information, and other internet functions. Their method ensures that real-time interaction between a power grid and user response was achieved and was a research-based model and was not implemented physically (Duan, Li, Li, & Yang, 2015).

The Internet of things finds it application in a smart miniaturized grid system where the data was stored in cloud management layer and data retrieval was made possible. The system ensures data communication and monitoring on real-time basis over long distances. The systems made provision for displaying the power transmission and distribution parameters visually on PC and smartphones. The applications of Internet of Energy (IoE) in power systems was explored. The study involved the role of IoE in supply-side and demand-side of power systems encompassing renewable energy generation section, large-scale energy storage section, thermal power plant section, system operation and protection. Their methods digitalized various sectors of the power grid and enhanced information sharing over a global or local network. The method improved the observability and controllability of the components of a power grid and ensured that all the system components were properly maintained (Shahinzadeh, Moradi, Gharehpetian, Nafisi, & Abedi, 2019).

Oliveira, Reis, Rodrigues, & De Sousa (2015) proposed that the solution for monitoring and actualizing home power utilization requires IOT-enabled devices. The system was composed of IoT nodes, a gateway which connects the IoT to the internet and an application server. Three different IoT nodes were designed to measure energy, voltage, current and temperature. 6LoWPAN was used to provide connectivity between two incompatible layers of IoT devices and provided interaction between the devices and the internet. The 6LoWPAN technology uses low-power resources and was used as a unifying layer among all the IoT devices.

The design was done using standards open source and freeware software but it was proven that the design was not completely secured.

Furthermore, an android-based mobile control room brought to bear its application in industries, where the output of two process variables; temperature and liquid level of tank were measured using a Resistance Temperature Detector (RTD) sensor. An Ultrasonic sensor detected the output signal and conditioned it via Arduino for further processing. The Arduino was connected through a Bluetooth module to the android device which displays the result of the process with documentary. The continuous reading of the sensors in real time made it possible for the operator to monitor the changes in the values of the processes. The operator could not remotely monitor the process completely because of the short range of Bluetooth connectivity between the microcontroller and the android device (Alexander,2015).

The continuous research gave way to the design of an android based smart security monitoring system for homes. The design uses IoT for intelligent home condition monitoring and safety assessment. The android system remote operation was based on the MVP model for its applications development. Neural network was used to affect its daily operation usage. All information from the users were established by the network data model. Microcontrollers were used in the gateway and power line communication network was used to connect the intelligent electrical appliances to the gateway. Packet collision may occur as all nodes were connected by physical wires thereby increasing the rate of packet loss. The success rate of the network nodes of these intelligent devices was guaranteed (Wang & Li,2018).

Banerjee & Roy (2019) stated that Bluetooth and android-based real-time observation and control of power consumption for domestic appliances using Arduino was experimented and two compact fluorescent lamps, a fan, a tungsten bulb and a shunt motor were used as household appliances for a period of one hour. Current sensor was used to determine the current consumed by these appliances, the output processed by the Arduino microcontroller and displayed on a cellular device through a Bluetooth connection was achieved. The load curve calculated was used to predict the future consumption of electrical power and energy for a certain period of time. The design helps in the optimization of load consumption by consumers and ensures the amount paid on electric bills was reduced to the minimum.

Rey, Arce, Ulloa, Cacabelos, & Miguez (2015) opines that the application of LabView and Android in the automation, monitoring and control of an ICE based micro-CCHP system is possible. The use of an android application and the integration of a LabView program was used in the development of an automated system, these were used in controlling the small-scale combined heat and power system (micro-CHP). The proposed system was able to achieve synthesizing system analysis and also reduced human dependence in operation. Their methodology was also able to create a suitable architecture for monitoring and controlling the proposed plant and also remotely communicating with the develop database. Regardless of the high efficiency of the system, this method was unable to provide analysis of past result gotten from the database with the aim of improving on the system application for future design. With the aspect of LabView approach which is said to be one of the best solutions for system control, the proposed method was said to be effectively achieved because it recorded a huge success in the automatic monitoring and control of the proposed plant. Their research did not consider Android app to enable machine and human interactions (Lu & Yi, 2016).

Sahat *et al*., (2019) uses Android application in the development of a home monitoring and power management control system. The design of an android application in monitoring of home environment and management of power consumption for the convenience of home users was achieved. Owing to the wide area of application of the system, ranging from account management, home monitoring, relay control etc, the system was still able to maintain a suitable standard when up to 150 users utilized of the application simultaneously. The use of IoT in their research work poses risk of cyber crime by having unwanted access into the security of home with the attendant security risk to the resident. This required a lot of data for the running and maintenace of the application and database. The interfacing of IoT into their project makes the method durable and effective in the development of smart home. The use of an android application interfaced with IoT system was used to monitor the security condition of homes and also control electronic devices remotely.

Development and implementation of a photovoltaic inverter mmonitoring system with the use of an Android device was not left out of the android experimentation. The developed system could not just monitor power usage alone but also performed data collection on the inverter actions, detection of fault in grid connection and analysed the operation status accurately and also displayed the data of the inverter to the user. The method was able to successfully acquire, transmit, record and display the acquired data of the photovoltaic inverter (Xia, Miao, Ding, Zhu, & Xu, 2013).

Development of a real time energy monitoring device with the use of an android-based system was also achieved, microcontroller was used in the development of smart meter which was used in monitoring the amount of electricity used in a house in order for the residents to control the consumption of power and also view the total quantity of electricity consumed. These android base monitoring systems were able to monitor separate areas of the house without conflicting results from other electronic devices, and also notifying the user of the electronic device that has the highest electricity consumption level. The provision of either turning off or regulating the device consuming more power was not integrated into the system in order to enable the user turn off the device remotely. The Android application was able to monitor the electricity usage in different areas of the house and also store the data in the online database successfully (Isa, Latip, Zaini, & Alias, 2016).

Furthermore, a Bluetooth low energy smart monitoring system was developed. The use of a Bluetooth low energy smart plug which comprises a relay, AC power socket, hall effect sensor and a wireless communication module was integrated into an android-based application and was employed in controlling and monitoring household appliances energy usage. The methodology used provided a broad use of IoT in the domestic house automation that was able to control and maintain power usage in homes without the help of human and was effective both in cost and energy consumption. The working of this system requires a lot of data usage in other to stay connected to the internet for the storage of data and also for the effective maintenance of the system. This approach is cost efficient and has shown to be effective in monitoring of electricity power comsumption. The effective monitoring and control of energy usage in household was successfully implemented (Jung & Kim 2018)

In furtherance to the android system approach in energy integration, a three-part system consisting of a smartphone application, base station and sensing node was proposed. The sensing node uses a current and voltage sensor with an Arduino microcontroller for calculation of the power consumed by connecting electrical appliances in real-time. The measured readings and calculated values were displayed on a liquid crystal device. The base station receives all transmitted measurement readings from the sensing node and relay was added to allow control of appliances by sending commands to the microcontroller wirelessly from the base station, according to the consumer requirements and turning off the system immediately when the permitted consumption limits are exceeded. Their work discovered that designing a system for a larger purpose would involve the use of many relays (Nayyef & Husein, 2018).

Islam, Akter, Nipu, Das, Mahbubur-Rahman, & Rahman, (2019) explained that a sensor node, gateway node and irrigation node can be incorporated into an Android application design. The sensor node comprised 4 units: the sensors; communication unit, data processing unit, and power unit. Data from the sensor node were transmitted to the cloud server using LoRa IoT protocol through the gateway node and LoRaWAN was used for data transmission between the sensor nodes, gateway and irrigation node. The irrigation node was composed of an irrigation pump and a reservoir with a solenoid valve and a controller to operate the valve. Web and mobile application were designed for field users to easily use the system. The system ensures that user can irrigate their farm from any location using either the mobile application or the web application which were designed with a simple and easy to use user interface.

Khan, Rahman, Nadeem, Siddiqui, & Khan, (2018) uses smart sensor network and IoT to monitor and control a microgrid system remotely and the microgrid system was designed and controlled by an advanced computer based distributed control system (DCS). Smart sensors and IoT were integrated in the DCS and used for the monitoring of the system conditions. The DCS had access to a user-friendly human machine interface and had supervisory control for all its critical assets. The performance of the microgrid at various load conditions and available energy generation were monitored. The microgrid was controlled remotely using a personal computer along with Object Linking and Embedding device (OLE) for process control server. Monitoring ensures that problems are spotted before they occur. The method helps to prevent unplanned downtime and the cost associated with lost production. The monitoring of motor condition brings proper servicing to the motor before unwanted failure. These androids and IOT related approaches find suitable application in this research involving co-located energy integration scheme.

2.7 Arduino and Generator Starting System

The Arduino microcontroller has both hard and software components, the hardware components consist of boards of embedded electronic devices capable of accomplishing numerous tasks. Its applications include Embedded systems development, Robotics, Artificial Intelligence and control systems development. Its software component comprises the ARDUINO IDE, which permits data acquisition and analysis depending the commands given via a programming code. The Arduino board has digital input and output pins up to 14 numbers and also analog inputs pins up to 6 numbers. It has a high-speed crystal oscillator up to 16MHz and its complete board has a port for USB connection and a power jack coupled with an ICSP header and a reset button. Its application depends on the Arduino memory capacity ranging from Nano, Uno, Mega and Mini. Depending on the capacity and area of usage the speed of the Arduino types varies and characterizes its capability in Switching the system input ON/OFF similar to this design (Dandge *et al*, 2016).

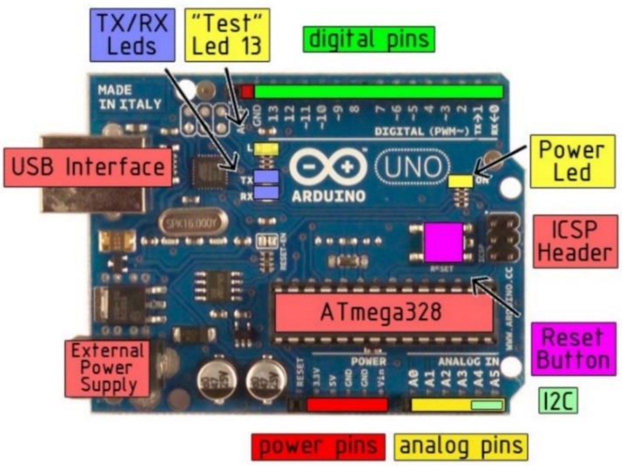


Plate 2.37: A simple ARDUINO UNO Hardware package (Dandge, Shirwadkar, Gite, Odhekar, & Kakad, 2016)

A simple Arduino UNO hardware board is as shown in plate 2.37, the power source of the Arduino through an external power supply is connected through the USB connection port and the board operates through 6-20 Dc volts of external supply. Although the recommended range of operation so as not to damage the board is 7-12Dc volt. The Arduino hardware and software find application in a Keyless-entry system where web program gave the user interface, Wi-Fi/GMS module aids interface control for the keyless-entry system by accepting commands from the user remotely and sending such commands to the Arduino which automatically locks and unlocks the door through a PHP program (Areed, 2019).

2.7.1 Arduino IDE

This is the integrated development environment for the Arduino program code writing and aids to embed the code into the microcontroller during schematic design. It is an application used in writing the programming codes necessary for the Arduino micro-controller actions. The Arduino board is used for communication with the physical world through its inputs and outputs. There are varieties of Arduino board, depending on the size of its memory. This work employs the use of Arduino-Nano to design a model for the power pool system. Its IDE creates an enabling environment libraries and modules for the programmer to be able to write commands and give functionalities to the micro-controller. In this research, the Arduino board is made to interface with an android application which the operators use in switching from one source to another remotely via a Wi-Fi module. This is similar to its applications in environmental monitoring with mobile application (Akhmetov & Aitimov, 2015).

2.7.2 Arduino and its Data Acquisition and Analysis Technique

Data-acquisition systems are extensively used in renewable energy applications in order to collect data regarding the installed system performance and for evaluation purposes (Mezzai, Rekioua, Rekioua, Mohammedi, Idjdarane, & Bacha, 2014). Data Acquisition in this work is achieved using the micro-controller ATMega 328P (ARDUINO).

Basically, it is a hardware part which helps in interfacing the signal of the outside world with the power pool system. The basic principle is to convert an analog signal into a digital form so that the computer can sense it. An analog signal can be a voltage, current, temperature, etc. which is used in its digital form. The main measurement features of the Arduino are signal conditioning, analog to digital conversion and computer bus. The Proteus software designs, simulates and provides the prototype of the integrated hybridized energy system behavioral parameters.

2.7.3 Generator Starting and Switching System

Amuzuvi & Addo (2015) developed an automatic transfer switching system for a standby electric generator using a microcontroller and this electric generator was used as an alternative power source and later was integrated to the grid for optimal use. The design was put to use with voltage sensing circuit, Hall Effect current sensor, relays, light emitting diodes (LED) alongside liquid crystal display (LCD).

These design function using PIC16F877A microcontroller and the speed of operation of the changeover system was enhanced as a microcontroller-based device was used to bring together all components to function. Their research established that the use of microcontroller to bring together components speeds the operation of the system to match each other, though the design was without automatic generator starting mechanism. Azeem, Habib-ur-Rehman, Ahmed, & Khattak, (2016) in its analysis, developed an automatic transfer switch which enabled load transfer, their designed circuit gave an output waveform showing smooth transitions without having any fluctuation. The continuous operation for load over different power source was ensured in an uninterrupted manner. Though it was limited by the range at which the power sources could change over to another with low-cost materials.

Dinh, Marco, Greenwood, Harper, & Corrochano, (2017) developed a system to control micro-mild hybrid machine and the developed power train model for engine helps to start and stop the machine. Mathematical approach for powertrain model of generic construction was developed. A simple parameterization procedure with a minimum set of data required to characterize the dynamic model was presented. This model-based adaptive controller was designed for the starter to crank the engine swiftly and smoothly without the need of fuel injection while the critical problems of vibration, harshness and machine noise was eliminated.

2.8 Energy System Controller and Trends

The recent continuous research in energy sector has been targeted to improvement in power quality, energy generation and enhance availability. Management of energy resources with the use of controllers are assumed to give a preset preferences operation based on energy prices and consumptions. In traditional power systems, large power generation plants located at adequate geographical places produce most of the power and then transferred towards large consumption centers. Kumar, (2013) developed remote energy monitoring and control system but absence of Android Apps for energy switching limits is operations.

Programmable Logic controller-based energy management and control system was introduced with human machine interface with SCADA capabilities to manage energy resources within a geographical area, this design was hindered by short distance communication model (Reddy *et al.*, 2013). Similarly, the automated energy management system was also developed by Thamarai and Amudhevalli (2014) and witnessed the same limitation of about 30m communication distance but has human machine interface and SCADA using PLC via RS 232.

Baral and Kim (2014) developed and analyzed hybridized system of wind and solar systems and there was no consideration for energy integration configuration (Power Pool) and controller as against Sagala et al., (2015) design which have a controller with human machine interface using secure communication modules. However, the design was without Android application and WIFI devices. A python coded graphical user interface displayed on a touchscreen and LABVIEW program written for energy control but without remote monitoring and control module (Haines & Joyce, 2017) (Lu & Yi, 2016).

Investigated on energy pool reliability leads to the design of demand-side management scheme for co-located banks in Owerri with recommendation that controller development would handle resources considering it close proximity to each other (Ezugwu *et al*, 2018). Access to electricity in west African countries could be visible if the available power resources are pooled together (Tehetro, 2021). Continuous sufficient energy attainment requires the deployment of energy controller to generate control signals that aids in regulating the overall system activities. Controlling power system entails switching of its device using digital or conventional analogue techniques. In digital or discrete control, hearts of the controller are the digital computers, these gives flexibility in controlling the power systems. The conventional analogue techniques apart from giving a continuous control action requires a signal conditioning system to arrives at the final readable output. The analogue control system also introduces noise and inability to fast-match the raw energy sensors information from the field device (Paraskevopoulos, 2011). Pool control center were seen to be necessary for optimal energy control, thus Kundur (2012) proposed power system control hierarchy to coordinate and manage the quality of power in a given sources which would be applied in this research work. Different types of digital controller were reviewed for power system conversion implementations (Patel and Sood, 2018).

A unified controller was proposed for the management of the power flow in smart systems as a result of rapid introduction of renewable energy integration into the already existing power source to handle the increasing power demand. The design provides simultaneously and selectively smart power systems control at real-time with flexible alternating current transmission system incorporated power electronic-based controllers to enhance controllability and increase power transfer capability (Georgilakis and Hatziargyriou, 2019).

Fardanesh (2010) opined that to centrally coordinate to attain a wider energy monitoring and control, online power injection and flow operation, the multilevel hierarchical control schemes are required. The future state of power system operations and control based on a number of assumptions and provides an analysis of the direction that this area might take over the nearest future. The application of a centralized substation protection system based on a centralized digital control (computer-based) system was proposed to be the most suitable approached in energy control. The relay protection had gone through a number of development stages, migrating from electro-mechanical to semiconductor, and subsequently to integrated circuit and microprocessor technologies recently. Today, microprocessor-based digital and numeric relays are replacing conventional relays in all areas of power system switching and protection (Bo *et al*, 2016).

Digital control techniques are adopted for this research work in that its practical implementation over decades has replaces most of the conventional analog types and power related system switches faster and requires computer-based controller. Energy outage from one source requires fast transfer of power from another source for continuous energy supply. This is due to the fact that controlling systems with computers offers great advantages over conventional techniques giving attention to greater control flexibility, fast switching, simple data processing, superior sensitivity, reliably and smaller in size. It keeps memory of the event and easily controlled by a program.

2.9 Control System Concept

Every control system is expected to provides the anticipated response from the input to control the output. In Fig.2.9, the general block diagram of the control system has the input and the output. The input is the inlet for the desired signal and the output gives the processed signal from the control system with feedback loop. The control system has a controller embedded in it as the major device alongside other components parts. The output is regulated (controlled) by changeable (varying) input.

Fig. 2.9: General block diagram of a control system (Ezhilmaran,2010)

Control Systems could also take the form continuous time or discrete time;their input/output relationship could be represtented in single input, single output (SISO) or multiple inputs, multiple outputs(MIMO) or an open loop or closed loop control systems depending on the desired signal.

$$Transfer\ function\ (TF) = \frac{Output\ Signal}{Input\ Signal} \tag{2.1}$$

Transfer function model provides the system behaviour for a feedback system from its output and input interactions it is the laplace transform of the ratio of output to input of the differential equation model of the system. Fig.2.10 shows the close loop control system block diagram with feedback loop for a typical dymanic system. The control model has the input, the controller, the plant, the output and the feedback element with summing junction for signal error detection (Zhang, Zhu, Mobayen, Yan, Qiu & Narayan, 2020).

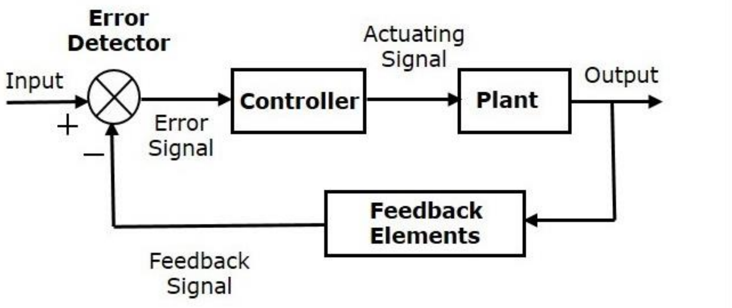


Fig. 2.10: General Close loop Model of a control system (Zhang et al, 2020)

The feedback loop is classified into positive and negative, depending on its applications, or both could be used. The positive feedback is used in adding the reference input R(s) and feedback output as shown in Fig.2.11, whereas, the negative feedback is used in reducing the reference input, R(s) and feedback output Fig.2.12.

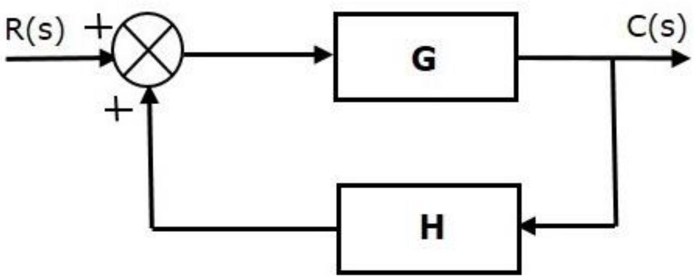


Fig. 2.11: Positive Feedback of the close loop system (Kani,2010)

The transfer function is given as: $TF = \frac{C(s)}{R(s)} = \frac{G}{(1-GH)}$ (2.2)

Where, TF is the transfer function, G is the open loop gain, and H is the gain of feedback path.

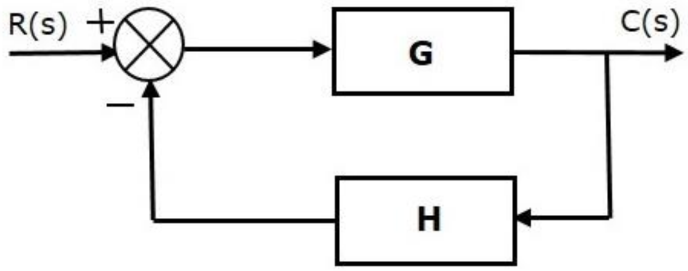


Fig. 2.12: Negative Feedback of the close loop system (Kani,2010)

The transfer function is given as $TF = \frac{C(s)}{R(s)} = \frac{G}{(1+GH)}$ (2.3)

Every control system must have mathematical models. The most used model are the differential (t-domain based), Transfer Function (s-domain based) and State Space (can be obtained from differential and transfer function for system controllability and observability according to Kalman's theorem) form.

Control system must have standard test signal format, these are; impulse, step, ramp and parabolic. For the aforementioned signals, their signal values are one during this interval for all positive signal of time(t) whereas the signal value zero for all negative values of time(t) (Ezhilmaran,2010).

i. The unit impulse function $\delta(t)$ and signals of the system.

$$\delta(t) = 0; t \neq 0$$

$$and \int_{0-}^{0+} \delta(t)dt = 1 \quad (2.4)$$

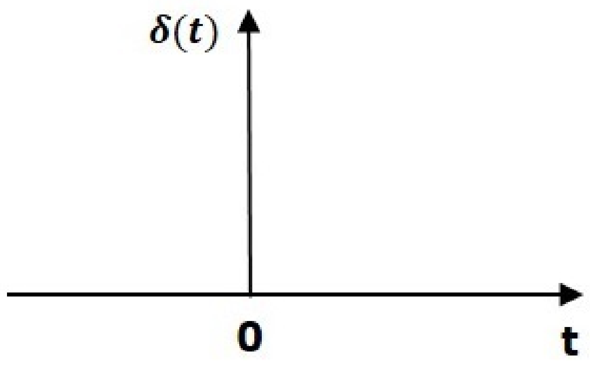


Fig. 2.13: Unit impulse Signal (Kani,2010)

ii. The unit step function U(t) and signal of the system.

$$u(t) = 1; t \geq 0$$

$$u(t) = 0; t < 0 \quad (2.5)$$

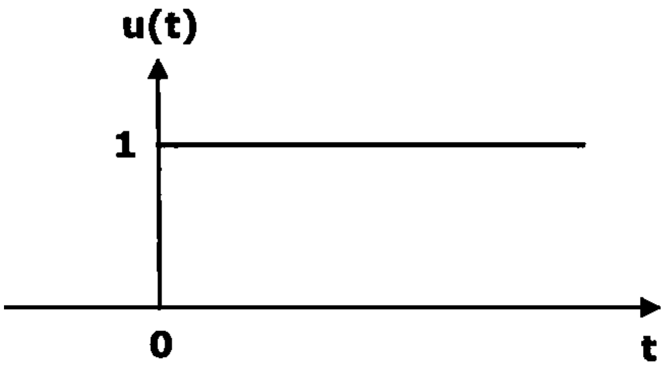


Fig. 2.14: Unit step input (Kani,2010)

iii. The Ramp function r(t) and signal of the system

$$r(t) = t; t \geq 0$$

$$= 0; t < 0 \quad (2.6)$$

$ramp\ signal, r(t)\ in\ term\ of\ unit\ step\ signal, u(t) is\ given\ as$

$$r(t) = tu(t) \quad (2.7)$$

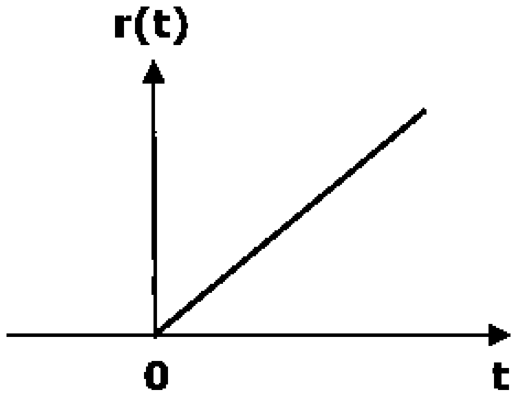


Fig. 2.15: Unit ramp input (Kani,2010)

iv. Parabolic function p(t) and signal of the system

$$p(t) = \frac{t^2}{2}; t \geq 0 \tag{2.8}$$

$$p(t) < 0$$

$$But\ ramp\ signal, p(t)\ in\ term\ of\ parabolic\ signal, u(t)\ gives$$

$$p(t) = \frac{t^2}{2}u(t) \tag{2.9}$$

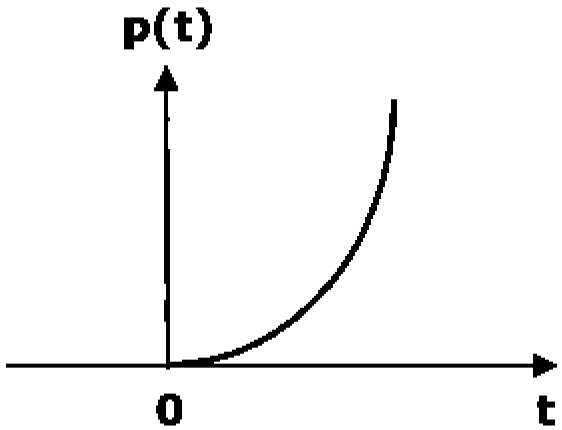


Fig. 2.16: Parabolic function signals (Kani,2010)

A stable system gives a bounded output for any given bounded input and they are classified into absolutely, conditionally and marginally stable system. If the pole lies on the left-hand side of the plot the system is said to be stable other unstable.

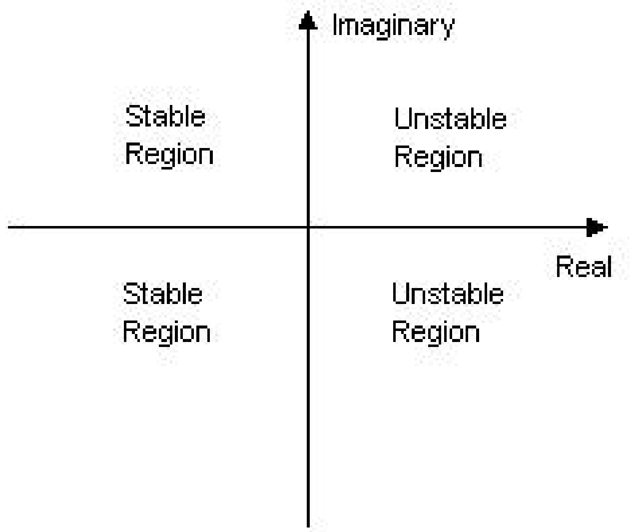


Fig. 2.17: S-plane stability Plot (Ezhilmaran,2010)

In control systems the stability analysis is carried out using the following Methods (Ezhilmaran,2010):

i. **Routh Hurwitz Stability Criterion**

In this theorem, the characteristic equation is determined and used for stability analysis. For Routh Hurwitz stability conditions to be satisfied, all the coefficient of the characteristic's equations must be positive. For stability attainment, all the roots of the characteristic equation must be on the left half of the s-plane and instable system could be determine if at least one root of the characteristic equation must be on the right half of the s-plane (Vatansever & Hatun,2019)

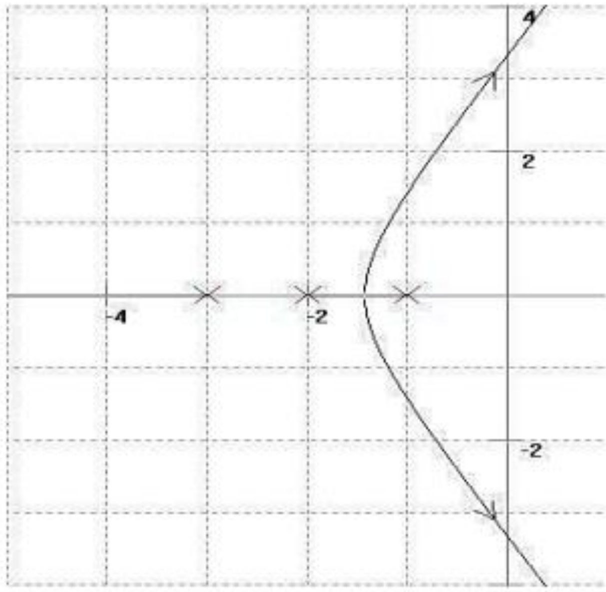


Fig. 2.18: Routh Hurwitz Stability Plot

ii. **Root locus stability criterion**

In this theorem, the root characteristic equation is varied by varying one of the system variables apart from the gain to determined stability. Constant changes in position of the poles and zeros are use in determining the system stability.

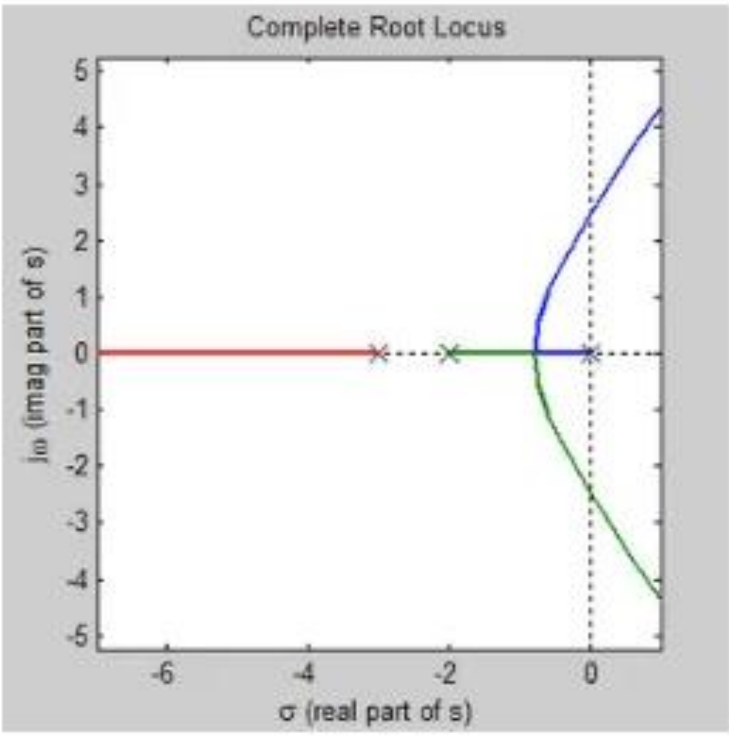


Fig. 2.19: Root Locus Stability Plot

iii. **Nyquist stability criterion**

For stability attainment, the different between the poles and zeros in the close loop system must lie on the right half of the s-plane and instable system could be determine if at least one root of the characteristic equation must be on the right half of the s-plane.

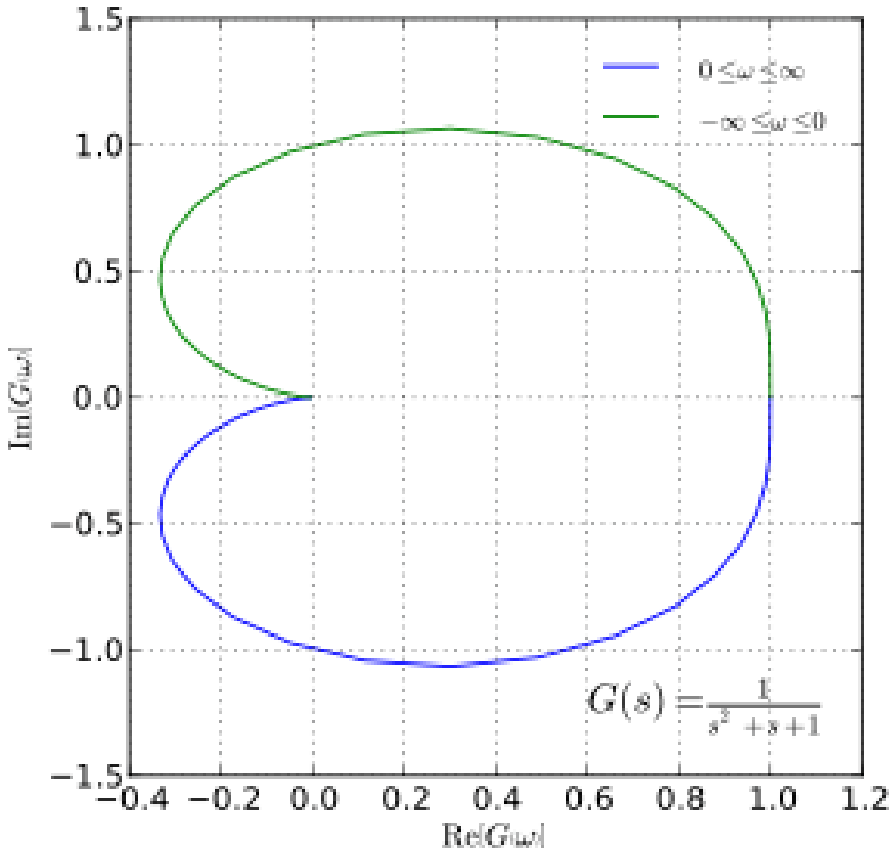


Fig. 2.20: Nyquist Stability Plot

iv. Bode Plot stability criterion

The plot of the magnitude of the loop transfer function and phase versus frequency provides the stability information of the system

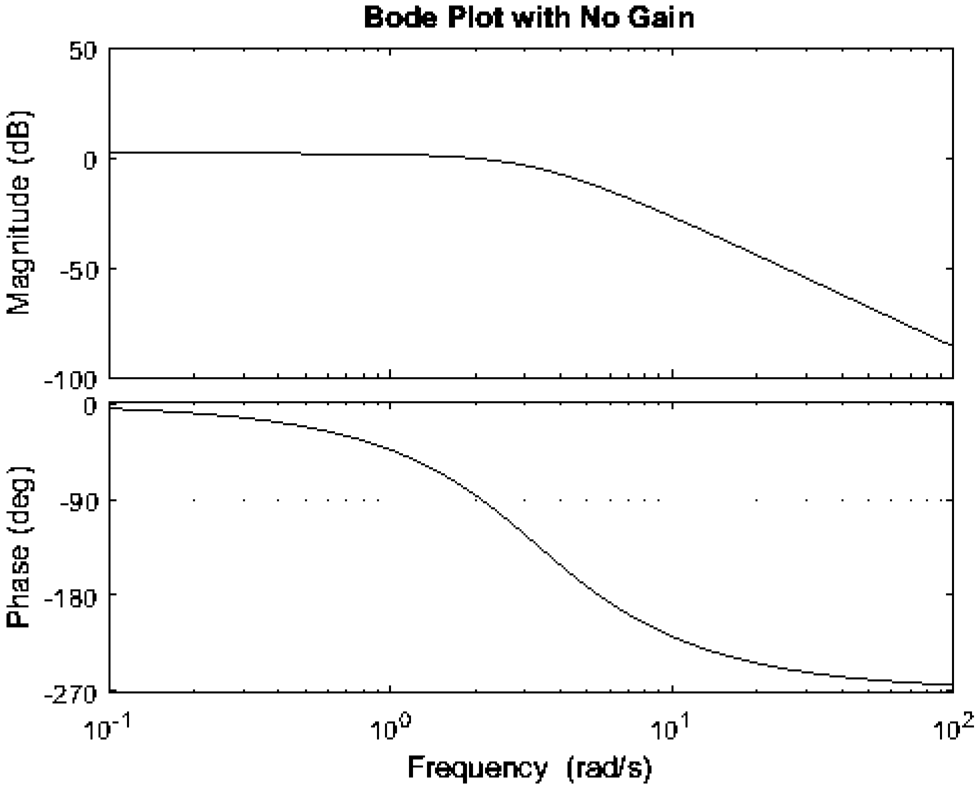


Fig. 2.21: Bode Stability Plot

Controllers Classifications

Controllers are classified according their Control actions such as:

i. ON/OFF control action controller: These are two position controllers

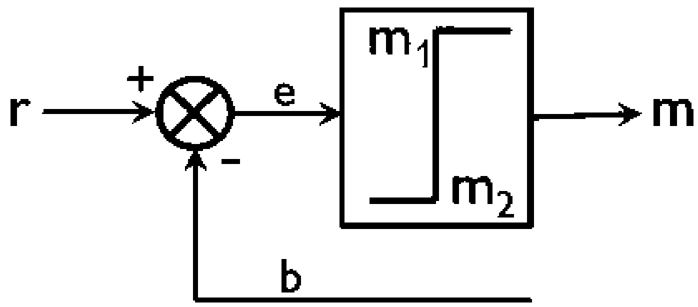


Fig. 2.22: Two position controllers (ON/OFF)

ii. Proportional control action controller

iii. Integral control action controller

iv. Proportional + integral control action controller

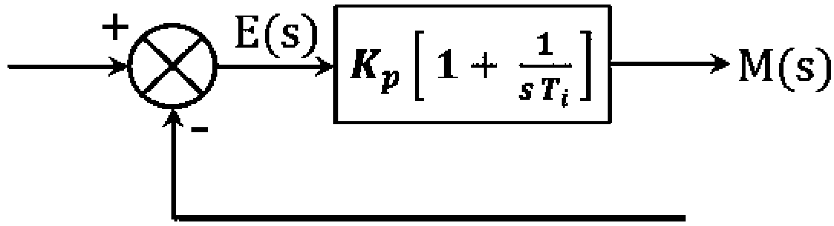


Fig. 2.23: PI controllers

v. Proportional + Derivative Control Action Controller

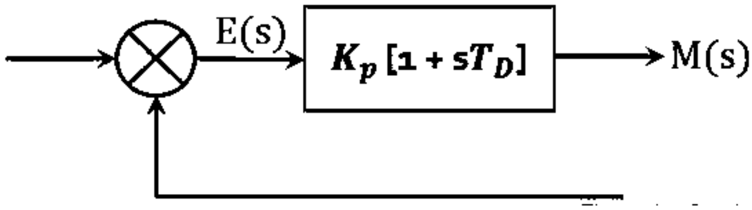


Fig. 2.24: PD controllers

vi. Proportional + Derivative + Integral Control Action Controller

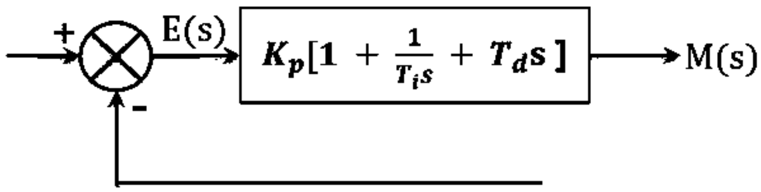


Fig. 2.25: PID controllers

The PID controllers are electronics control with gain, it has its own tunning algorithm, and is capable of increasing or decreasing the feedback signals.

State Space Model

State Space as a model in contol system engineering help in the analysis of complex systems even with its multiple input/output.It also help to determine the internal behaviour of the system (controllability and observability) and easy computation. State Space to equation model also help to design the system compenation scheme due to its various measurable state.

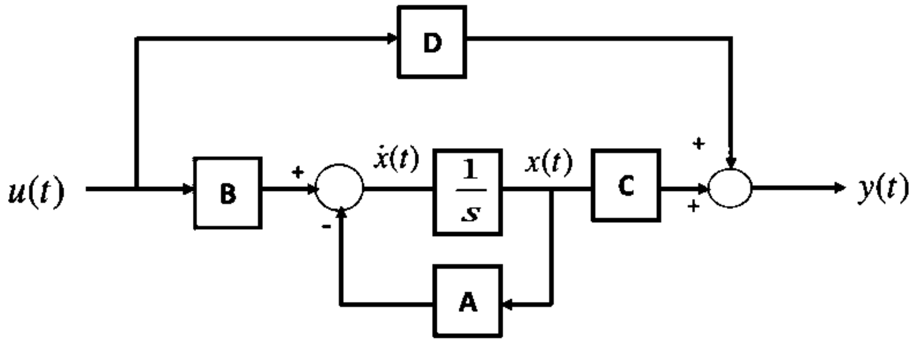


Fig. 2.26: General block representation of the state space model

The mathematical expression of a State Space dynamic equation is given by equation (2.10) and (2.11):

$$\dot{\boldsymbol{X}}(\boldsymbol{t}) = \boldsymbol{AX}(\boldsymbol{t}) + \boldsymbol{BU}(\boldsymbol{t})$$ State equation (2.10)

$$\mathbf{Y}(\boldsymbol{t}) = \boldsymbol{CX}(\boldsymbol{t}) + \boldsymbol{DU}(\boldsymbol{t})$$ Output equation (2.11)

where;

$\boldsymbol{X}(\boldsymbol{t})$ is the state Vector

$\mathbf{Y}(\boldsymbol{t})$ is the output vector

$\boldsymbol{U}(\boldsymbol{t})$ is the input vector

$\boldsymbol{A}$ is the state matrix

$\boldsymbol{B}$ is the input matrix

$\boldsymbol{C}$ is the output matrix

$\boldsymbol{D}$ is the feedback matrix

The system's transfer function can be used to obtained the state and vice versa.

$$\left(TF\ or\ G(s)\right) = \frac{C(s)}{R(s)} = C(sI - A)^{-1}B + D$$

$$or$$

$$(TF\ or\ G(s)) = \frac{C(s)}{R(s)} = \frac{C\ adj(sI-A)B}{\det{(sI-A)}} + D \qquad (2.12)$$

$$\det(sI - A)\ represent\ the\ poles\ of\ the\ systems$$

For a single input system; $\dot{\boldsymbol{x}} = \boldsymbol{Ax} + \boldsymbol{Bu}$; single output; $\mathbf{y}(\boldsymbol{t}) = \boldsymbol{Cx}$; $\mathbf{x} \in \boldsymbol{R^n}$

$$If\ C(A,B) = [B|AB|A^2B| \ldots\ldots |A^{n-1}B]\ \ the\ system\ is\ controllable \quad (2.13)$$

$$If\ O(C,A) = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix}\ the\ system\ is\ observable \quad (2.14)$$

Mathematical Model are representation of a physical system using differential equations, these equations help in establishing a relation that exist between the different system variables (Dundar, Gokkurt, & Soylu, 2012).

Chen & Zhou (2005), carried out a research on Variable Frequency Transformers which are a novel asynchronous power system interconnection technology that works in the same way as a back-to-back High Voltage Direct Current (HVDC) device. The Variable Freqeuncy Transformers energization, rotor speed regulation, synchronization, ramp power control, step power control, voltage dependent power limit control, power supply for an isolated passive system, and reactive power balancing have all been studied using these models. This model was also validated by investigating its Multi-terminal capability in HVDC system with three or more converter stations to ascertain the usefulness of modelling in engineering practice (Hu, Fu, Wang, Rao, & Liu, 2012).

Yuchen, Qi, Weirong-Chen & Hong, (2019), investigate on the notion of an hybrid power control system introduced to control voltage in power systems, and the research establishes a static Hybrid Automatic Voltage Control system which is similar to hybridized power pull system. Their operating procedure was designed using a hybrid hierarchical voltage control system model to justify hybrid theory. In order to drive the system mathematical model was formulated which specifies the system stability mode (Sun,Guo, Zhang,Wu & Tong, 2009). Furthermore, the technology makes it much easier to accomplish optimal automatic voltage regulation, making it very practical in reality. The system's controllable targets, which are driven and detached by discrete events, are sent to separate sub-layer modules, allowing for more efficient calculations by better utilizing available technologies like MATLAB/Simulink.

Simulating the system with parallel time domain is one of the most dependable and promising ways for performing real-time online power system transient stability study (Lin, Tong, Wang, & Wang, 2008). The research proposes a new parallel calculation approach for power system transient stability analysis based on the waveform relaxation method. The method divides the entire transmission network into several subsystems based on geographical location; neighboring systems are represented as equivalent voltage sources at the boundary buses for each subsystem; tie line flows were considered as the communication waveform among the subsystems; and then time domain simulation was performed in parallel for each subsystem. The practical system's test results show that the new parallel method completely achieves on-line real-time or even over-real-time calculation speed and can be applied to the practical system's on-line transient stability analysis.

In a variety of military philosophies, command and control are critical components integrated in the entire system. The simulation of a command and control system makes use of computer simulation technology to evaluate the performance of the designed command post system. This study examined the weaknesses and flaws in present command and control system modeling and recommended an entity-relationship-based command and control system modeling. This study used command and control system models for scenario analysis, in combination with the Lanchester model that considers command efficiency (Meng & Song, 2012).

Michaels, Pagerit, Rousseau, Sharer, Halbach, Vijayagopal, Kropinski, Matthews, Kao, Matthews, Steele, & Will, (2010), carried out a research on model-based control system design which enhances quality while also reducing development time, engineering costs, and rework. The time and money spent on hardware and software for each design iteration was saved by evaluating a control system's performance, functionality, and reliability in a simulation environment. Simulating a design's performance can be simple (though time-consuming, depending on the complexity of the system being built) with mathematical models for the system's hardware components (plant models) and embedded control algorithms controllers. This work offered a software tool and approach that not only allows for a complete system simulation early in the design cycle, but also substantially simplifies model development by automatically integrating the components and subsystems that make up the model. The software-in-the-loop (SIL) capability is a major component of this technique, since it allows compiled legacy source code to be inserted into the simulation environment, allowing incorporation of algorithm functionality for which no simulation models exist. The development of the control system can be done early in the vehicle or powertrain design cycle using this approach as it incorporates plant models, algorithm models, existing controller code, and architectural constructs to greatly speed up the creation of a system simulation that can be used for algorithm development, testing, and validation.

Mu, Wang, Hou, & Wang, (2019), worked on the electromagnetic transient simulation of a photovoltaic (PV) power system. It is a small step system that is slow due to the converter power electronic equipment. Numerically, efficient models were required for effective modeling of large-scale PV power systems. The simplified equivalent AC-DC controlled source model by averaged switching function was constructed based on the principle of Pulse Width Modulation (PWM), and the unified averaged equivalent DC-DC model in the discontinuous conduction mode (DCM) and continuous conduction mode (CCM) was presented. The regular operation of the converter and the low-voltage-ride-through control techniques were also investigated. Furthermore, using Power Systems Computer Aided Design/ Electromagnetic Transient including DC (PSCAD/EMTDC) simulation software, a fast electromagnetic transient simulation model of a PV power system based on averaged convert models with control strategies was created, and the model was validated based on model correctness and simulation step adaptabiity.

Naşcu, De Keyser, Naçcu, & Buzdugan, (2010), carried out a research on the model of a labouratory level control system (Festo Compact Workstation). The model for each component in the system was based on both theoretical and experimental findings. This paper discusses the steps taken in creating an accurate model of a laboratory level control system.

A method to solve parameters of load model frequency characteristics was provided based on extensive research on frequency characteristics of power loads. The weighted total of each static load component's power in the load station was used to determine the static load frequency factor. The load frequency parameters of power generators cluster in the entire load station were calculated using a combination of the statistic synthesis method and the fault fitting method. In addition, simulation results demonstrated the efficiency of the proposed strategy (Wang et al., 2018).

Qing, Xi, Zanxiang, Lipei & Kai, (2013), carried out a study on the permanent magnetic linear generator side converter, grid side converter, controller, and grid as part of a directly driven wave power generating system that is connected to the power grid. The following control strategies were presented based on the back-to-back converter structure: The generator side converter was subjected to vector decoupling management in order to maximize power extraction from wave energy. Grid voltage-oriented control was employed to make the current sinusoidal and achieve unit power factor control on the grid side converter. Because the DC link voltage fluctuates when using the standard method, a power feed forward method was proposed to keep the DC link voltage steady and increase the system's dynamic response. In MATLAB/Simulink, a simulation model for the entire system was created, and simulation results confirmed that the proposed control approach is practical and successful.

Schoder, Ravindra, Stanovich, Langston, Leonard, & Steurer,(2019) asserted that the key building blocks for the future include advances in power electronics, controls, and computer networking. As a result of rising medium voltage, AC and DC systems have different power requirements. Before the potential benefits of new technologies can be assessed, baseline information about a system is analyzed in a system-relevant context. It is necessary to use modern technologies and operating concepts. However, efforts to establish such theoretical baselines was summarized as well as benchmarking performance of shipboard power systems and the results were compared. The potential benefits of alternative electric distribution system design options, operational processes, and enhanced controls are of particular relevance in relation to the efforts presented.

Due to the high randomness of wind power, a much higher demand for load frequency control in the power system has been made. The load frequency control strategy based on the wind power prediction by Kalman filter is proposed to reduce the influence on the system frequency using the interconnected power grid with wind power as the research object. Initially, the Kalman filter technique was employed to estimate wind power. The load frequency controller was designed using the expected wind power and a load frequency control model for an interconnected power system was also constructed.This control strategy was applied to a four-area power system with integrated wind power in three areas. The simulation results obtained using MATLAB/Simulink displayed that the suggested load frequency control technique based on Kalman filter wind power prediction successfully reduces frequency fluctuation and keeps the system frequency fluctuation within a narrow range. When compared to traditional PID-based load frequency control, simulation findings show that frequency fluctuation was outperformed (Yang-Wu, Xun, Ao, Yang-Guang, Ting, DIng, & Jian, 2019).

The application of a neural network-based approximate dynamic programming method, direct experimental dynamic programming, to power system stability control was discussed in this research. Direct experimental dynamic programming is a learning and approximation-based method for nonlinear system control in uncertain situations. In the study, real-time system responses from the wide area measurement system were used to build controllers that were specifically customized to the problems at hand. Furthermore, the controller learning objective was designed as a reward function that represents global characteristics of low frequency oscillation in the power system while taking coupling into account. A convergence proof of the experimental dynamic programming algorithm employing a Linear Quadratic Regulator (LQR) framework was included in this study, as well as a case study to demonstrate the suggested learning control mechanism. The case study uses the China Southern Power Grid to provide a new solution to a difficult large-scale system coordination problem (Yu, Lu, & Liu, 2014).

Zhang *et al.,* (2020), carried out an investigation on the fundamental concepts and technical details of a U-model-based control system design framework, including U-model realization from classic model sets, control system design procedures, and simulation showed off several examples. Consequently, the framework equips readers with clear understanding and practical abilities for further research growth and applications. This methodology contrasts the traditional model-based and model-free design techniques. Two parallel formations were used in model-independent design as explained; creating an invariant virtual controller in a feedback control loop with a defined closed-loop transfer function, and resolving the inverse of the plant U-model to identify the real controller output. It is worth noting that U-control is a universal control system design platform for many existing linear/nonlinear and polynomial/state-space models, and it complements many existing design methodologies. Simulation studies were used to show how analytically produced formulations and guidelines may be applied in real-world situations.

The review of control system principles, concepts, theories, techniques and mathematical model as displayed above will be used in the implementation of an intelligent master controller for hybridized power pool system application.

2.10 Summary of the Reviewed Literature

The intelligent master controller and its associated monitoring and control devices with its application was reviewed. This review with its application reveals several possibilities with the use of intelligent master controller with a soft-touch human machine interface in monitoring and controlling a co-located community-based hybridized power pool system using mobile application. Researchers involve human machine Interface design from diversified approaches and technology. Among these technological approaches and techniques; some of the practices have been on a standalone scenario. Notably, among the human machine interface reviewed in this report: button operated (hard touch) and screen operated (soft touch) were left in the hands of the researcher based on their research target. Graphical user interface and human machine interface were also left in the hand of the researcher depending on their research tasks. Programmable Logic controller (PLC) play vital role in several monitoring and control system applications from the reviewed works. Although, the Programmable Logic Controller is only used to integrate renewable energy resources into the 11KV bus through its simple switching concept implemented on the software basis. However, considering the cost and availability, Arduino microcontroller is selected for use due to its simplicity, effectiveness, availability and compatibility with other devices. Developing supervisory control and data acquisition system also plays a prime role in human machine interface modern designed because of its remote monitoring capabilities. Arduino microcontroller is capable of undertaking a similar task. Mobile application interface with Arduino hardware device is adopted for the development of an integrated power monitoring and control scheme with human machine interface for control of community-based hybridized power pool system in this research. This aids in the design of soft Screen touch intelligent master controller device with HMI for the control of the power pool system; with its associated SCADA system development, it aids in the design and implementation of a remote access monitoring of this community-based renewable energy resources for this power pool system application. SCADA presents system production time, trends and targets on real-time bases. From the already reviewed model and data; a formidable data injection models representing the respective hybridized power pool system supply is developed. Arduino is adopted for the model design with a Proteus simulation providing the visual representation of the system model for result analysis and validation.

In this study, electrical power generated from a group of communities is transmitted into a power pooling system where it is further redistributed in an intelligent manner to those communities. The system comprises solar, hydro-electric power, wind, biomass and two backup power sources (Public power supply and generator). Arduino uno with Program code adapted for effective management and control of the allocated power for the five communities. Power generated by renewable energy sources are transmitted and synchronized into the 11KV bus. Controllers are used in monitoring and controlling each of the sources (public source, renewable energy source and backup generator source), these three controllers are slave controllers and are then controlled centrally by the central master controller. The central master controller is a smart system interfaced with a mobile application for effective remote control, monitoring and management of the pool resources. At each point of its operation, every control and monitoring parameter are displayed on the soft-touch human machine interface. Power system and its control concept applications were understudied and the analysis showed the suitable control system model and principle to adopt in this work. The transfer function which leads to the characteristic equation determination were also uncovered as the result of the review, stability criterion and state space coefficient were derived which would provide an estimate of the system observability and controllability status. To this end, the overall system is designed, modelled, optimized and installed for use as a prototype for the multi-sources energy systems management.

2.11 Research Gap

Considering the reviewed literature, the following were established as the research gaps:

(a.) There has been no attempt to design an intelligent master controller with human machine interface for power pool system control for community-based micro-grid system despite all the optimize hybrid system researched on and implemented (Kumar,2013). Proper management of the power pool system requires a formidable intelligent master controller with a soft-touch screen human machine control interface.

(b.) Zhang & Zho (2012) previously implemented the HMI and SCADA system design without making effort to monitor their individual resources with the view of converting the unused renewable energy resource from communities that have abundant resources to others that have limited power supply. These renewable energy resources continuously require remote monitoring for proper energy allocation. Failure of one pool agent to generate and integrate its energy into the centralize pool system will not stop other agents from contributing their energy quota to serve in view of the pool design monitoring and control criteria (Tehero,2021),(Baral & Kim, 2014).

(c.) Previous research only recommended for several standalone renewable systems to be hybridized and with this, the introduction of the unified energy concept (pooling) is novel. Some communities are energy-endowed than others with different energy potentials and pooling their energy resources engenders steady, constant and efficient energy system in that when one pool system is ineffective others make up, thereby eliminating wastage of the hybridized power pool system from the community with excess energy resources (Gupta et al., 2018), (Yang et al., 2018).

(d.) There has not been a hardware implementation of some of the physical model via Internet of Things, which this work takes on (Ezuwu et al.,2019).

(e.) There has not been an attempt to introduce remote monitoring and control of Integrated power pool system for community-based purpose using Web/Android applications (Haines & Joyce, 2017).

(f.) There has not been any attempt to introduce remote multiple generators starting system for complete energy integration cycle, thus witness low energy yield (Dawound et al., 2018).

(g.) Following the reviews of literature, there was no attempt to design an intelligent master controller with human machine interface for power pool system control in (a.), hence there was no control system mathematical model, stability test to ascertain the disturbance handling, feedback system algorithm and optimization process.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

The materials for this research require software and hardware.

3.1.1 Software

The following software as listed below were used to develop the intelligent master controller for hybridized power pooling system applications:

(a.) KV Studio V11 Keyence PLC Programming Software

(b.) Arduino IDE

(c.) Proteus

(d.) Sublime text (Text Editor)

(e.) Android App

(f.) Cloud Service (ThingSpeak) and GitHub (host)

(g.) MongoDB: NOT ONLY Sequential Query Language (NoSQL)

(h.) MATLAB/ Simulink

3.1.2 Hardware

The following hardware materials as listed below were used to develop the intelligent master controller for hybridized power pool system applications:

(a.) Microcontroller (Arduino ATmega 2560)

(b.) Microcontroller (Arduino Nano)

(c.) Display Screen (Thin-Film-Transistor Liquid-Crystal Display)

(d.) Relay driver module

(e.) Relays(60A)

(f.) WIFI module (ESP8266)

(g.) Light Emitting Diodes

(h.) NRF Module (2401)

(i.) Transformer

(j.) Diodes

(k.) Resistors

(l.) Current Sensor

(m.) Voltage Sensor

(n.) Voltage regulator

(o.) Capacitors

(p.) Lamps

(q.) Battery

(r.) PC (Laptop)

(s.) Android Phone

3.2 Methods

The experimental techniques is employed for the development of this intelligent master controller for the power pool system applications.

3.2.1 Design of Intelligent Master Controller Architectures

The design of the intelligent master controller architecture provides the operational model for the power pool system and facilitates easy injection of energy into the micro-grid system.

(a.) Design of the Conceptual Power Pooling System Configuration

From fig. 3.1, GEN represents the generator which generates 415V and it is stepped up to 11KV, Q7 as an isolator when operated on either opens or closes the 11KV line. The stepped-up voltage is synchronized into the bus. CB1 is the tie breaker. The tie breaker in this design aids in isolating the synchronized voltage from the renewable energy input supply and the grid input supply.

Similarly, the 33KV generated, transmitted and distributed from the grid is stepped down to 11KV, Q6 as an isolator when operated on either opens or closes the 11KV line. This stepped voltage is synchronized into the bus. CB2 is the tie breaker. The tie breaker in this design helps in isolating the synchronized voltage from the renewable energy input supply and the supply from the generator.

From fig. 3.1, AF represents Afikpo community, AM represents Amasiri community, EN represents Enohia community, UN represents Unwana community and OZ represents Oziza community. S represents solar energy, W represents wind energy, B represents biomass energy and H represents Hydro energy system.

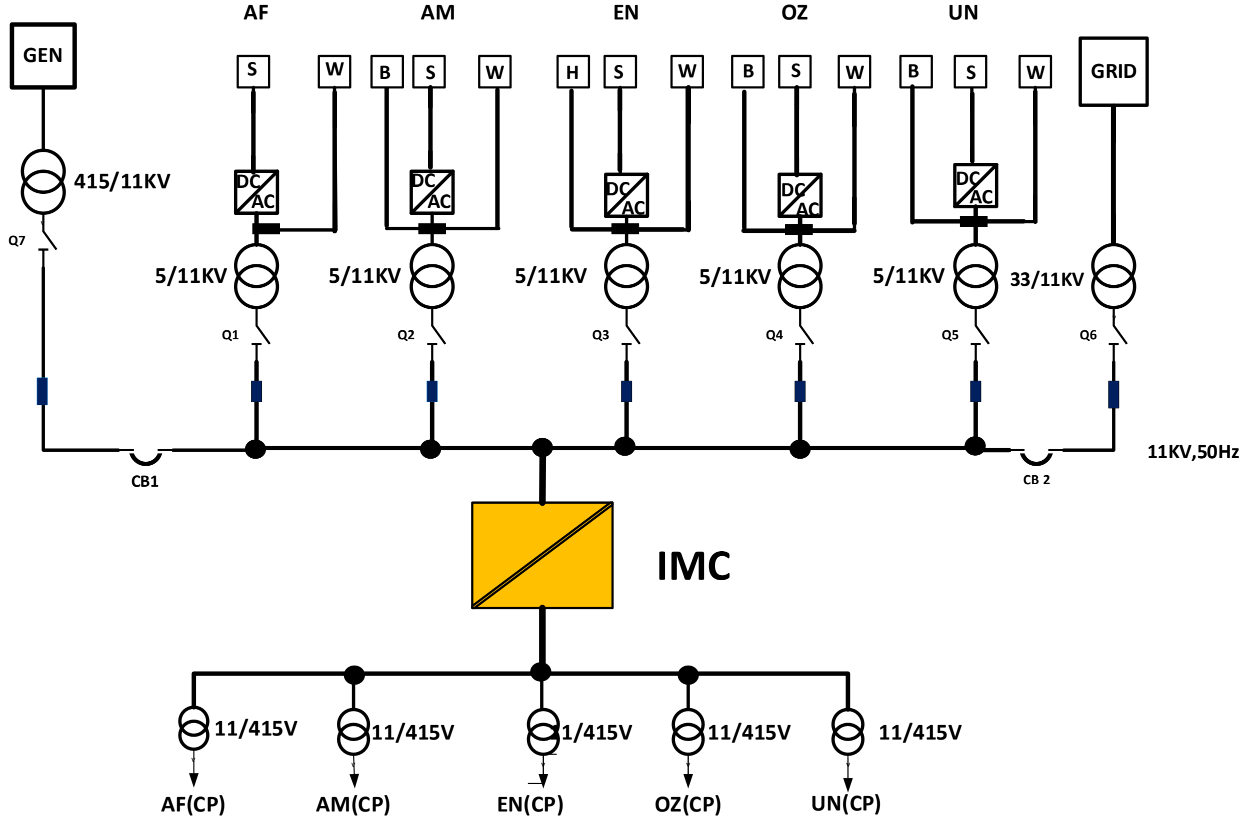


Fig. 3.1: Conceptual Power Pooling System Configuration

The integration of solar energy from Afikpo community produced a DC voltage which was fed to the AC converter alongside with the wind energy and the AC voltage of 5KV was generated. The alternated voltage was stepped up to 11KV. Q1 as an isolator when operated upon either opens or closes the 11KV line. This stepped-up voltage is synchronized into the bus.

The integration of solar and biomass from Amaziri, Oziza and Unwana community produced a DC voltage which was fed to the AV converter alongside with the and wind energy and 5KV AC voltage was generated. The AC voltage was stepped-up to 11KV. Q2, Q4, and Q5 respectively are isolators when operated upon either opens or closes the 11KV line. This stepped voltage is synchronized into the bus.

Also, the combination of solar energy from Enohia community generated DC voltage, the voltage was fed to the AC converter alongside with hydro and wind energy. The AC voltage produced was 5KV. This alternated voltage was stepped-up to 11KV. Q3 is an isolator when operated upon either opens or closes the 11KV line. This stepped-up voltage is synchronized into the bus.

For the intelligent master controller to work effectively, it requires three other slave controllers. These three slave controllers are placed for unparalleled operation for grid input, renewable energy and the generator input. It is assumed that all the renewable energy sources were hybridized and optimized via the slave controller in charge of the renewable energy resources. The modelled control voltages of 5V was generated to handle the control action in the pool system. The control voltages were fed to IMC, where IMC is known as the Intelligent Master Controller. The intelligent master controller does a priority check first, where the supply from the grid is considered to have the highest priority followed by the supply generated from the integration of the community's renewable energy resources and lastly, the generator supply which automatically come on if there are no supplies from the grid and renewable energy sources.

With the controlled voltage, the 11KV is controlled and stepped down to 415V and redistributed to each of the five communities.

(b.) Design of Intelligent Master Controller Block Representation

The fig, 3.2 is an extraction of intelligent master controller (IMC) unit from the conceptual power pooling system architecture as configured in fig. 3.1. The block in fig. 3.2 shows the three energy generating sources units, the DC power supply unit, the display unit, the generator starting unit, the fault isolation unit, the relay unit, analogue to digital conversion unit, Microcontroller unit, the sensor unit, RF wireless module unit, WIFI module unit and the interfacing modules units.

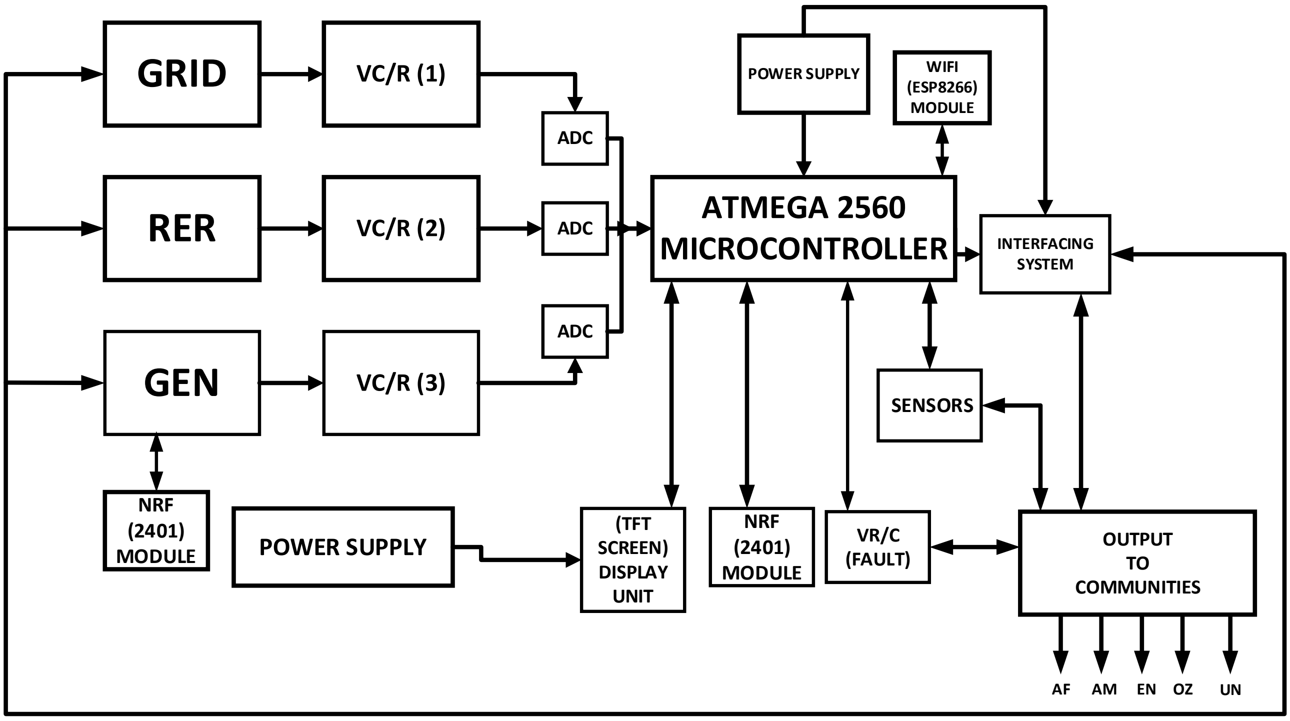


Fig. 3.2: Intelligent Master Controller Block Diagram

(c.) Design of intelligent master controller integrated hybridized scheme

Five communities living closely have different renewable resources which are integrated and controlled with this design. There are three power supplies respectively, they are as follows; Grid, Renewable and Generating set.

i. The Grid Input Supply

In this work, the grid system here represents the principal supply input to the five communities under study. This provides a means of supplying energy generated from different companies, transmitted on a common frequency and distributed for use. Its existence in these five communities has been before the advent of this research, thus there will be no elaborate design on this grid input supply. In this research, for the three power supplies to be adequately controlled, the supply from the power grid is considered to have the highest priority while other power supplies (the renewable sources and generator) are made functional if there is no power from the national grid.

ii. The Renewable Energy Resources

I. Wind Energy

II. Solar Energy

III. Hydroelectric Energy

IV. Biomass

Fig. 3.3 is an extract from renewable energy resources (**RER**) integrated unit in Fig. 3.2. This shows the block diagram of individual units that formed the Intelligent

Master Controller but with preference to renewable Energy resources input to the intelligent master controller. This is represented by a five input OR logic gate. Further central model integration is demonstrated with Programmable logic controller in Section 3.2.1: A to 3.2.1: H.

From Fig. 3.3, AF means Afikpo community, AM means Amasiri community, EN means Enohia community, UN means Unwana community and OZ means Oziza community. In this design, the renewable energy resources available for Afikpo community are wind(W) and solar(S) energy. This combined wind and solar formed the hybridized system and is connected to a two input OR logic controller which is in turn connected to hybridized renewable energy sub-master controller.

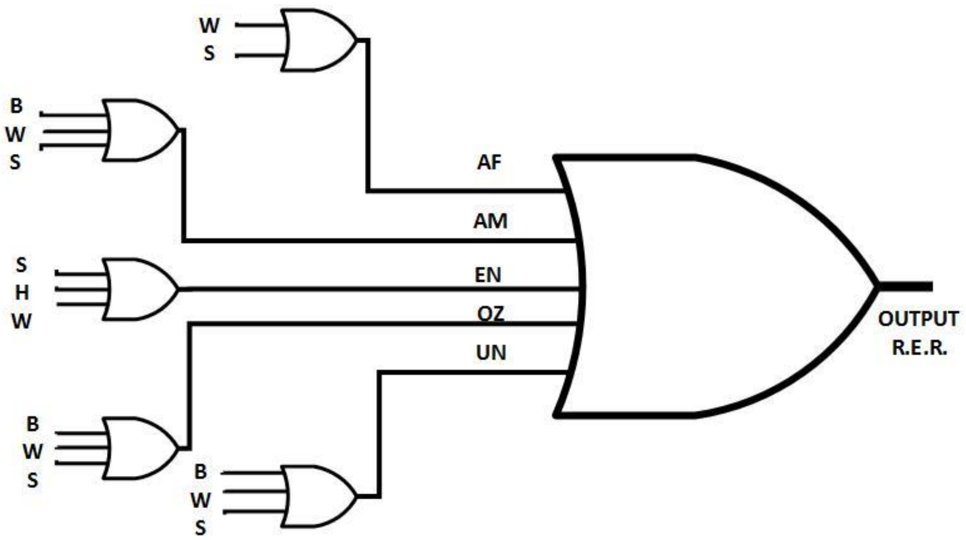


Fig. 3.3: Hybridized Renewable Energy Resources logic

This is assumed to have been optimized and synchronized via the 11KV bus. Similarly, the renewable energy resources available for Amasiri community are biomass(B), wind(W) and solar(S) energy. This combination formed the hybridized system and is connected to a three input OR logic controller which is then connected to hybridized renewable energy sub-master controller. This is assumed to have been optimized and synchronized to the 11KV bus. In Enohia community, the hydro(H), wind(W) and solar(S) renewable energy resources are available. This formed its hybridized system. On its integration into the bus, it follows a particular sequence such that all cannot be loaded at the same time (three input OR logic). Same as in Amasiri community, the renewable energy resources available for Unwana and Oziza community are biomass(B), wind(W) and solar(S) energy. This combination formed its hybridized system and is connected to a three input OR logic controller which is then connected to the hybridized renewable energy sub-master controller. This is assumed to have been optimized and synchronized to the 11KV bus. The Hybridized Renewable Energy Resources logic in Fig. 3.3 was designed. This shows how individual community with their OR logic controller are used in conveying or injecting their energy resources to the sub-master controller in charge of the hybridized renewable energy resources. The implementation of this hybridized renewable energy resources logic was made possible with Programmable logic controller.

This programmable logic controller design injects or integrates the renewable energy resources harvested from these five communities into the 11KV Bus. The Kenyence PLC with model number KV24-R was used. This is a modular PLC with a total of 24 analogue and digital input / output terminals and uses LADDER BUILDER software for its programme implementations, Rs 232 to communicate on the PC side and RJ 11 or 45 to communicate on the PLC side. The hybridized renewable energy injection model in Fig. 3.3 demonstration with Kenyence PLC is as shown in Fig.3.4 -3.10.

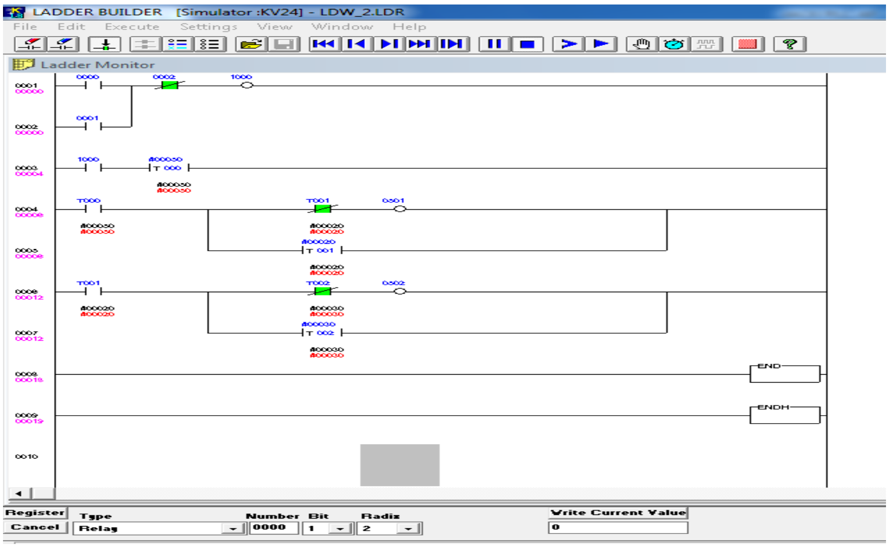


Fig. 3.4: PLC Program for the integration of Afikpo Renewable Energy Line

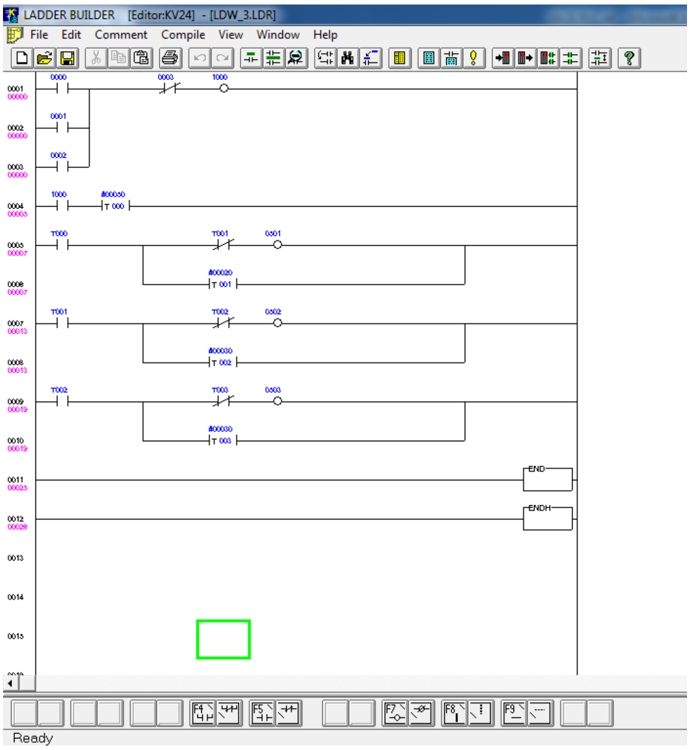


Fig. 3.5: PLC Program for the integration of Amasiri Renewable Energy Line

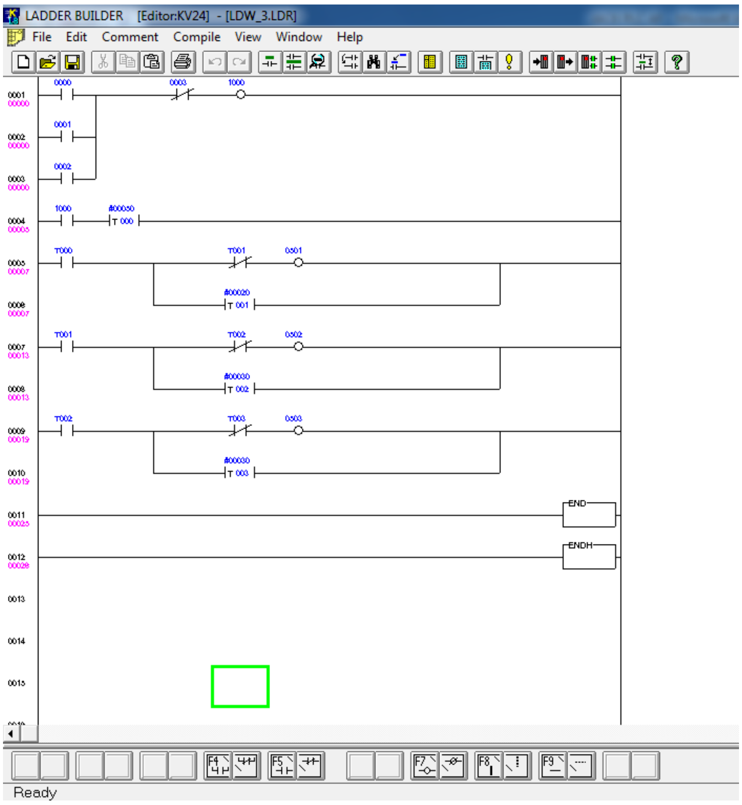


Fig. 3.6: PLC Program for integration of Enohia Renewable Energy Line

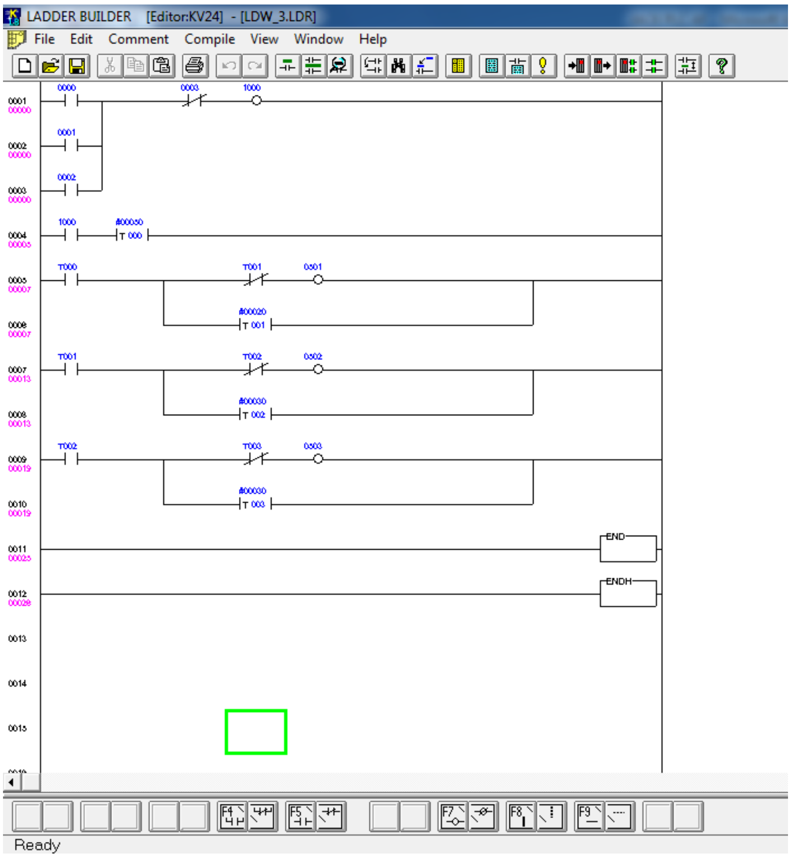


Fig. 3.7: PLC Program for the integration of Oziza Renewable Energy Line

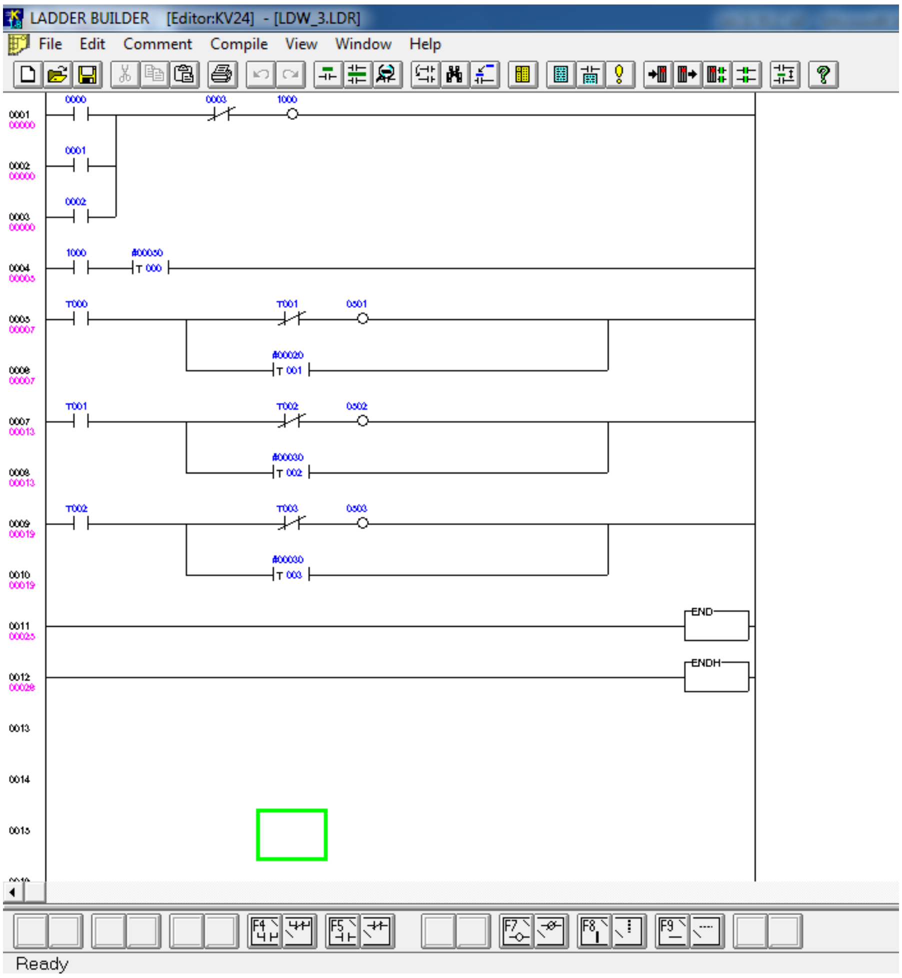
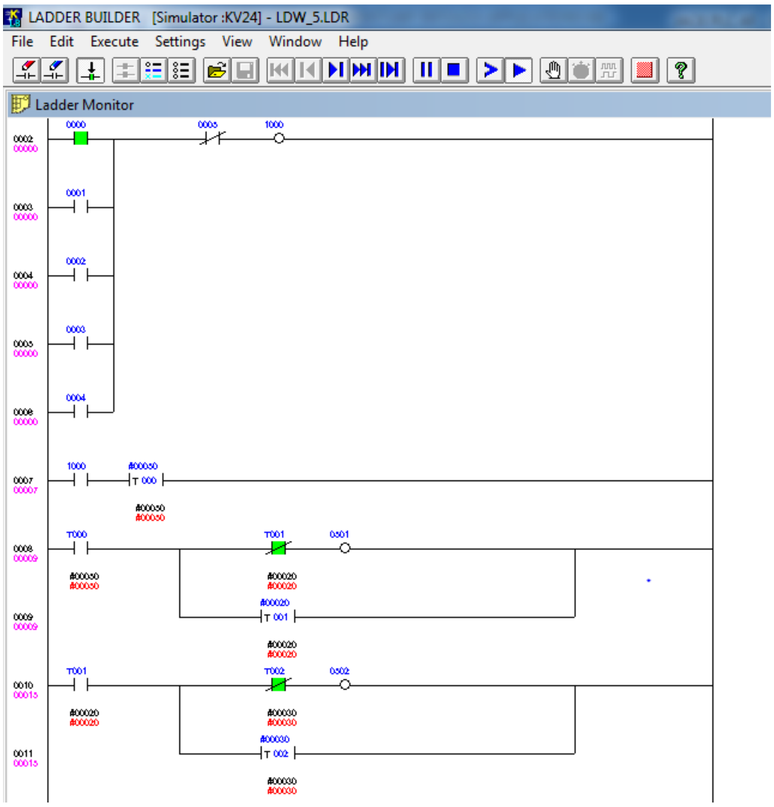


Fig. 3.8: PLC Program for the integration of Unwana Renewable Energy Line



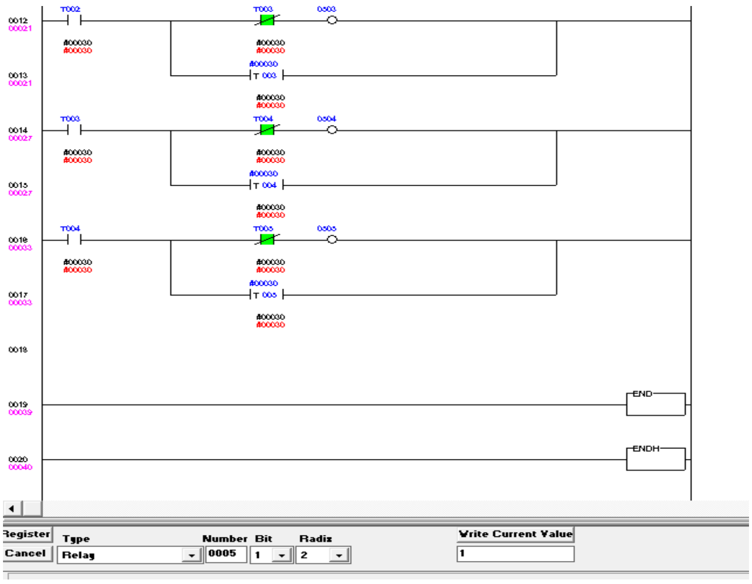


Fig. 3.9: PLC Program for the control of the Five Communities under study

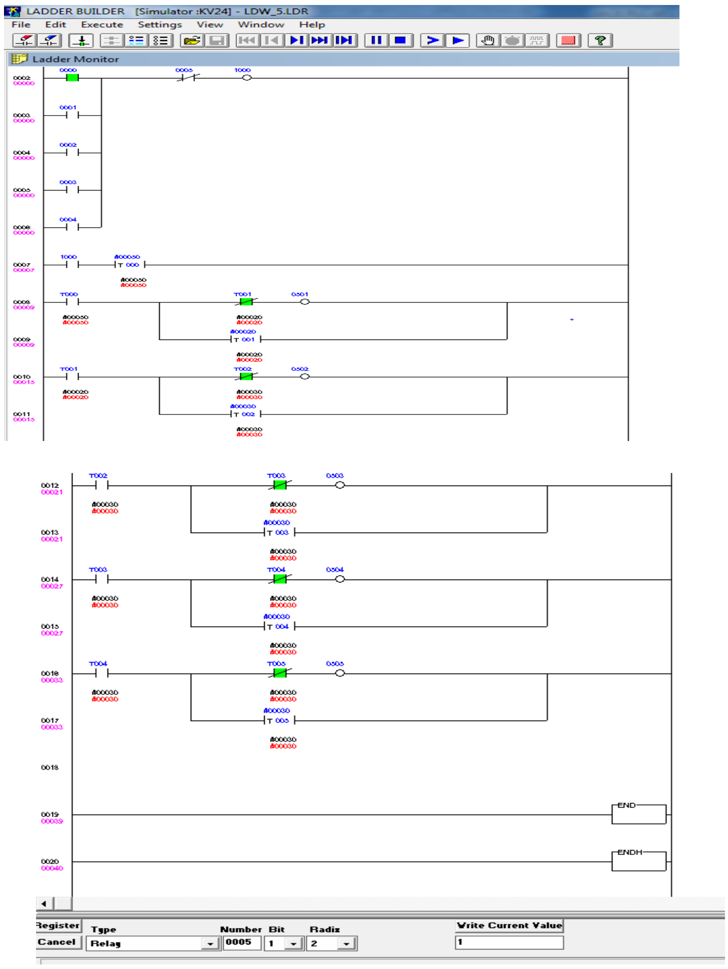


Fig. 3.10: PLC Program for the control of the Five Communities under study with fluctuation allowance.

The energy data injection Model to represent each of the community renewable energy resources with their respective generated energy were developed, hybridized and integrated to its individual logic controllers which was then fed to the Renewable energy sub-master controller using PLC codes. For the complete monitoring and control of the hybridized renewable energy resources within these five co-located communities, supervisory control and data acquisition (SCADA) system was developed. The PLC and SCADA interaction gives the human machine view of the available renewable energy resources and also creates an operators-machine interaction platform.

(d.) Design for PLC Program and SCADA System Interaction

The SCADA design for the Renewable Resources fed to the Sub-master (slave) microcontroller after it assumed hybridized and optimized configuration. Wonderware InTouch software is used for this SCADA design from the design scripts is shown in Plate 3.1.

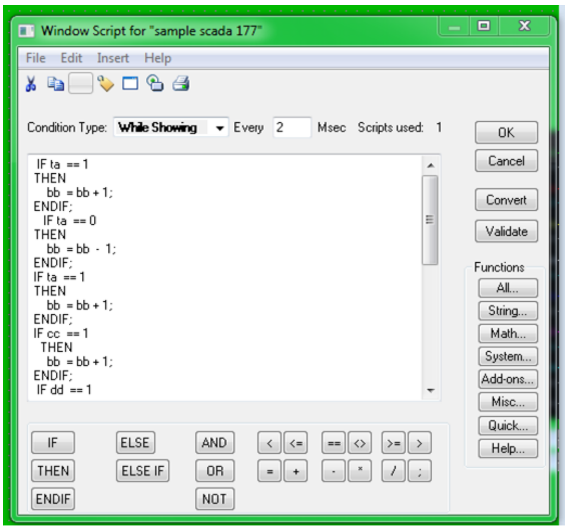


Plate 3.1: PLC Program and SCADA System Interaction code

iii. Generator Input Supply

In this work, the generator here represents the fallback power supply input to the five communities under study. This provide a means of supplying energy to the five communities when all other input sources are out. In this research, the design is made such that all the combined generating sets are made to automatically come ON whenever the intelligent master controller senses the absence of energy in the grid and the renewable energy input. This research also concentrates on the automatic switching and starting of all the combined generating sets. Whenever there is energy restoration from either the grid or renewable energy sources, the controller intelligently senses it and automatically turns OFF all the combined generating sets and connect the available supply after due priority scan.

(e.) Integration of the three Energy Sources to the Intelligent Master Controller Logic and Priority Scheme

From intelligent master controller (IMC model) unit in Fig. 3.1 and the grid input; renewable energy resources input and generator set input connected to the microcontroller in Fig. 3.2. and Fig. 3.11 shows the overall intelligent master controller using three input OR logic configuration.

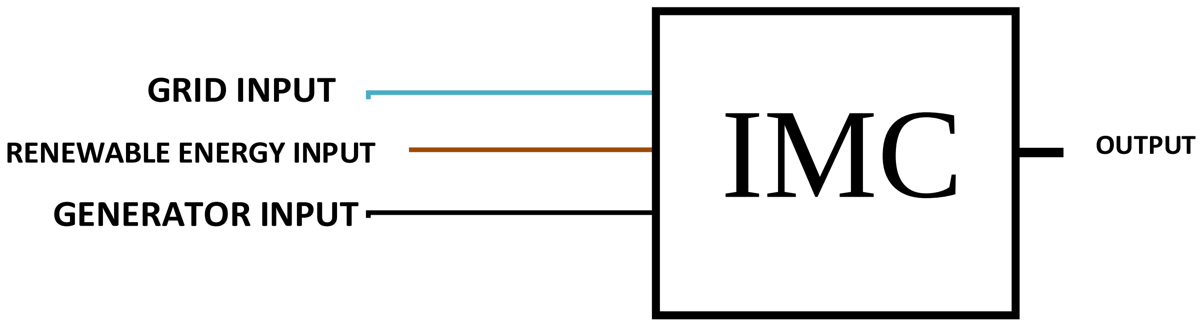


Fig. 3.11: Diagram for the integrated three energy sources to the intelligent master controller system for power pooling

Fig. 3.12 shows how the three energy resources were integrated into the micro grid system for monitoring and control with prioritize scheme. This design is implemented using six relays.

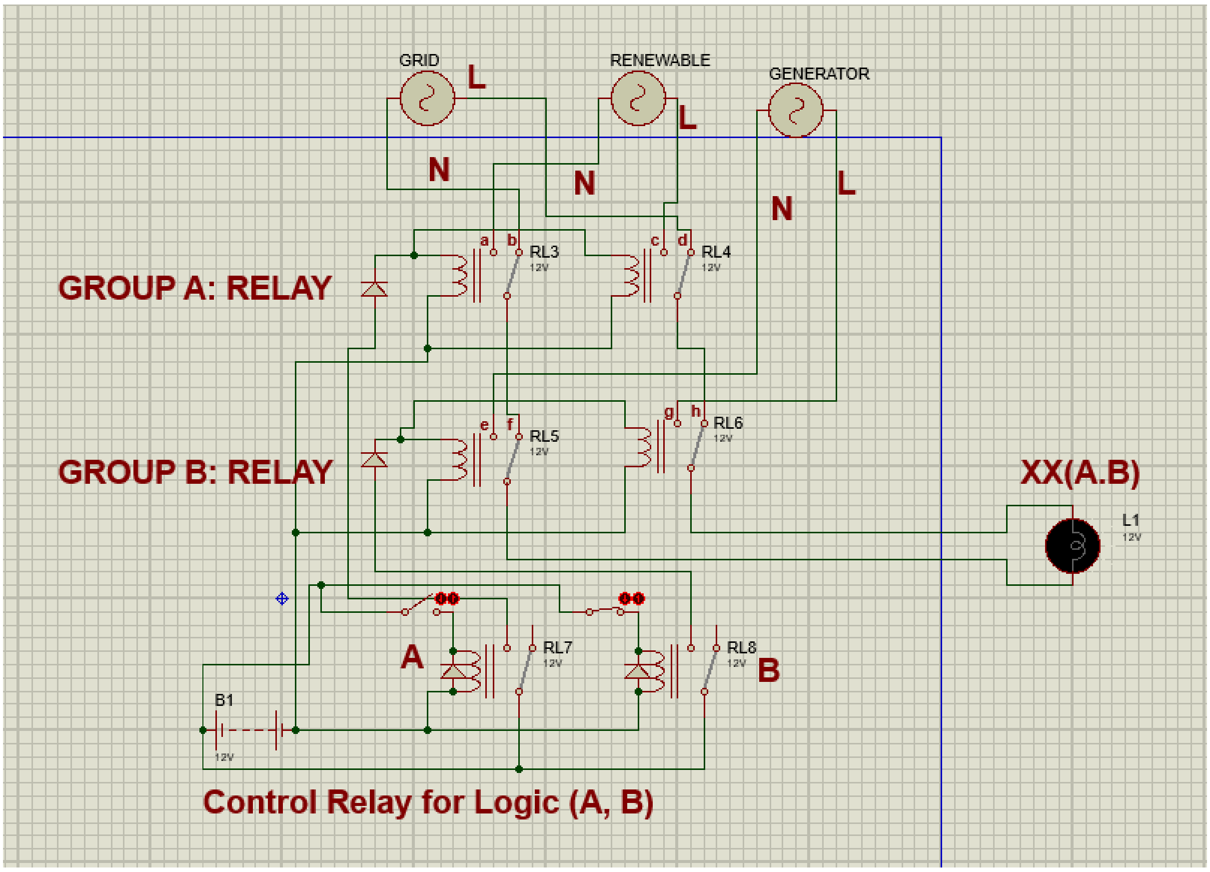


Fig. 3.12 Intelligent Master Controller Priority Scheme

3.2.2 Design of a remote monitoring scheme interlinked with Screen-touch Human Machine Interface through Android Application

The following sub-design gives the remote monitoring and control platform for the intelligent master controller:

(a.) Writing of the Hypertext mark-up language (HTML), Cascading Style Sheet (CSS) and JavaScript

The design of the user interface for the intelligent master controller in this centralized power pool monitoring and control system considers sublime text as it editing platform. In this research, sublime text provides an integrated development environment for writing, editing and modifying codes or programs for the development of the soft-touch user interface. These Hypertext Mark-up Language (HTML), Cascading Style Sheets (CSS) and JavaScript, codes written in this language were edited and modified using Sublime text. The following are images showing the codes written in Sublime text.

i. The HTML code for the Soft-touch Human Machine interface design

Here, HTML provides the general outlook of the pool interface without any functionality given to the components of the pool interface, it allows for the arrangement of words and paragraphs on the interface see **Appendix A** for the HTML codes.

ii. The CSS code for the Soft-touch Human Machine interface design

Cascading Style Sheets (CSS) provides different styles and colours used in designing the pool interface. It beautifies the interface making it eye-catching to the pool operator see **Appendix B** for the CSS codes.

iii. *The JavaScript code for the Soft-touch Human Machine interface design*

JavaScript gives functionality to the components of the interface. The components on the interface are buttons and switches. These buttons and switches are used to actuate the transfer of energy within the system. On the account of each energy transfer, JavaScript enables visible display of the device on the interface see **Appendix C** for the JavaScript codes.

(b.) Design of the Operator's SIGN-IN/UP Page

To develop the operator's sign-in/up page, HTML, CSS and JavaScript were used. The HTML, CSS and JavaScript helps in the arrangement of words, component style creation and gives functionality to those components.

i. Hypertext Mark-up Language (HTML) Code for the Sign-IN/UP Page

HTML provides the general outlook of the sign-in/up interface without any functionality given to the components to the sign-in/up interface, it allows for the arrangement of words and paragraphs on the interface. Apart from word arrangement and paragraphing, it also creates textboxes, which allows operators to input their details for authentication and authorization see **Appendix D** is the HTML codes for the Sign-IN/UP Page.

ii. Cascading Style Sheets (CSS) code for the Sign-IN/UP Page

Cascading Style Sheets (CSS) provides different styles and colours used in designing the operator's sign-in/up interface. It beautifies the interface making it eye-catching to the pool operator see Appendix F is the CSS codes for the Sign-IN/UP Page.

iii. JavaScript for the Sign-IN/UP Page

JavaScript gives functionality to the operator's sign-in/up interface. These displays only the buttons and the text box which enable the operators to sign-in and up for authentication and authorization see **Appendix E** is the JavaScript codes for the Sign-IN/UP Page.

(c.) Cloud Platform for the Intelligent Master Controller Information Storage

The data documentation from the Intelligent Master Controller was stored in the cloud server, ThingSpeak. ThingSpeak provides an open IoT services on local area network or internet and as well has the virtual analytical tools for acquired data. However, MongoDB is also needed to provide the storage which does not require initial table formulation template for data documentation which makes the database heavy and complex. MongoDB uses JavaScript Object Notation (JSON) format. In JSON format, the heavy data are compressed into its light-weight form for human writability and readability. MongoDB is open sourced and has standard file template with ability to accommodate data that are large and unstructured. The MongoDB also aid the system authentication from the registered users.

From 3.1.2, The data created from the power system and its consumption are transfered to and from the Intelligent master controller through the universal asynchronous receiver-transmitter (UART) system via the internet module. The internet module then communicates (trans-receive) using GET HTTP method via the cloud, where web and mobile application users can access and interact back to the cloud with the same GET HTTP technology. The Administration Applications and

Users (operators) Applications information; the server documentary for the operators/administrator details; the intelligent master controller interface information; the energy (sources) generated and the consumption information as well as the co-located community's operation details. In this design, all the developed codes were hosted to server (see **Appendix K & J**).

Fig. 3.13 gives the overview of the server interaction with other units that form the intelligent master controller system using GET HTTP method. The server, database and the android interact with the intelligent master controller through WIFI module on a real time basis.

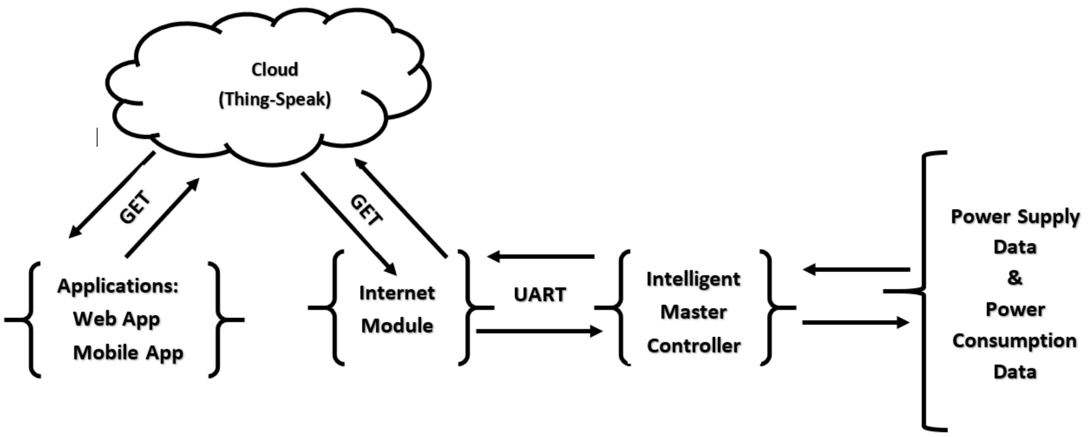


Fig. 3.13: Database/ Server(cloud) services for the design interaction

(d.) Development of the Storage for Administrator and the Operator's Sign-IN/UP information

The operator's and the unified central administrator details as designed are stored in the database using MongoDB**.** The database is designed with an operator's authentication prompt and by this all the registered operators require an authorization from the unified system administrator before signing in is accepted at first instance.

The record of the number of times each operator sign-in are kept for the admin to oversee **(**see **Appendix G).**

(e.) Development of the storage for the Generating energy (Input) information

Apart from the operator's data, the daily energy operational trend is also stored and can be recalled as need arises. In this storage design, MongoDB is used with its associated JavaScript Object Notation capability. The template for the Energy generated and energy consumed are created and documented (see **Appendix H**). The first template is for energy generated. This stores data from the energy generated by the three sources. The variation of the energy stored is in terms of voltage, current and power parameters.

(f.) Development of the Storage for the energy Consumption (Output) information

This stored the energy consumed by the five communities and the variation of the energy stored is in voltage, current and power. The Load consumption in this experimental model is visibly monitored and controlled using Android and web application. The management System from data gathered gave the forecast of the individual energy requirements for future proposals (see **Appendix I**).

(g.) Determination of Data Size for storage Handling

To estimate the storage size, the following are considered: the number of characters in each of the field, the number of fields per records and the numbers of records in the table.

$$Number\ of\ character\ in\ each\ field\ (field\ sizes) = x$$

$$Number\ of\ fields\ per\ record = y$$

$$Number\ of\ records\ in\ each\ table = z$$

$$Estimated\ \ size\ of\ each\ table\ = \frac{x \times y \times z}{1024} \qquad (3.1)$$

The data size is considered for 6hours operation and was estimated from the parameters in section 4.2.10 and documented.

From Table 4.3, the data size stored from the generated energy from the three sources experimented.

$$Number\ of\ character\ in\ each\ field\ (field\ sizes) = x = 3$$

$$Number\ of\ fields\ per\ record = y = 5$$

$$Number\ of\ records\ in\ each\ table = z = 8$$

$$Estimated\ size\ of\ each\ table\ = \frac{(3 \times 5 \times 8)}{1024} = \frac{(120)}{1024} = \boldsymbol{0.12kb}$$

From Table 4.4, the data size stored from the consumed energy from the five experimented communities.

$$Number\ of\ character\ in\ each\ field\ (field\ sizes) = x = 3$$

$$Number\ of\ fields\ per\ record = y = 7$$

$$Number\ of\ records\ in\ each\ table = z = 8$$

$$Estimated\ size\ of\ each\ table\ = \frac{(3 \times 7 \times 8)}{1024} = \frac{(168)}{1024} = \boldsymbol{0.16kb}$$

$$Estimated\ size\ from\ table\ 4.3\ and\ table\ 4.4\ = [0.12 + 0.16] = 0.28\boldsymbol{kb}$$

Table 4.5 give a forecast that the estimated daily data trend for 10 days would occupy the space of 2.8kb in the cloud.

3.2.3 Development of the Software for the unified sequence of operation for the System

In Fig. 3.14, four microcontrollers are used for this design, three are slaves and one is the master controller. The grid Controller(slave) represents the first microcontroller used in controlling the power generated and injected from the national grid coming into the pool. The renewable controller(slave) represents the second microcontroller used in controlling the power generated and injected from the Renewable energy resources coming into the pool whereas the generator controller represents the third microcontroller(slave) used in controlling the power generated and injected from the generating set coming into the pool.

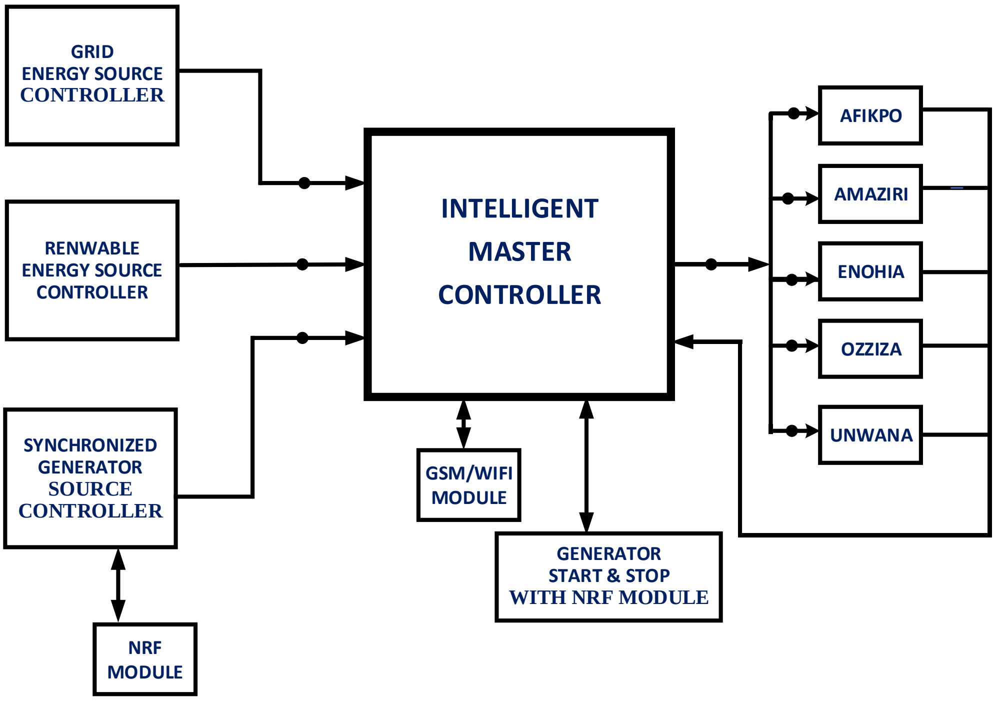


Fig. 3.14: Intelligent Master Controller Unified Sequence of operation

The three energy sources are connected to a common bus after synchronization. The synchronized energy is then fed into the intelligent master controller for the unified system monitoring and control.

(a.) Integrated Energy Resources Design Simulation

In Fig. 3.15, three input from the transformer representing the Grid, Renewable energy and generator source are stepdown and rectified to provide the circuit with 12V DC. The two sensors (current and voltage) are connected to detect the presence of current and voltage in any of the available sources. Six relays are configured such that four of it handles the priority, polarity and total isolation of the live and neutral in the circuit. The remaining two relays are configured to interact with the microcontroller for the switching of the first four set of relays on source priority arrangement. Also, five optocoupler are configured to detects the present of supply availability and unavailability for the microcontroller action in the five communities unified energy network.

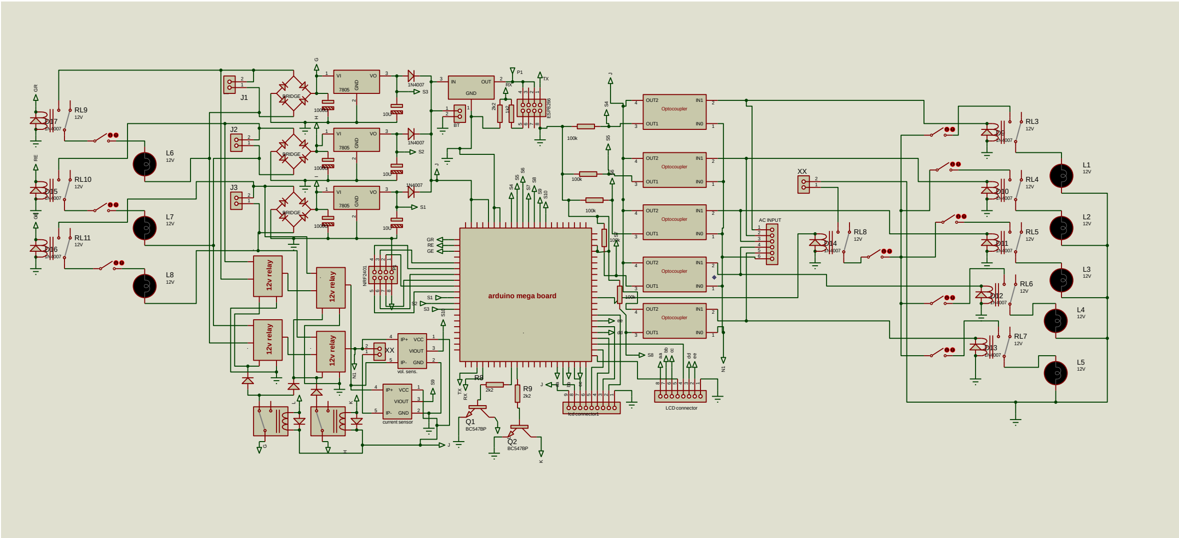


Fig. 3.15: Simulation design Circuit Diagram for the intelligent master controller system for power pooling

The sensor(optocoupler) is connected to the 220v terminals of the configures relay input and the WIFI module (ESP8266) are connected to provide the internet interconnectivity within the system whereas the transceiver (NRF2401) is connected to provide a wireless communication between the main circuit and the generator for the automatic starting and stoppage. The system display is made possible with thin film transistor (TFT) liquid crystal display and the overall system activity is coordinated by the mega microcontroller (ATmega2560). The microcontroller (Arduino) code is written in C++ programming language for the hardware device (see the code in **Appendix J)** whereas the code for the WIFI (ESP8266) is written in C++ programming language (see the code in **Appendix K**). The system was tested and simulation result was documented in section 4.1.1.

(b.) Design Hardware Implementation

Fig. 3.16 shows the pre-design implementation of the intelligent Master controller, the Grid input is loaded to supply the five communities and the renewable energy input is designed not to function alongside with the Grid Input, but whenever the Grid input goes OFF, the renewable energy input is automatically put ON to supply the five communities. The test result was documented in section 4.1.2.

Fig. 3.16: Pre-Implemented Intelligent Master Controller

Whenever the Grid and Renewable energy sources are inactive, the generator will automatically come up to supply the five communities.

(c.) The Design Flowchart for Intelligent Master Controller

Fig. 3.17 gives the operation sequence for the intelligent master controller.

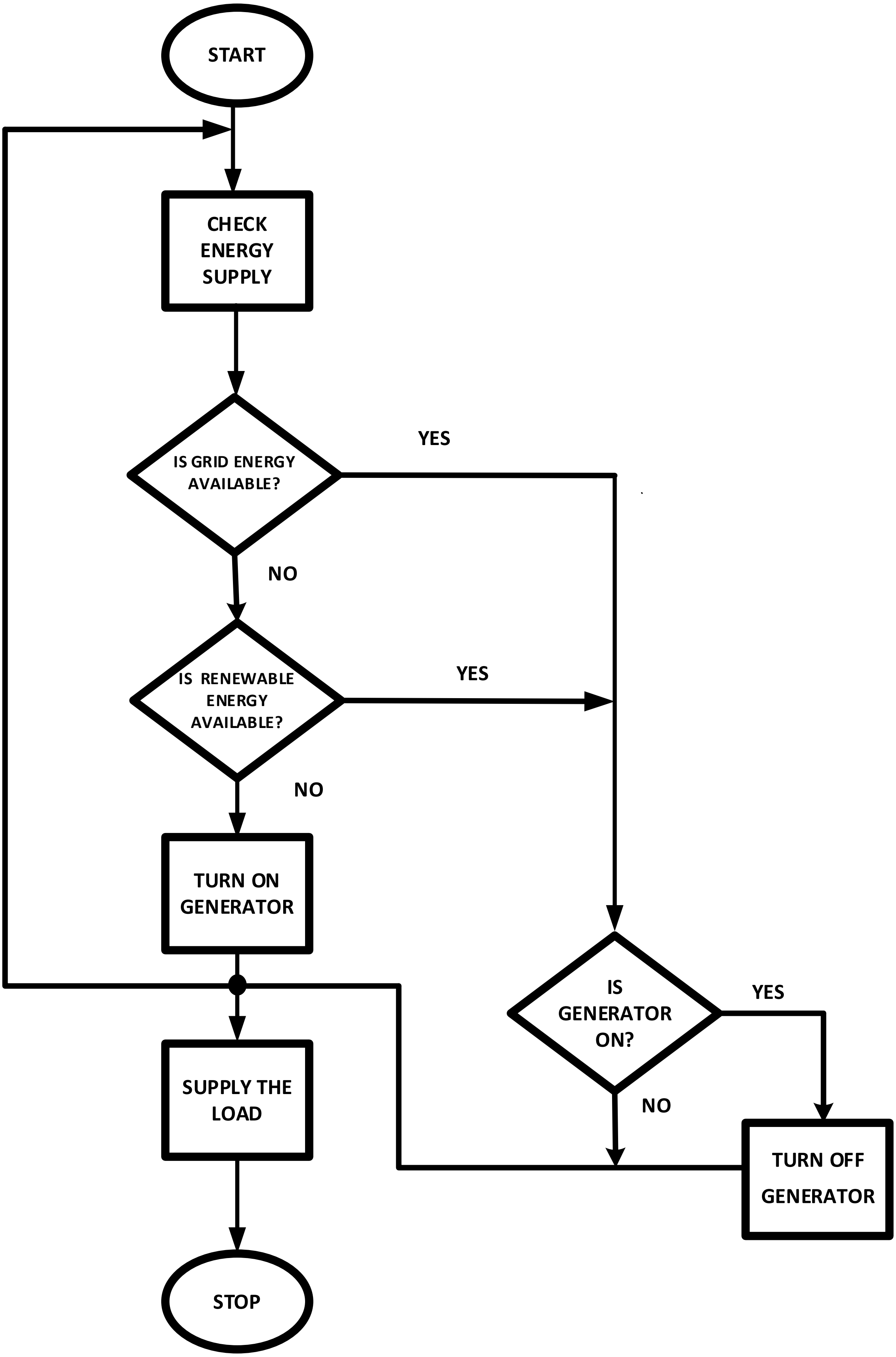


Fig. 3.17: Flow Chart of the Intelligent Master Controller

PSEUDO-CODE

Check Energy Supply

If grid is available

Switch to grid

If RE is available

Switch to Renewable Energy

If grid and Renewable Energy are not available

Switch to Generator

Else

Check Power Supply

(d.) The Final Design Hardware with Assembly

Fig. 3.18 shows how the microcontroller is configured to toggle between the three energy sources with priority to Grid source (GREEN indicator) followed by the renewable source (YELLOW indicator) and to initiate the generator (RED indicator) start-up operation whenever the first two sources are OFF.

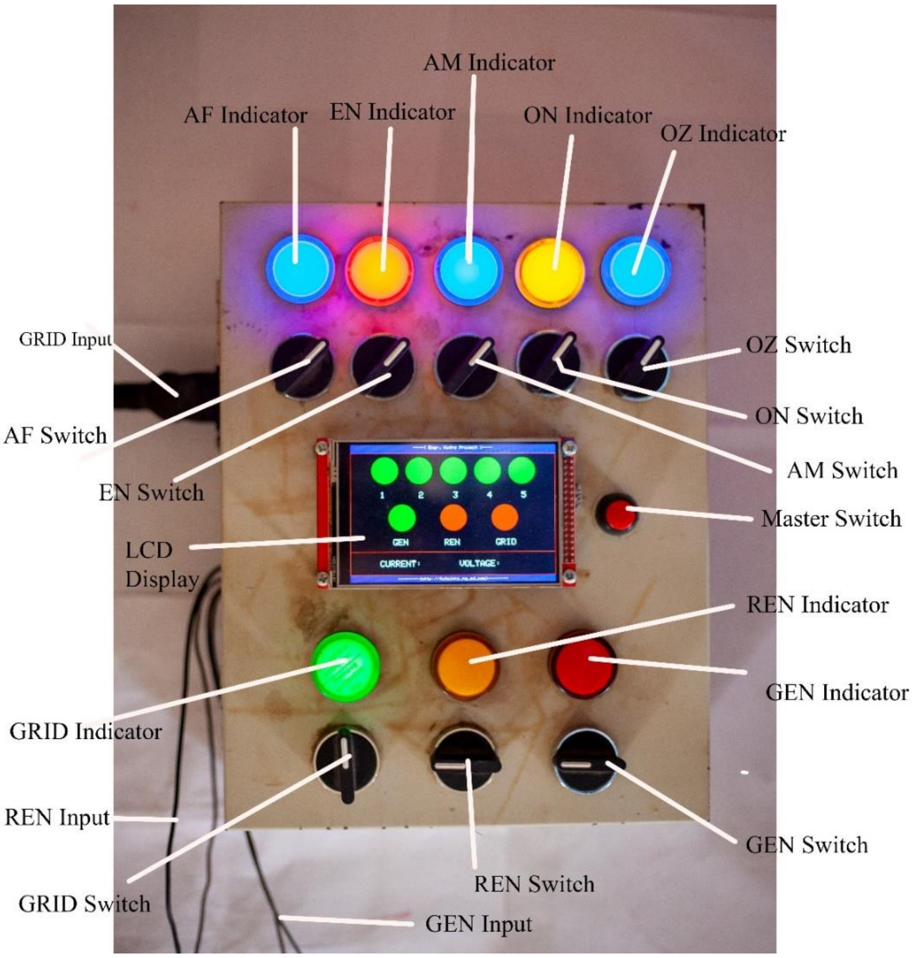


Fig. 3.18: The hardware assembly of the Intelligent Master Controller

This was achieved through relay operation. The indicator shows how the five communities' benefit from the integrated energy resources.

(e.) Design of an Automatic Generator Starting System

The multiple generator starter circuit shown in Fig.3.19comprises of the following component: Arduino Pro Micro (an atmega328 microcontroller-based board), it works as the processor; NRF 2401 module for wireless communication between the generator and the main system (master and slave); Actuators (relay) circuit which comprise of three relays, two 12V dc relay and one 5V dc relay. The twelve-volt relay will be controlled by the 5-volt relay; 220/240V Timmer relay which is connected to the generator output to sense when the generator is ON, so that the system can turn off the kick starter; LM7812 and LM7805 are 12V and 5V voltage regulators, which take supply from the generator battery and regulate it to the voltage needed by the relay and the microcontroller; Terminal block or connector are terminal for input and output connection; Backup battery and Indicator led to show the status of the generator (ON/OFF).

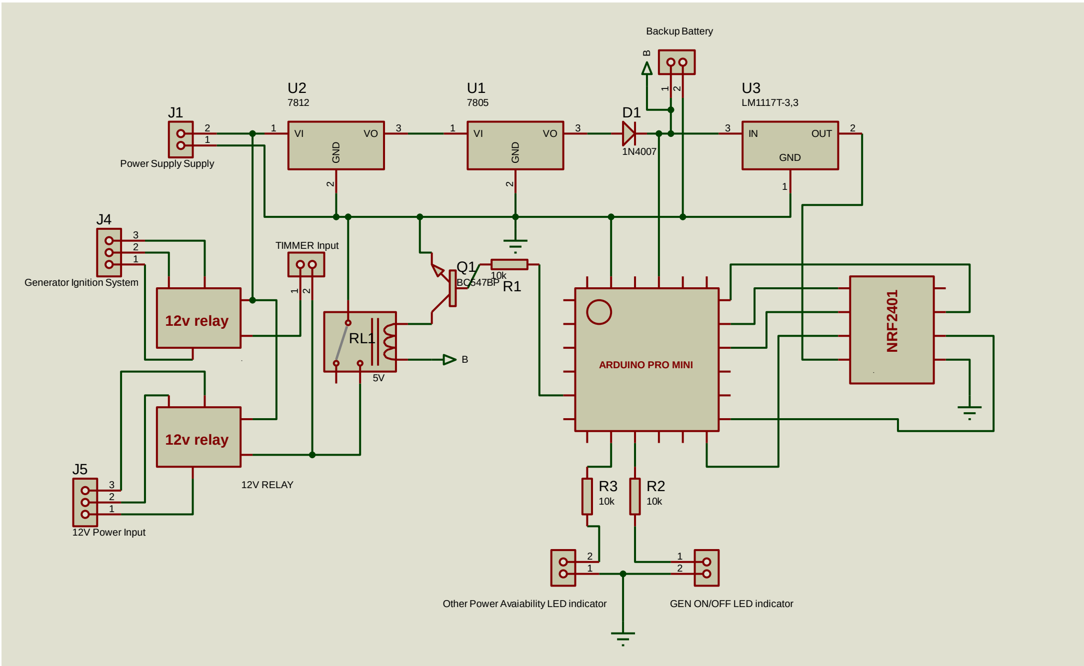


Fig. 3.19: Multiple Automatic Generator Starting Circuit

The generator turn OFF/ON circuit is in constant communication with the master circuit in other to receive command to either turn on or off the circuit. Depending on the type of generating set, the controller turns on the relay in a logic that will turn on the generator. The timer relay sense when the generator is on and turn off the kick starter. To start a small, kick starter generator, the following most be connected to the 12V terminal of the battery, the fuel solenoid switch and the kick starter. The keck starter must be disconnected when the generator is ON to avoid damaging the kick starter. To turn OFF the generator the fuel solenoid switch is closed (disconnected from the 12V of the battery).

From Fig. 3.20, the automatic generator starting system design is developed to facilitate smart switching whenever the energy from the Grid and the renewable energy source are absent. The intelligent master controller system has an incorporated NRF module which trans-receives signal between main system and the sub-starting system. The starting system has relays, current sensors, indicators and transistor.

Fig. 3.20: Multiple Automatic Generator Starting assembly

When energy from the two prioritized sources are ON, the automatic energy starting system indicates RED to show that the generator is OFF; but when energy from the two prioritize sources are **OFF**, the automatic generator starting system start-up the system and indicates **GREEN** to show that the generator is on the Starting Mode and switch to the running mode to show **BLUE** Colour with **ON indication.**

(f.) Design of a Multiple Automatic Generator Starting Flow Chat and operational sequence

Fig. 3.21 gives the operation sequence for the multiple generators starting scheme.

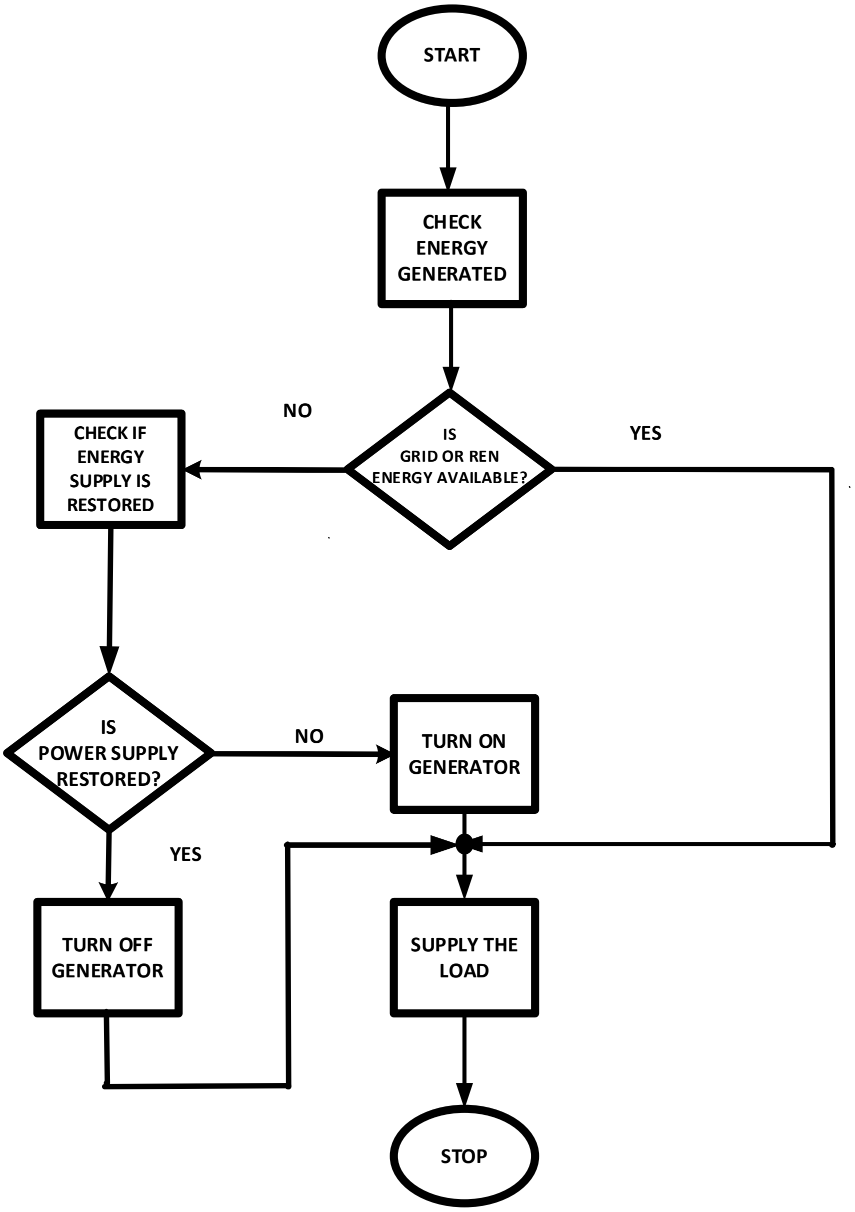


Fig. 3.21: Flow Chart for the Multiple Generator Starting System

Pseudo code

Start and initialized the system

Check and scan for the energy sources

If Grid or Renewable energy is available
Then, supply the Load
Else, check if energy supply is restored

If energy supply is restored

Then, turn off generator and, then Supply energy to the load

Else, turn on generator

Then, supply load

Stop the system

The generator starting sequence

The generators are linked to the grid through synchronizer and with enabling generator starting sensors. There are phase start sensing systems available in most of the parallel generators (e.g. Cummins), so each generator comes up after 10sec if the available energy from the first generator is no enough for the connected load. All the five communities have their individual generator set programmed for continue energy supply.

3.2.4 Design of a Performance Validation Test Criteria for the System

The validation test was carried out in three ways: software, hardware and Internet of Things (IoT) Devices.

(a.) Design of a Performance Validation Test Criteria for the software System

For the software test; Proteus schematic environment has virtual measuring instruments such as voltmeters, ammeters and oscilloscope and the design test was validated using this virtual instruments, the validation test was also carried out on the master PC via the design hardware. At the same time the slave controllers were also enabled and all the operation simultaneously observed.

(b.) Design of a Performance Validation Test Criteria for the Hardware System

The hardware test was carried out with voltage and current meters. The level of the system performance was ascertained. The design parameters conformed with the software validated test results.

(c.) Design of a Performance Validation Test Criteria for IoT System

The performance of the design was validated by creating an interaction between the developed hardware and the software using GET HTTP, UART and internet via Cloud (Thing-Speak). The ThingSpeak was used as a storage for the status of the hardware and the developed applications sent the request to the database which altered the status of the hardware to show the level of the hardware responsiveness to the database. The ThingSpeak was used for real time data acquisition and analysis from its MATLAB embedded analytical tools. Placeholders or variables were created to depict the individual response parameter for the slave controllers via the intelligent master controller.

i. **Allocation of placeholders for the generating input sources:** The Grid controller output switch was tagged **S_GRID**, the renewable controller output switch was tagged **S_RENEW** and the generator controller output switch was tagged **S_GEN**. These placeholders S_GRID, S_RENEW and S_GEN send voltage to the controller, the controller on receiving the voltage signal and then sent the HTTP request to the cloud using Application Programming Interface (API) via the intelligent Master microcontroller.

ii. **The system indication Status indication for the input generating sources:** Whenever the **S_GRID**, **S_RENEW** and **S_GEN** switches are toggled, their status change from true (1) to false (0) and vice versa corresponding to the change in value from the database for the intelligent master controller actions.

iii. **The system Status display for generated energy:** The Grid controller output button was tagged **GRID**; the renewable controller output switch was tagged **RENEW** and the generator controller output switch was tagged **GEN**. These placeholders GRID, RENEW and GEN were used. These placeholders S_GRID, S_RENEW and S_GEN send voltage to the controller, the controller on receiving the voltage signal and then sent the HTTP request to the cloud using Application Programming Interface (API) via the intelligent Master microcontroller and the generated energy were visually shown in the liquid crystal display.

iv. **Allocation of placeholders for the supply and consumption energy:** The Afikpo supply switch was tagged S_AF, the Amasiri supply switch was tagged

S_AM, the Enohia supply switch was tagged S_EN, the Unwana supply switch was tagged S_UN and the Oziza supply switch was tagged S_OZ. The consumed voltage signal was sent to the controller, the controller on receiving the voltage signal is then sent the HTTP request to the cloud using Application Programming Interface (API) via the intelligent Master microcontroller.

iii. **The system indication Status for the Consumption Supply:** Whenever the S_AF, S_AM, S_EN, S_UN, and S_OZ switches toggled, their status change from true (1) to false (0) and vice versa corresponding to the change in value from the database.

iv. **The system Status display for consumed energy:** The Afikpo line output button was tagged **S_AF**; the Amaziri line output button was tagged **S_AM**, the Enohia line output button was tagged **S_EN**, the Unwana line output button was tagged S_UN and the Oziza line output button was tagged S_OZ. The placeholders S_AF, S_AM, S_EN, S_ UN and S_OZ send voltage signal to the controller, the controller on receiving the voltage signal and then sent the HTTP request to the cloud using Application Programming Interface (API) via the intelligent Master microcontroller and the consumed energy were visually shown in the TFT liquid crystal display and Android phone soft-touch interface with its own corresponding variable recognized in the storage.

v. **Allocation of placeholders for the Master Controller**: The master controller central control switch was tagged S_MASTER and the placeholders S_MASTER. These placeholders S_GRID, S_RENEW and S_GEN send voltage signal to the controller, and the controller on receiving the voltage signal and then sent the HTTP request to the cloud using Application Programming Interface (API) via the intelligent Master microcontroller to monitor and control the overall unified Afikpo Metropolitan Power system.

To convert the JavaScript code to android apps and web apps using WebView, react and Cordova, WIFI module facilitates the hardware design connection to the internet. The sending and receiving of the operation request from the storage was made easy.

(d.) Design of a Performance Validation Test Criteria for the Hardware, Software and IoT System

Performance test for the intelligent master controller was carried out with the hardware, software and IoT systems within 6(six) hours for the three-input power supply, the design operational reliability was validated using the under-stated equations.

$R = e^{-\lambda t}$ (3.2)

$where\ \ R\ is\ the\ reliabilty\ of\ the\ intellgient\ master\ controller\ ,$

$\lambda\ is\ the\ failure\ rate\ and\ t\ is\ the\ operational\ time$

The system performance was validated with the reliability probability test within 6(six) hours with its three-input power supply simultaneously.

$The\ system\ reliabilty\ (R) = e^{-\lambda t}$

$But\ the\ probabilty\ concept\ for\ its\ sucessive (p) and\ unsucessive\ (q) operation$

$is\ given\ thus,\ p + q = 1$ (3.3)

$6\ hours\ = 360 seconds = n$

$Assuming\ the\ possility\ of\ failure\ q =\ 0.06$

$So\ the\ possility\ of\ succesful\ power\ supply\ p + q =\ 1$

$Hence\ , p + 0.06 = 1\ \therefore p = 0.94$

$(P + q)^n = (p + q)^6\ according\ to\ Pascal\ triangle\ theory,$ (3.4)

$(p + q)^6 = p^6 + 6p^5q + 15p^4q^2 + 20p^3q^3 + 15p^2q^4 + 6pq^5 + q^6$

$(p + q)^6 = 1\quad 6\quad 15\quad \mathbf{20}\quad 15\quad 6\quad 1$

$p^6\ means\ the\ three\ power\ sources\ would\ work\ reliably\ for\ 6\ hours\ without$

$failure$

$6p^5q\ means\ the\ three\ power\ sources\ would\ work\ reliably\ for\ 5\ hours\ with$

$1 hour\ failure$

$15p^4q^2 means\ the\ three\ power\ sources\ would\ work\ reliably\ for\ 4\ hours\ with$

$2 hours\ failure$

$20p^3q^3 means\ the\ three\ power\ sources\ would\ work\ reliably\ for\ 3\ hours\ with$

$3 hours\ failure$

$15p^2q^4 means\ the\ three\ power\ sources\ would\ work\ reliably\ for\ 2\ hours\ with$

$4 hours\ failure$

$6pq^5 means\ the\ three\ power\ sources\ would\ work\ reliably\ \ for\ 1\ hour\ with$

$5 hours\ failure$

$q^6\ means\ the\ three\ power\ sources\ would\ not\ work\ reliably\ \ at\ all\ but\ fail$

$completely\ withing\ \ 6 hours$

$The\ possbility\ that\ the\ integarted\ power\ pool\ system\ controller\ will\ regulate$

$and\ deliver\ energy\ for\ the\ five\ community\ in\ Afikpo\ Metropolitan\ city$

$$atleast\ \ 5 hours\ out\ of\ the\ 6 hours\ operation = p^6 + 6p^5q \qquad (3.5)$$

$$p^6 + 6p^5q = \ (0.94)^6 + 6(0.94)^5 \times 0.06 = 0.95$$

The design system would function successfully at 95% with only 5% unsuccessful operation within 6hours.

$The\ system\ reliabilty\ (R)$

$(R) = e^{-\lambda t}\ \ \ assuming\ the\ system\ failure\ rate\ is\ unknown$

$$0.95 = e^{-\lambda \times 360 sec}$$

$\therefore 0.95 = 5.89\lambda$ and $\lambda = 0.16$

$Sine\ \lambda = 0.16,\ it\ therefore\ \ means\ that\ the\ imminent$

$Reliability\ attainment\ is\ 84\%$

$while\ unreliabilitylevel\ is\ 16\%\ within\ 6 hours\ of\ \ operation.$

3.2.5 Development of System Control Stability Model and Cost benefit Analysis for the System.

3.2.5.1 Design of an Intelligent Master Controller Control and Stability System Model

In developing control system model for the intelligent master controller, the input to the system is the three energy sources, fed into the controller to manage the hybridized power system (plant) with the feedback system (sensors). The output of this system is controlled by changes in the input parameters(voltage and current) and observation are made to ascertain the system behavior whether or not it conforms with the control system set rules.

$where: r\ is\ the\ input\ power\ system\ signal\ to\ the\ IMC$

$y\ is\ the\ output\ power\ system\ signal\ from\ the\ IMC$

$ym\ is\ the\ feedback\ power\ system\ signal\ to\ the\ IMC$

$e\ is\ the\ error\ signal$

It is apparent that although the properties of $G\ and\ H$ are such that the inner-loop feedback is unstable, because $GH = -1$, the overall system can be stable by properly selecting the outer-loop feedback gain, K.

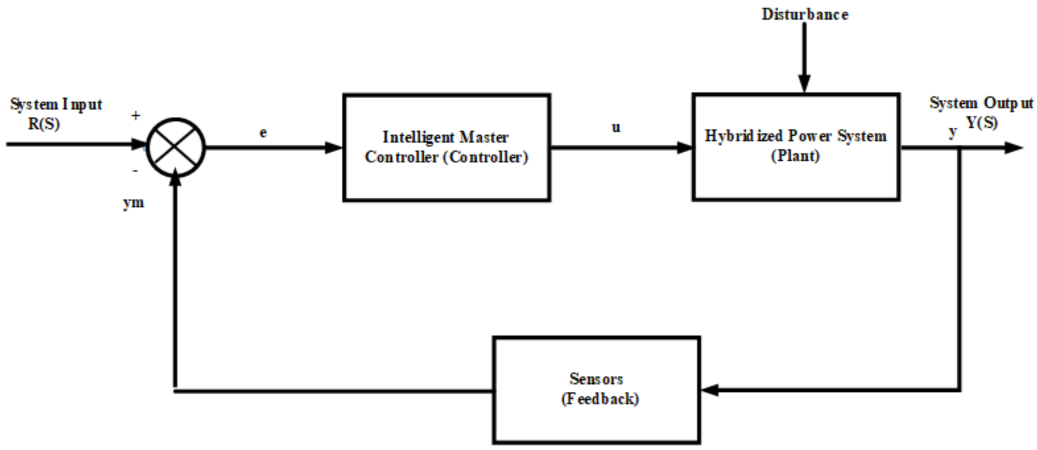


Fig. 3.22: Close Loop control system with Feedback for Intelligent master controller

In Fig. 3.22, feedback control loop is designed to reduce error between the reference input and the power output. Every physical system requires a feedback design to ascertain its system performance characteristics such as stability, overall gain and sensitivity. This design deployed a digital control technique, it operates on the concept of zero (0) and one (1), and follows a unit step response principle. Close loop concept is adopted based on its feedback capability, accuracy and sensitivity. Some control assumptions are made in an attempt to formulate the initial system parameters:

(a.) Intelligent Master Controller Mathematical Model

The mathematical model relates the input/output variable by differential equations to determine their responses for necessary control action. The principle of superposition and homogeneity are adopted due to its ability to follow the linear pattern of the system response. The developed close loop control system has three input and a single output and this conforms to a multiple input single output (MISO) control system model, the three-input system is reducing to a single system model with the block represented in fig 3.23. The reduced block diagram gives the transfer function for the intelligent master controller model.

$$The\ system\ transfer\ function\ (TF) = \frac{Output\ signal\ of\ the\ IMC}{Input\ of\ the\ IMC} \qquad (3.6)$$

Where:

G_1 represent input from Grid power supply

H_1 represent the loop gain from Grid power supply input

G_2 represent input from Renewable power supply

H_2 represent the loop gain from Renewable power supply input

G_3 represent input from Generating Set power supply

H_3 represent the loop gain from Generating Set power supply input

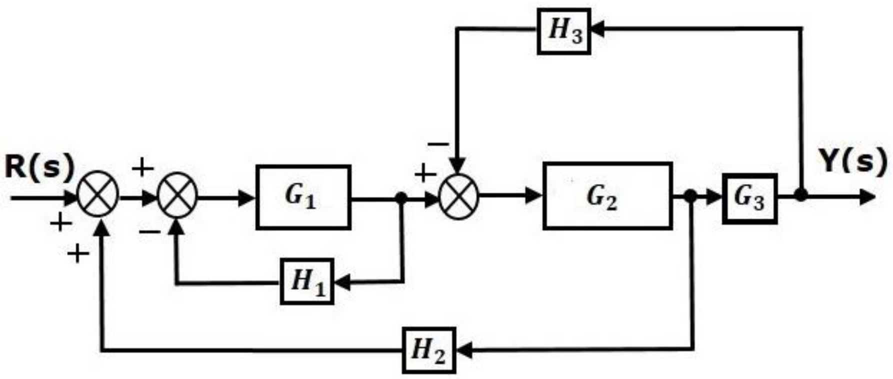


Fig. 3.23: Intelligent master controller close loop control system design

Fig.3.23(a) to 3.23(g) are reduced block diagram gives the transfer function for the intelligent master controller model in equation 3.14.

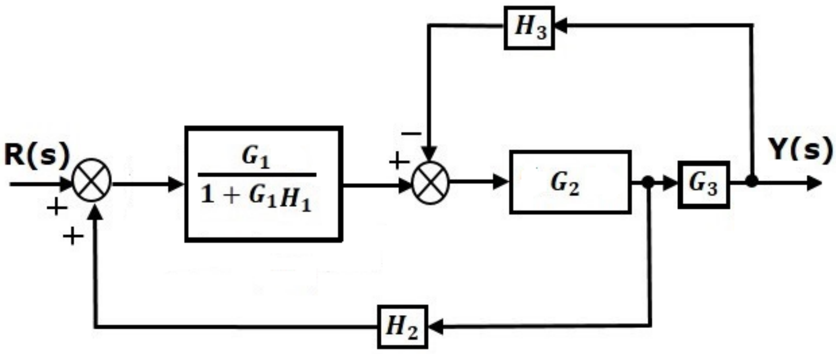


Fig. 3.23(a)

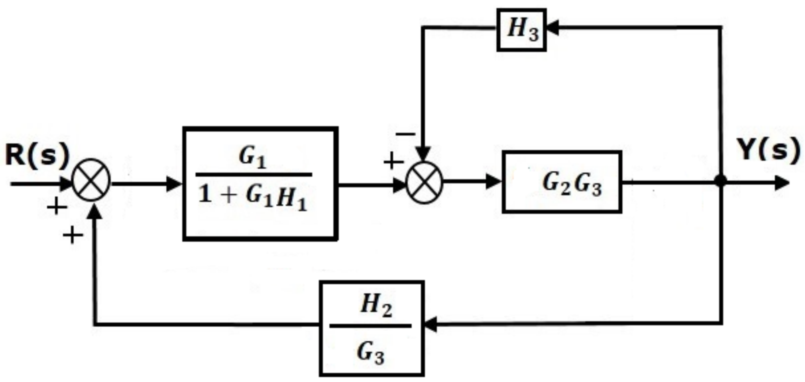


Fig. 3.23 (b)

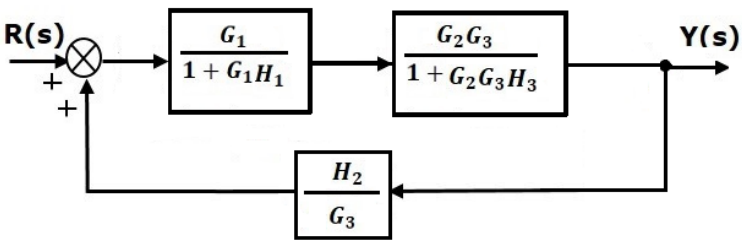


Fig. 3.23 (c)

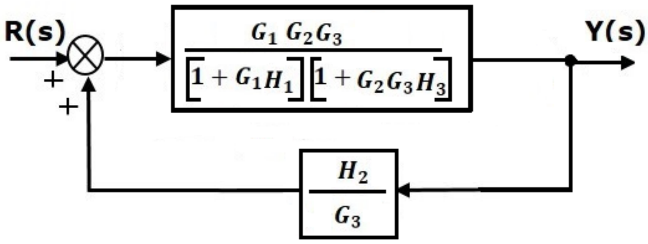


Fig. 3.23 (d)

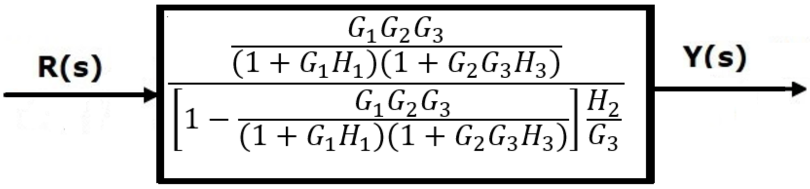


Fig. 3.23 (e)

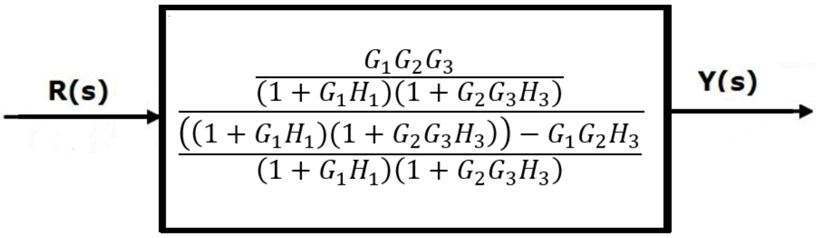


Fig. 3.23 (f)

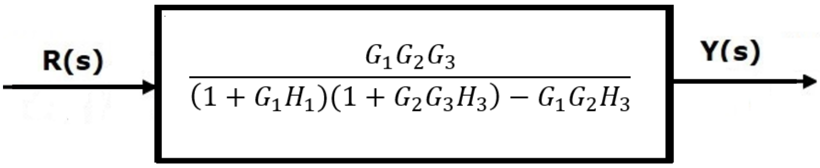


Fig. 3.23 (g)

$$Transfer\ Function = \frac{Y(s)}{R(s)} = \frac{Output\ signal\ of\ the\ IMC}{Input\ of\ the\ IMC}$$

$$Transfer\ Function = \frac{G_1 G_2 G_3}{(1+G_1 H_1)(1+G_2 G_3 H_3) - G_1 G_2 H_3} \qquad (3.7)$$

For efficient switching operations, the intelligent master controller is a close loop second order system.

$$\frac{Y(s)}{R(s)} = \frac{G_1 G_2 G_3}{(1 + G_1 H_1)(1 + G_2 G_3 H_3) - G_1 G_2 H_3}$$

$$G(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad (3.8)$$

Standard closed loop transfer function of the second order system equ (3.8)

ω_n *is the undamped natural frequency, rad/sec*

ζ *is the damping ratio*

The system characteristic equation is derived from the denominator of the transfer function of the second order model.

$$The\ IMC\ characteristic\ equation = s^2 + 2\zeta\omega_n s + \omega_n^2 = 0 \qquad (3.9)$$

The unit step input is design to follow the critically damped second order system from its derived characteristic equation, so if $\zeta = 0.5$

Whenever the unit step input $r(t) = 1$ *and* $R(s) = \frac{1}{s}$ (3.10)

The undamped natural frequency and damping ratio are assumed to be the same value for the entire system because the intelligent master controller uses a digital control technique that 0 or 1 or ON/OFF etc. The assumption is due to the fact that the three energy sources understudy are synchronized and therefore shares the same bus parameters.

The input follows the unit step function U(t)

$$u(t) = 1; t \geq 0 \;\; and \quad u(t) = 0; t < 0$$

The controller is in the ON/OFF (digital system). The feedback is given by $H = 1$ which is in s-domain = $\frac{1}{s}$ and in first order system; the transfer function is given as $TF = \frac{G(s)}{1 \pm G(s)H(s)}$ whereas in the second order system,

the transfer function $G(s) = \frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$ and is adopted from the system model.

$$\frac{Y(s)}{R(s)} = \frac{G_1 G_2 G_3}{(1 + G_1 H_1)(1 + G_2 G_3 H_3) - G_1 G_2 H_3}$$

$$The\ response\ in\ s - domain\ \ becomes$$

$$= \frac{\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)}{\left(1 + \frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2} \times \frac{1}{s}\right)\left\{1 + \left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)\right\}\frac{1}{s} - \left(\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right) \times \frac{1}{s}\right)}$$

$$\frac{Y(s)}{R(s)} = \frac{\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)^3}{1 + \left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)\frac{1}{s} + \left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)^3 \times \frac{1}{s^2}}$$

$$= \frac{\left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)^3}{\frac{1}{1} + \left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)s + \frac{(\omega_n^2)^3}{S^2(S^2 + 2\zeta\omega_n S + \omega_n^2)^3}}$$

$$= \frac{S^2(S^2 + 2\zeta\omega_n S + \omega_n^2) + S\omega_n^2 + (\omega_n^2)^3(S^2 + 2\zeta\omega_n S + \omega_n^2)^3}{S^2(S^2 + 2\zeta\omega_n S + \omega_n^2)}$$

$$= \left(\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}\right)^3 \times \frac{S^2(S^2 + 2\zeta\omega_n S + \omega_n^2)}{S^2(S^2 + 2\zeta\omega_n S + \omega_n^2) + \omega_n^2 S + (\omega_n^2)^3(S^2 + 2\zeta\omega_n S + \omega_n^2)^2}$$

$$= \frac{(\omega_n^2)^3}{(S^2 + 2\zeta\omega_n S + \omega_n^2)^2} \times \frac{S^2}{S^2(S^2 + 2\zeta\omega_n S + \omega_n^2) + \omega_n^2 S + (\omega_n^2)^3(S^2 + 2\zeta\omega_n S + \omega_n^2)^2}$$

$$= \frac{\left(\omega_n^2\right)^2}{(S^2 + 2\zeta\omega_n S + \omega_n^2)^2} \times \frac{S^2}{S^2 + 2\zeta\omega_n S^2 + \omega_n^2 + \omega_n^2 S^2 + \omega_n^2 S + (\omega_n^2)^3(S^2 + 2\zeta\omega_n S + \omega_n^2)^2}$$

$$= \frac{\left(\omega_n^2\right)^2}{(S^2 + 2\zeta\omega_n S + \omega_n^2)^2} \times \frac{S^2}{\omega_n^2(S^2 + 3\zeta\omega_n S^2 + S) + (\omega_n^2)^2(S^2 + 2\zeta\omega_n S + \omega_n^2)^2}$$

$$= \frac{S^2\left(\omega_n^2\right)^2}{(S^2 + 2\zeta\omega_n S + \omega_n^2)^2(S^2 + 3\zeta\omega_n S^2 + S) + (\omega_n^2)^2(S^2 + 2\zeta\omega_n S + \omega_n^2)^2}$$

Assuming the initial value of the $\zeta = 0.5$ *and* $\omega_n = 1$

$$\frac{Y(s)}{R(s)} = \frac{S^2}{(S^2 + S + 1)^2(2.5S^2 + S) + (S^2 + S + 1)^2}$$

$$\frac{Y(s)}{R(s)} = \frac{S^2}{(S^2 + S + 1)^2(2.5S^2 + S + 1)}$$

$$\frac{Y(s)}{R(s)} = \frac{S^2}{(S^4 + 2S^3 + 3S^2 + 2S + 1)(2.5S^2 + S + 1)}$$

$$\frac{Y(s)}{R(s)} = \frac{S^2}{2.5S^6 + 6S^5 + 10.5S^4 + 10S^3 + 7.5S^2 + 3S + 1} = 0 \qquad (3.11)$$

(b.) State Space representation of the intelligent master controller model

The transformation of the transfer function to the state space model aids in determining the system internal behaviour (controllability and observability). Its mathematical expression of State Space dynamic equation is given by (2.10) and (2.11) as derived from the Transfer Function in equation 3.7

$$\dot{x} = Ax + Bu = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -a_3 & -a_2 & -a_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ b_0 \end{bmatrix} u$$

$$y = Cx + Du = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}; B = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}; C = \begin{bmatrix} c_1 & c_1 & c_1 \end{bmatrix}; D = 0$$

Considering the three-input power supply, the Grid, Renewable and Generator set such that when the Grid is ON it implies (1) and gives an output of (1) and then when other sources are OFF (0) is represented in a matric form for controllability and observability analysis according to Kalman's theorem.

$$\frac{Y(s)}{R(s)} = \frac{S^2}{2.5S^6 + 6S^5 + 10.5S^4 + 10S^3 + 7.5S^2 + 3S + 1}$$

$$R(s) = X(S)$$

$$Y(S)[\,2.5S^6 + 6S^5 + 10.5S^4 + 10S^3 + 7.5S^2 + 3S + 1] = S^2 X(S)$$

the differential equation for the model becomes;

$$2.5y'''''' + 6y''''' + 10.5y'''' + 10y''' + 7.5y'' + 3y' + y = \ddot{x}$$

$$x_1 = y$$

$$x_2 = y' = \dot{x}_1$$

$$x_3 = y'' = \dot{x}_2$$

$$x_4 = y''' = \dot{x}_3$$

$$x_5 = y'''' = \dot{x}_4$$

$$x_6 = y''''' = \dot{x}_5$$

Recall that the state space is given by

$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$\dot{y}(t) = Cx(t) + Du(t)$$

$$U(t) = u$$

$$2.5\dot{x}_6 + 6x_6 + 10.5x_5 + 10x_4 + 7.5x_3 + 3x_2 + x_1 = \ddot{U}(t)$$

$$\dot{x}_6 = -\frac{6}{2.5}x_6 - \frac{10.5}{2.5}x_5 - \frac{10}{2.5}x_4 - \frac{7.5}{2.5}x_3 - \frac{3}{2.5}x_2 - \frac{1}{2.5}x_1 + u(t)$$

$$\dot{x}_5 = x_6 \ + 0 + 0 + 0 + 0 + 0 + 0$$

$$\dot{x}_4 = 0 + x_5 + 0 + 0 + 0 + 0 + 0$$

$$\dot{x}_3 = 0 + 0 + 0 + x_3 + 0 + 0 + 0$$

$$\dot{x}_2 = 0 + 0 + 0 + 0 + x_2 + 0 + 0$$

$$\dot{x}_1 = 0 + 0 + 0 + 0 + 0 + x_1 + 0$$

$$\dot{x} = 0 + 0 + 0 + 0 + 0 + 0 + x$$

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\\ \dot{x}_6\end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\\ -\frac{1}{2.5} & -\frac{3}{2.5} & -\frac{7.5}{2.5} & -\frac{10}{2.5} & -\frac{10.5}{2.5} & -\frac{6}{2.5}\end{bmatrix}$$

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\\ \dot{x}_6\end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\\ -0.4 & -1.2 & -3 & -4 & -4.2 & -2.4\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\\ x_6\end{bmatrix} + \begin{bmatrix}0\\0\\0\\0\\0\\1\end{bmatrix}\ddot{U}(t)$$

$$y = \begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\\ x_6\end{bmatrix}$$

i. Controllability

$$(A, B) = [B \ \ AB \ \ \ A^2B| \ldots\ldots |A^{n-1}B] \qquad (3.12\ )$$

$$|Co| \neq 0 \ and \ rank \ Co = n$$

ii. Observability

$$Ob = (C, A) = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix} \qquad (3.13)$$

$$|Ob| \neq 0 \; and \; rank \; Ob = n$$

(c.) Stability determination for the intelligent master controller model

The RH model is adopted for the stability analysis based on its simplicity in system stability determination by using the poles of the characteristic equation.

$Intelligent\ Master\ Contrlller\ Characteristic\ Equation\ in\ (equ. 3.11)$

$$= 2.5S^6 + 6S^5 + 10.5S^4 + 10S^3 + 7.5S^2 + 3S + 1 = 0$$

the Routh Hurwitz stability criterion is adopted for the design; this is due to its simplicity in stability.

(d.) Input Step Unit response of the Intelligent Master Controller

The step response model presents the transient, steady state and disturbance status of the intelligent master controller

$$y(t) = 1 - \omega_n t e^{-\omega nt} - e^{-\omega nt} \qquad (3.14)a$$

$$y(t) = 1 - e^{-\omega nt}(1 + \omega nt) \qquad (3.14)b$$

$$Unit\ step\ response\ = 1 - e^{-\omega nt}(1 + \omega nt) \qquad (3.14)c$$

$$Step\ response\ = A[1 - e^{-\omega nt}(1 + \omega nt)] \qquad (3.14)\text{d}$$

3.2.5.2 Development of the Cost Benefit Analysis Template for the System

Table 3.1: The Bill of Engineering Measurement and Evaluation

	Item	**Description**	**Unit Price (₦)**	**Quantity**	**Total (₦)**
1.	Arduino Pro Min	Pro Micro chips	2,500	4	10,000
2.	Arduino ATmega	Atmega Chips	3,500	1	3,500
3.	TFT Liquid Crystal Display Screen	155mm x 86mm	12,000	1	12,000
4.	Relay	12VDC	750	4	3000
5.	Transformer	12VAC, 1A	600	5	3,000
6.	Diodes	IN4001	25	7	175
7.	Resistors	1KΩ	20	10	200
8.	Voltage regulator	7805, 7809, 7812	250	10	2,500
9.	Capacitors	1μf, 16V	10	10	100
10.	Relay Drivers Module		2,000	1	2,000
11.	WIFI		3,500	1	3,500
12.	Opto-Coupler, Vero and Bread Board		2,000	1	2,000
13.	AC Lamps	220v AC , 1A	350	8	2,800
14.	Switches	Toggle Switch	150	8	1,200
15.	Indicators	Light Emitting Diode	10	10	100

16.	Current Sensor		1,000	8	8000
17.	Voltage Sensor		1,000	8	8,000
18.	Connectors and lead		1,500	1	1,500
19.	Casing fabrication		4,000	1	4000
20.	Proteus	Single User	13,500	1	13,500
21.	Sublime Text	Open Source	0	0	0
22.	Programmable Logic Controller	Keyence Software	150,000	1	150,000
23.	Phone Gap	Open Source	0	0	0
24.	Arduino IDE	Open Source	0	0	0
25.	4G Module and Sim	Module and SIM	10,000	1	10,000
26.	WIFI	Subscription	15,000	1	15,000
	Miscellaneous		10,000	1	10,000
					₦266,075.00

Table 3.1 shows the financial implication of the intelligent master controller for the power pool application. The template shows that the construction was achieved with the sum of **(₦266,075.00)** two hundred and sixtyy-six thousand, seventy-five naira only. With this minimal cost of fabricating this design, the design demonstration shows that it is simple to use and users friendly, the energy generated and consumed are measurable, the system affordable, reliable and provides an efficient operation

time consideration (save time). The materials were locally sourced, assembled for demonstration and the result presented in chapter 4.

3.3 Summary of the Materials and Methods

All the material selected for the actualization of the intelligent master controller was with specification and were strictly adhered to. Individual materials selected were assembled in Proteus software to form the schematic setup for the intelligent master controller design. Almost every objective in this work has its own method: Programmable logic Controller was used to develop the hybridized system injection model with an OR gate incorporated logic; Proteus was used for the intelligent master controller schematic development and was simulated using the code written in C-language; Sublime text was used to create the HTML; CSS and the Java Scripts form the Human Machine interface with its android enabled device. MangoDB was used to create the database for the system whereas GItHub was used to host design on the server. The system mathematical model was developed, transfer function deduces from the model, the state space extracted from the transfer function and stability criteria formulated. These provided the result in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results and Discussion for the Intelligent Master Controller Architecture

4.1.1 Simulation Results and Discussion for the Intelligent Master Controller

The intelligent master controller design in Fig. 3.15 was assumed to be installed at Afikpo 33/11KV injection substation from which the 11/415V feeder distribution takes the power and delivers to the five communities. This design syncs with the distributed control system concept, where each of the five communities has its own local controller which can be islolated in cases of a fault condition pending when the faults are being cleared. The design has a three-input single phase power supply sources and one output to supply the communities. Results from simulation shows the three power input sources with the labels: yellow colour for the grid supply (11KV), blue for the renewable supply (11KV) and the pink for the generator supply (11KV) respectively. In Fig. 3. 15, the simulation result shows that the regulated input voltage to the microcontroller for logic manipulation indicates that yellow represents grid supply (5V), blue represents renewable supply (5V), pink represents generator supply (5V) and green represents input to the relay circuitries (12V) respectively. The system state in Fig. 3.15 shows that when there is no power supply, the microcontroller senses 0V, and when the supply is ON the microcontroller senses 5V. The supply voltage to individual community is 11KV, but the logic circuit takes into consideration the voltages between (0) and (1), which represents 0V and 5V respectively.

4.1.2 Experimental results and discussion for the Intelligent Master Controller (IMC) Architecture

Table 4.1 shows the binary status of the voltage regulated input to the controller and output to the communities. Fig. 3.16 and table 4.2 shows the equivalent binary conversion of the analogue input which includes 5V in base ten to give 101 in binary, 12V to give 1100, and 11KV to give 0b1011 in binary respectively. The 5V is an input to the microcontroller for its logic configuration, 12V for the relay control, and 10.9KV serves the community.

Table 4.1: Result of power supplied to the microcontroller.

Input (voltage to regulator)	***Output (voltage to regulator)***	***Input [microcontroller]***	***Assumed Generated and Supply Voltage***
12VDC	*5VDC*	*5VDC*	*10.9KV (AC)*

4.1.3 Comparison result and discussion of Software and Hardware Implementation of the Intelligent Master Controller (IMC)

The difference between the input voltage regulated for the relay between the simulation value and the hardware value as shown in Table 4.2 is 0.01VDC. The difference in the input voltage regulated for the microcontroller between the simulation value and the hardware value is 0.2VDC. generated and supply voltage between the simulation value and the hardware value is 0.1KV (AC).

These differences accounts for both error during simulation, and also incorrect components parameters selection for hardware devices used.

The difference in the output voltage from the microcontroller between the simulation value and the hardware value is 0.1VDC, while the difference in the

Table 4.2 shows the input status of the voltage regulateded input to the controller and output to the communities

Results	***Input (voltage to regulator)***	***Output (voltage to regulator)***	***Input [microcontroller]***	***Generated and Supply Voltage Aggregated***
Simulation Aggregated	12VDC	5VDC	5VDC	11KV (AC)
Hardware	12.01VDC	4.8VDC	4.9VDC	10.9KV (AC)
Differences	0.01VDC	0.2VDC	0.1VDC	0.1AC (V)

4.1.4 Result of and discussion of Integrated Hybridized Scheme for the Intelligent Master Controller (PLC Software Simulation)

The Fig. 4.1 shows the user interface for PLC and SCADA developed program for energy injection from the renewable energy resources. The renewable resources gotten from Solar, Wind, Biomass, and Hydro from the five communities were harvested and synchronized for use through simulation. The run time was selected and the toggle switch device was activated. The Real time trends and historical trends for this design result is shown in Fig. 4.2.

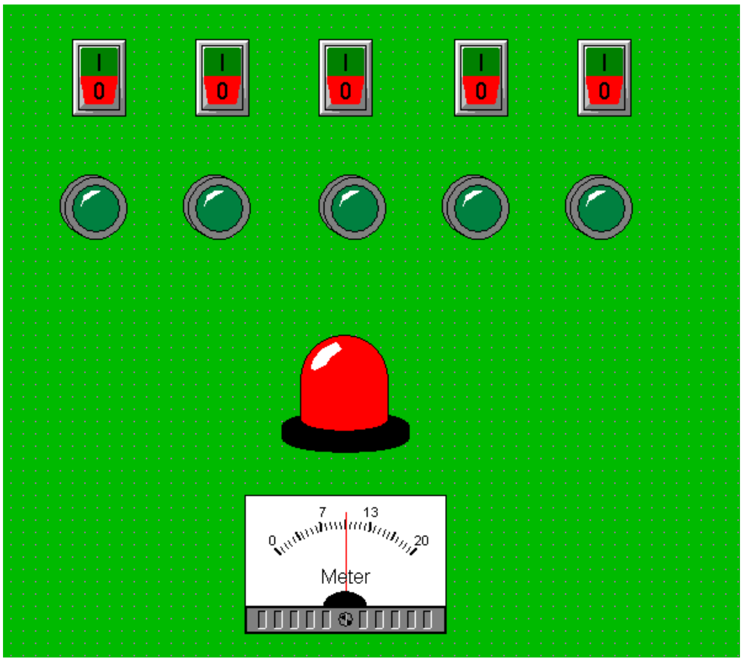


Fig. 4.1: PLC and SCADA System User Interface

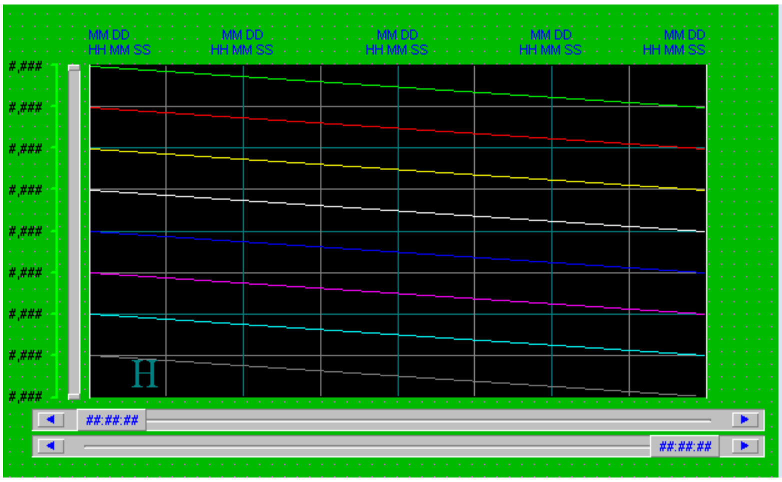


Fig. 4.2: The design trend Historical trends

The system also incorporated alarm and trip devices since it is a full automated system, one which also serve as a requirement for safety instrumented system. The alarm prime function is to alert the operator of the system malfunctioning while the trip is to isolate the system under the faulty condition. With this, whenever the alarm comes ON for three minutes without the operator's attention, the system is designed to shut down automatically.

4.1.5 Results and discussion of Software and Hardware Intelligent Master Controller with IoT System at "ON" Position with or without Input Voltage Available

Fig. 4.3,4.4,4.5 and 4.6 shows intelligent logic control deployment. The developed software application communicates with WIFI module in the hardware design, and the WIFI internet communicates with the master controller through its serial connection protocol called Universal Asynchronous Register Transfer (UART). When the system displays OFF; it shows that the system is on its default OFF status, meaning no source of energy is supplied to it and no community has power.

Fig. 4.7, shows intelligent logic control deployment. The developed software application communicates with WIFI module in the hardware design, and the WIFI internet communicates with the master controller through its serial connection protocol called Universal Asynchronous Register Transfer (UART). The system displays 1000 (”0”) value to so show that the system is ON but no source of energy is available and no community is supplied with power. However, when power is available in any of the input from either grid, renewable or generator, the system status changes to 5000(”1”), showing that the system is ON, and energy is available and the communities are supplied with power.

Fig. 4.8 shows the IoT main control scheme for voltage and current in the intelligent master controller design, the general physical control (Master Main Control Switch on physical device), and the general app control (Master Main Control Switch on

App). This analysis is made possible with the ThingSpeak online platform with its MATLAB associated tools.

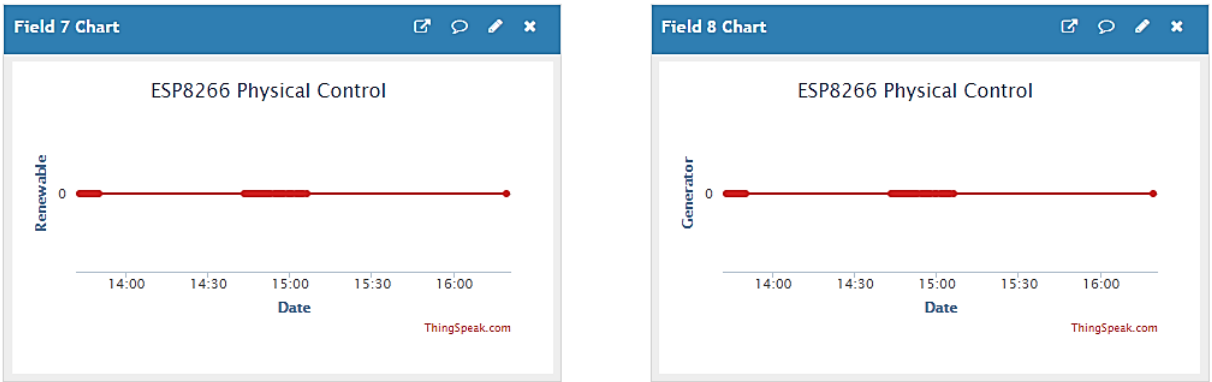


Fig. 4.3: Physical Control for Renewable and Generator with IoT Device

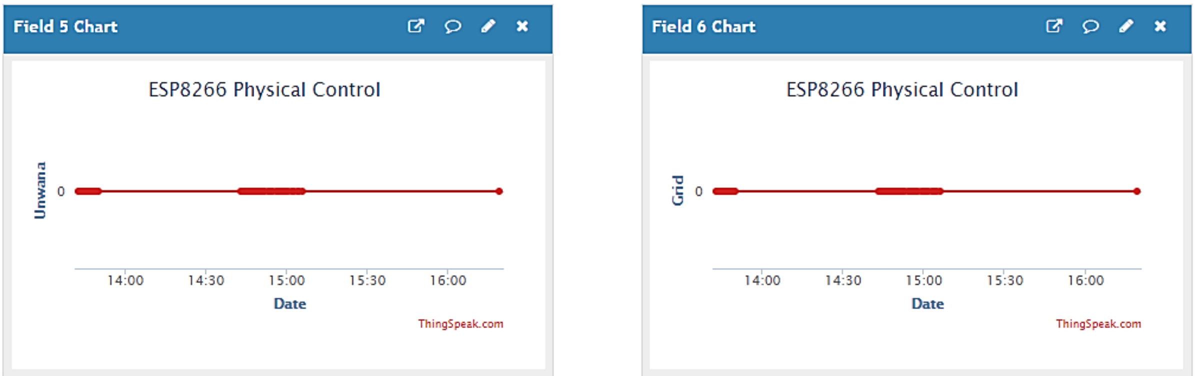


Fig. 4.4: Physical Control for Unwana line and Generator input with IoT Device

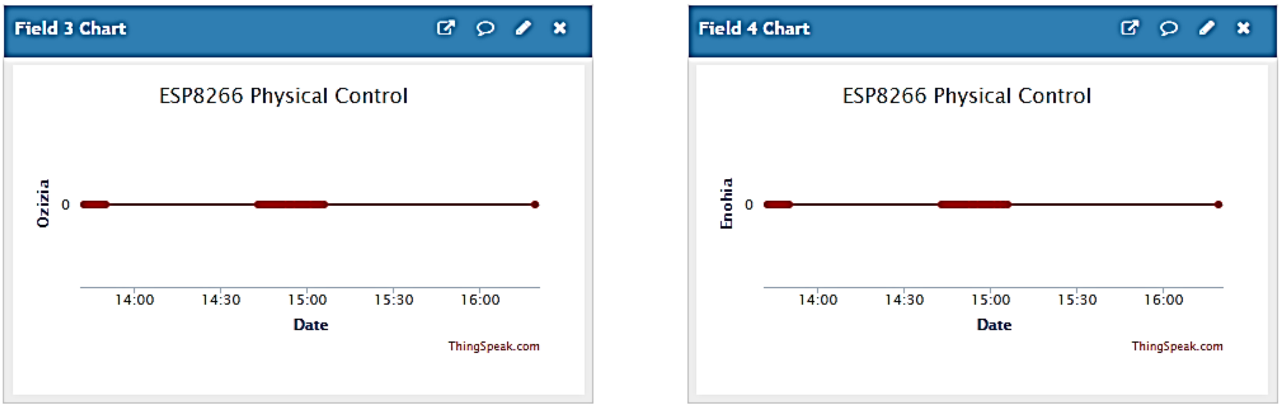


Fig. 4.5: Physical Control for Oziza and Enohia line with IoT Device

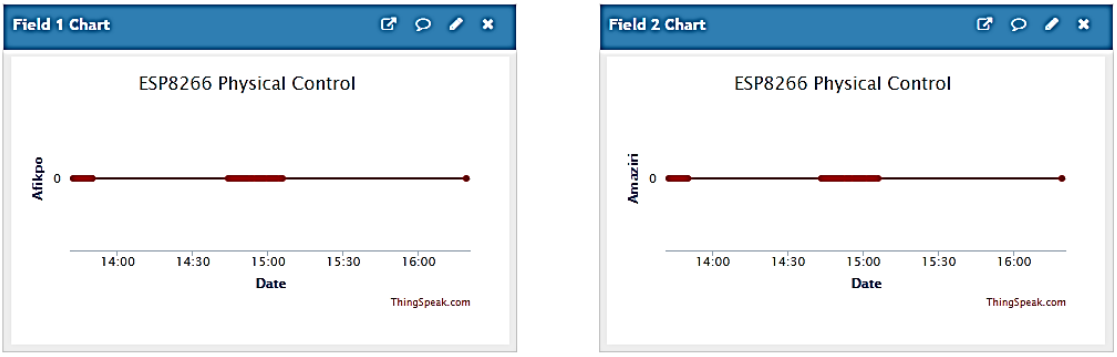


Fig. 4.6: Physical Control for Afikpo and Amaziri line with IoT Device

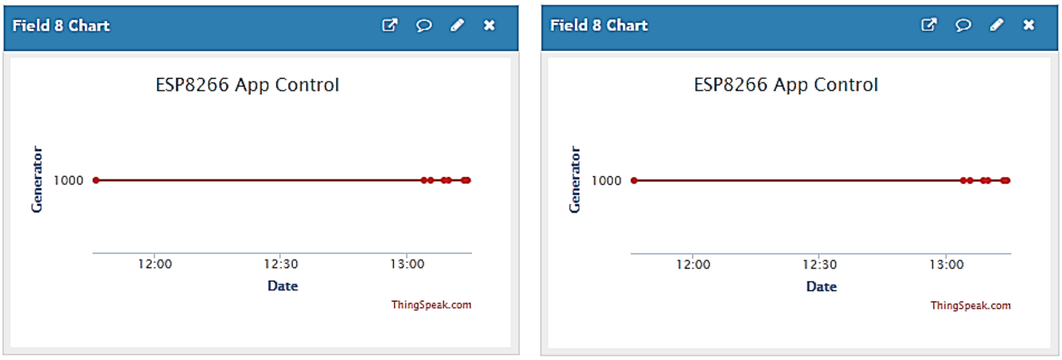


Fig. 4.7: Physical Control for a Source and one community with IoT Device on ON Status

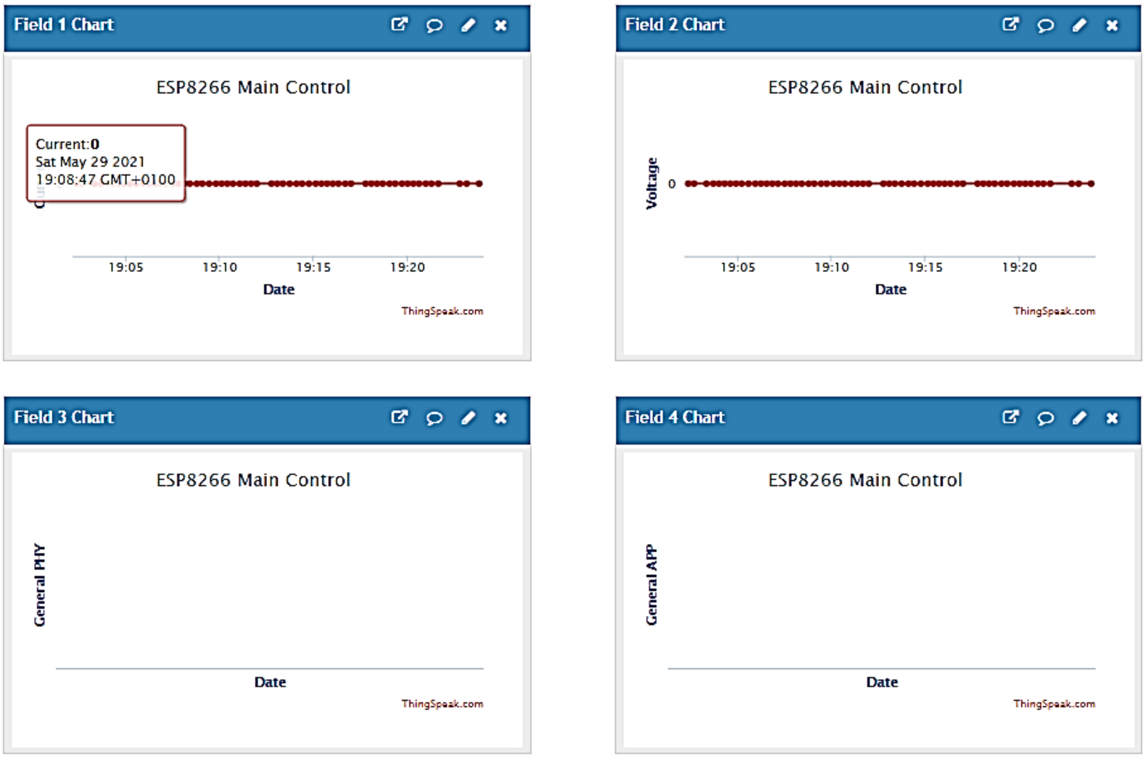


Fig. 4.8: Main Control with IoT Device

4.2 Result and discussion for the designed remote monitoring scheme with android application (Software)

4.2.1 Results and Discussions of the Operator's SIGN-IN/UP Page on Laptop/Web View

Fig. 4.9 corresponding to Section 3.2.2 shows the result of the operator's sign-IN/UP template for the intelligent master controller on the pool administrator's Laptop. A new operator is issued with an initial sign-up data, which will be changed after authentication and authorization by the central pool manager, after which all information are sent to the pool operator via electronic mail including the operator's password. After logging in with the required username and password, the operator power pool interface appears via the android application which is the replica of the hardware device.

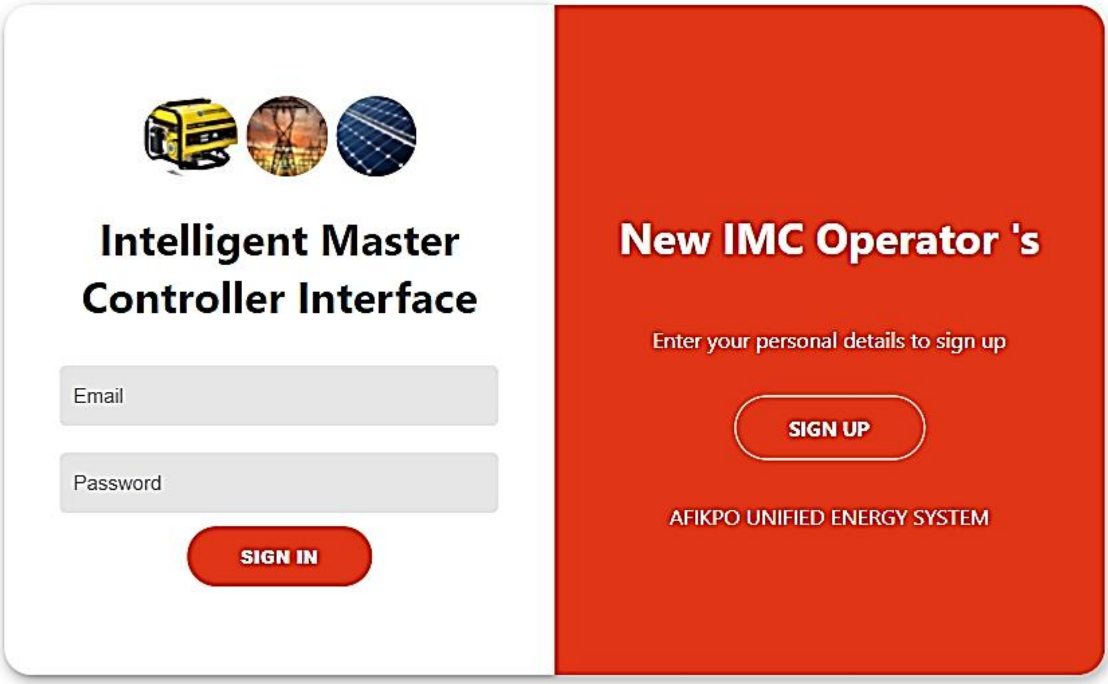


Fig. 4.9: Intelligent Master Controllers Operator's Sign IN/UP Interface

4.2.2 Results and Discussion of the code Written with Hypertext markup language (HTML), Cascading Style Sheet (CSS) and JavaScript for Human Machine Interface.

In Fig. 4.10, the result shows integration of HTML, CSS and JavaScript to produce the pool interface which consists of buttons, switches and bulbs showing the energy generations and consumption.

The grid source has a switching device and indicator(yellow), such that whenever the grid button is pressed, the information from the grid generated is displayed in both the hardware and the android application.

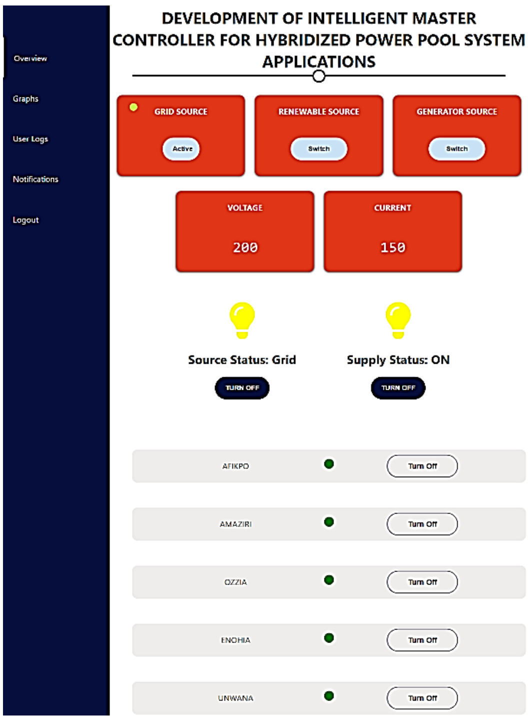


Fig. 4.10: Soft Screen Touch lntelligent Master Controller with a Human Machine Interface Laptop View

Similarly, for the renewable energy source, it has a switching device and indicator(red), such that whenever the renewable energy button is pressed, the information from the renewable energy source generated is displayed in both the hardware and the android application.

Furthermore, the alternative power source (Generator) has a switching device and indicator(blue), such that whenever the generator button is pressed, the information from the generator source is displayed in both the hardware and the android application. Also, on the HMI, the current and the voltage read from the sensors are displayed physically for the operator to see using TFT LCD system.

The design incorporated a master main switch to toggle between the energy input as well as the output to the communities.

Each of the sources were controlled by its individual slave controller and connected to the master controller which has the capability of controlling all the slave controllers. The master controller scanned through the three slave controllers and gives priority first to the grid slave controller followed by the renewable energy slave controller. When there is absence of energy from grid and renewable slave controllers the master controller initiated an action to turn on the generator by activating its slave controller. The energy generated from these three sources were integrated into a common bus for poolingn and further distributed to the five co-located communities. This design has a switching device for the AFIKPO consumption line and also has an indicator(red) showing that there is supply of energy to AFIKPO community. It has a button which when pressed reveals the energy consumption for AFIKPO. Similarly, the design has a switching device for the AMASIRI consumption line and also has an indicator(red) showing that there is supply of energy to AMASIRI community. It has a button that when pressed reveals the energy consumption for AMASIRI. Also, the design has a switching device for the OZIZA consumption line and also has an indicator(red) showing that there is supply of energy to OZIZA community. It has a button which when pressed reveals the energy consumption for OZIZA. Furthermore, the design has a switching device for the ENOHIA consumption line and also has an indicator(red) showing that there is supply of energy to ENOHIA community. It has a button which when pressed reveals the energy consumption for ENOHIA. Lastly, the design has a switching device for the UNWANA consumption line and also has an indicator(red) showing that there is supply of energy to UNWANA community. It has a button which when pressed reveals the energy consumption for UNWANA.

The consumption for the five co-located communities were displayed both in the hardware and android interfaces in terms of its voltage, current and power.

The energy generated from the three hybridized sources for the five co-located communities were displayed both in the hardware and android interfaces in terms of its voltage, current and power. The power pool control hardware device designed was interfaced with the android application via a WiFi module for its interactions (monitoring and control) alongside the human machine interface. The overall data emanating from the generating and consumption ends were stored in a cloud database.

4.2.3 Results and Discussion for the Operator's SIGNUP Authentication and information storage

The Fig. 4.11 shows the community operator log on status for authentication at the resumption of duty. The authentication is done only by the Pool admin officer, which has the absolute power to turn ON and OFF the Main Switch for both Physical and App domain, but the individual community operator has only the power to turn OFF or ON from its user app interface.

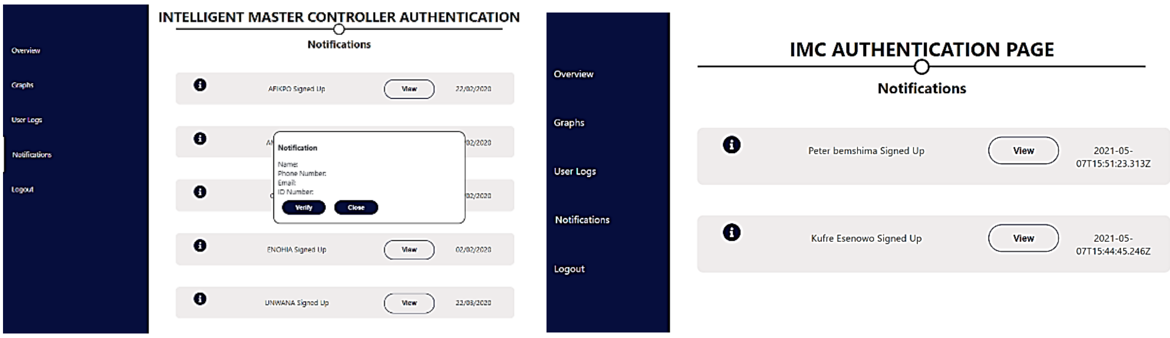


Fig. 4.11: The Operator's Signup Master Authentication page

The database for the documentation of the operator's sign IN/UP information was designed with NoSQL (MangoDB) and the result gives the operators details thus:

Operator 1:

*FirstName: **Kufre** *Last Name **: Jack**

*Phone Number: **08023774907** ***Date of Birth:1st May 2009**

*Staff Identification Number: **IM2440C** *** Location: Enohia**

*User-Email**: jackufre125@gmail.com** *Password**: xxxxxxxxxxx**

*Verify Pasword**: xxxxxxxxxxx** click **"Signup"**

Operator 2:

*FirstName: **Udeme** *LastName**: Udo**

*Phone Number: **08039149739** *Date of Birth:**1st April 1979**

*Staff Identification Number: **IM2550C** * Location: **Amasiri**

*User-Email**: udeme.u@gmail.com** *Password**: xxxxxxxxxxx**

*Verify Pasword**: xxxxxxxxxxx** click **"Signup"**

4.2.4 Results and Discussion for the Operator's Monitoring and Control Page after Signup

Fig. 4.12 shows the community operator's dashboard in case of system abnormalities. The community operator can carry out emergency shutdown operation and also view the supply and consumption status. The operator in-charge of the Enohia zone can only control his community and cannot switch ON /OFF the supply from other communities and vice versa.

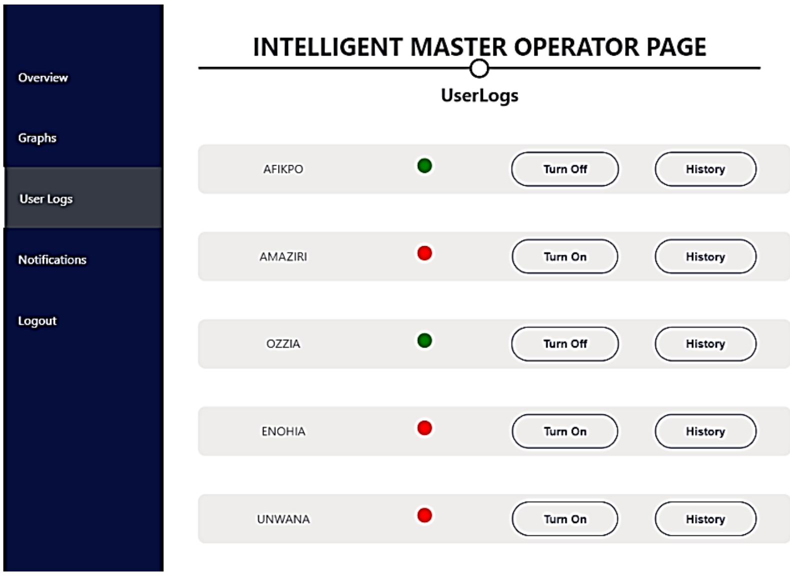
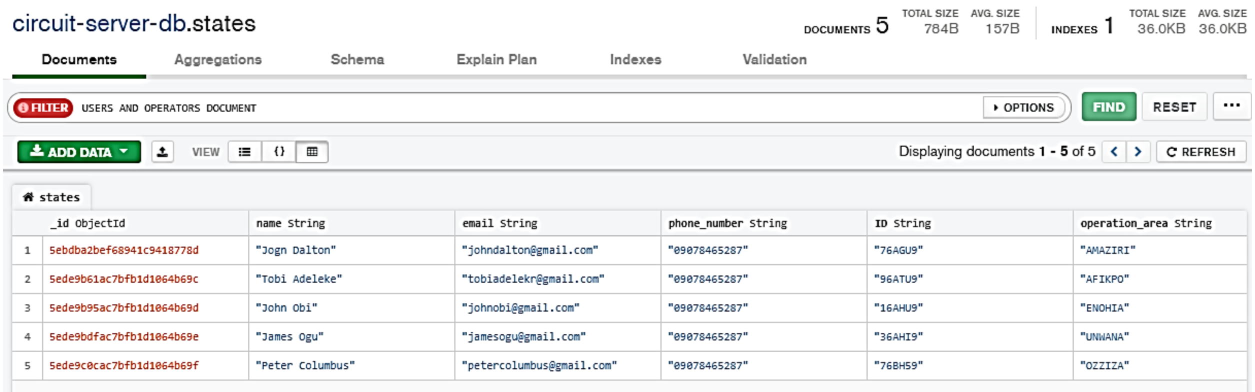


Plate 4.12: The Operator's Monitoring and Control Page after Signup

To navigate on the details of the previous operations the button with tag "history "is used. The database documentation is as shown in Fig. 4.15

4.2.5 Result and Discussion of the Database for the Operator's SIGN-IN/UP information storage

In Fig, 4.13, the design of the signup page is such that the pool administrator (Master Controller Administrator) must authenticate the status of the staff before their document and data are accepted for operational control action initiation.



	_id ObjectId	name String	email String	phone_number String	ID String	operation_area String
1	5ebdba2bef68941c9418778d	"Jogn Dalton"	"johndalton@gmail.com"	"09078465287"	"76AGU9"	"AMAZIRI"
2	5ede9b61ac7bfb1d1064b69c	"Tobi Adeleke"	"tobiadelekr@gmail.com"	"09078465287"	"96ATU9"	"AFIKPO"
3	5ede9b95ac7bfb1d1064b69d	"John Obi"	"johnobi@gmail.com"	"09078465287"	"16AHU9"	"ENOHIA"
4	5ede9bdfac7bfb1d1064b69e	"James Ogu"	"jamesogu@gmail.com"	"09078465287"	"36AHI9"	"UNWANA"
5	5ede9c0cac7bfb1d1064b69f	"Peter Columbus"	"petercolumbus@gmail.com"	"09078465287"	"76BH59"	"OZZIZA"

Fig. 4.13: Database for the Operator's SIGN-IN/UP information storage

This design uses MangoDB as its database, and during authentication calls up data from the web. When the status is confirmed, the new operator sign-in from the android Phone with enabling access from the human machine interface which provides remote monitoring and control. The results from this signup/sign-in page significantly unfold on the android via IoT application for the municipal energy monitoring and control scheme.

4.2.6 Results and Discussion on database for the generating energy (Input) information storage

Fig. 4.14, shows the Mango DB platform where generated energy data from the grid, renewable and generator are documented in cloud and can be accessed via a mobile application. These are done on the real time basis.

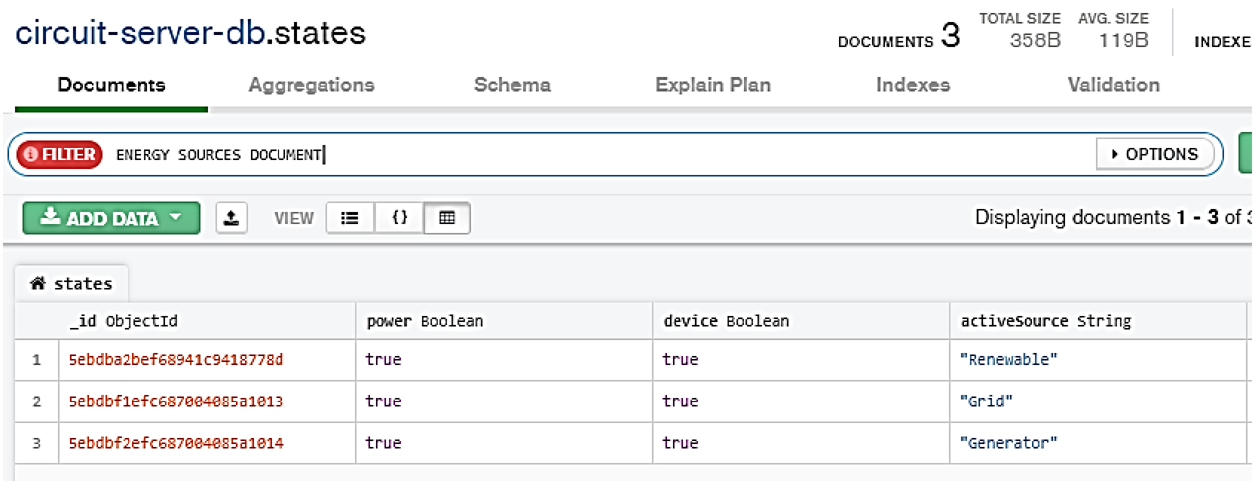


Fig. 4.14: Database for the Energy source information storage

4.2.7 Results and Discussion on database for the energy consumption (Output) information storage

Fig. 4.15, shows the Mango DB platform where consumed energy data from Afikpo, Enohia, Oziza, Amaziri and Unwana are documented on web and can be accessed via a mobile application. These are done on the real time basis.

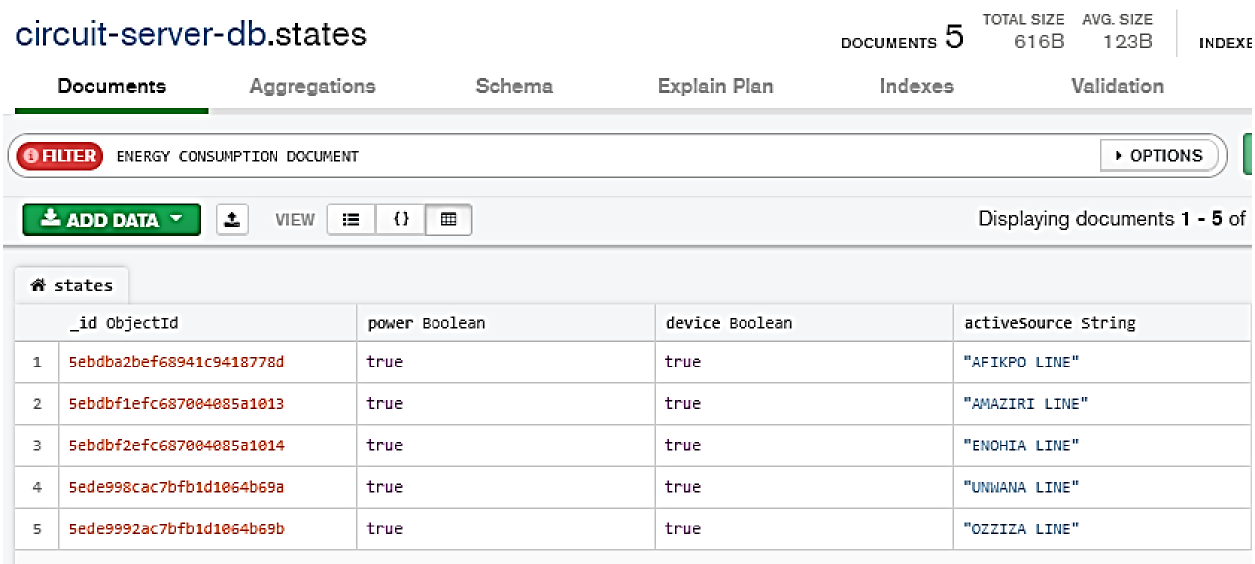


Fig. 4.15: Database for the Consumption Energy Information Storage

4.2.8 Results and Discussion for Remote Control with Android Applications

Prior to the hardware and software concurrent interaction test; the placeholders or variables for each of the master and slave controllers were created in section 3.2.4: C. Fig. 4.16 shows the android sign IN/UP view for both the pool administrator and community operators.

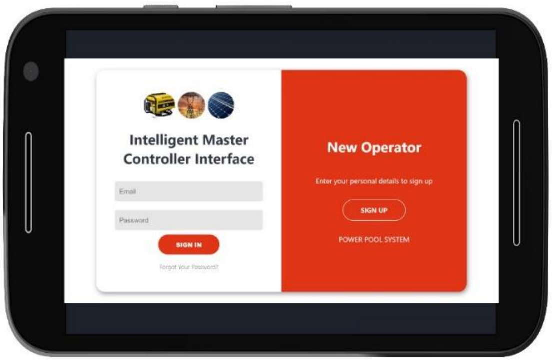


Fig. 4.16: The Android Interface for the intelligent Master Controller Sign IN/UP page

4.2.9 Results and Discussion of the Pool Admin Android Application Interface for the Intelligent Master Controller

When the unified energy Administrator logs ON, the manufacturer authenticates and authorizes its usage. After the authorization, Fig. 4.17 shows the human machine interface for control and monitoring operation.

Fig. 4.17: Pool Admin Soft-touch Human Machine Interface Android Application for the intelligent master controller

Fig. 4.17 shows the standard android interface displaying the intelligent master controller activities in three segments and the centralized controller of the hybridized metropolitan network (Pool Admin):

i. The first is the energy input (source), which include the GRID, RENEWABLE and GENERATOR source. When toggling on Grid switching interface with Green colour, the energy data from the database is called up and displayed in real-time basis whereas when toggling on grid OFF in green colour, the energy supplied to the micro-grid bus is turned OFF from the unified energy system and vice versa. Similarly, when toggling on RERs switching interface with Yellow colour, the energy data from the database is called up and displayed in real-time basis whereas when toggling on the RERs OFF in green colour, the energy supplied to the micro-grid bus is turned OFF from the pool and vice versa. In the same vein, when toggling on GEN switching interface with Green colour, the energy data from the database is called up and displayed in real-time basis whereas when toggling on the GEN OFF in green colour the energy supplied to the micro-grid bus is turned OFF from the pool and vice versa.

ii. The second is the energy control and display platform, which this includes the generated source display, master control switch and energy consumption display platform. Whenever there is energy in any of the grid, renewable and generator source, the **GREEN, YELLOW** and **RED** indicator lit but the prioritized energy source will be displayed on the generated energy platform. However, when the energy from the pool requires to be put OFF, the master controller toggles it.

iii. The third is the energy output (consumption), which includes the Afikpo, Amasiri, Enohia, Oziza and Unwana load line. The energy consumption platform displays the energy consumed in Afikpo, Amasiri, Enohia, Oziza and Unwana load line respectively but when toggling on switching interface with green colour, the energy data from the database is called up and displayed in real-time basis whereas when toggling on the grid OFF in green colour the energy supplied to the micro-grid bus is turned OFF from the pool and vice versa for all the load centers. Whenever there is energy in any of the grid, renewable or generator source, the **RED** indicator lit to show that the community bus is energized.

Fig. 4.18 aids in the authentication of the community-based operators during the signup at first instance. The operator can also check for their job schedule, when there is exchange of operator's assignment period remotely via the online services. The operator in charge of a particular zone solely oversees the remote intelligent master controller activities in their Metropolis hybridized energy management system.

Fig. 4.18: Android Apps for the Community-based operators Soft-touch Human Machine Interface

Fig. 4.19 shows the android view of the community-based operators' dashboard for energy monitoring and control.

Fig. 4.19: Android view of the Community-based operators' Energy dashboard

Fig. 4.20 shows energy generated into the integrated scheme and their daily consumption for each community. An operator cannot view another community's consumption level outside his operational jurisdiction.

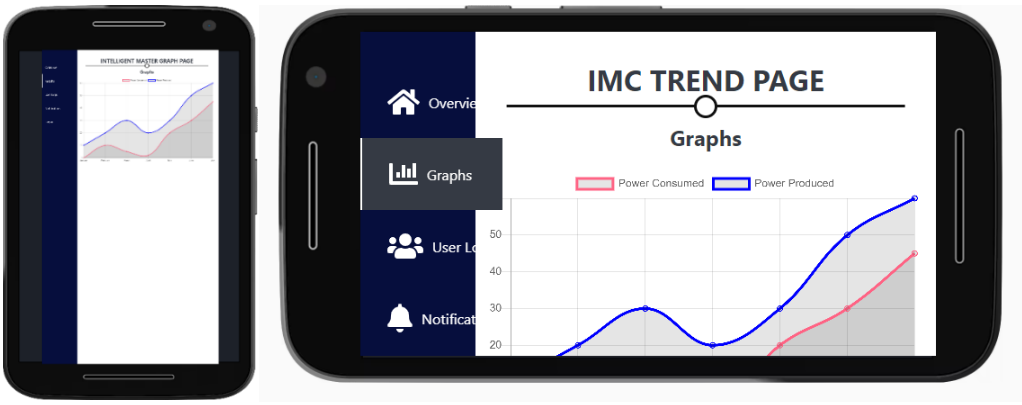


Fig. 4.20: Android apps for the Community-based operators' historical view

4.2.10 Results and discussions for Energy Data Handling Capability

Table 4.3 shows how the system was demonstrated for 6 hours, with 45minutes' intermittent checks. The result shows that when the grid, renewable and generating set energy were available and their respective loads were applied, the system with its priority activation feature selects the source for use.

Table 4.3 : The Power Supply within 6 Hours' Demonstration Period

Energy Supply (W) and Time Duration (30minutes)	**Grid**	**Renewable Energy (Solar)**	**Generator set**	**Total Available Power (W)**
6:00am-6:45am	300	000	000	**300**
6:45am-7:30am	000	000	475	**475**
7:30am-8:15am	000	000	360	**360**
8:15am-9:00am	250	000	000	**250**
9:00am-9:45am	000	000	340	**340**
9:45am-10:30am	450	000	000	**450**
10:30am-11:15am	000	180	000	**180**
11:15am-12:00pm	000	220	000	**220**

Table 4.3 and fig. 4.21 shows the 45 minutes' energy generated for the consumption with the five communities. The design is made such that only one source of energy operates within the designed 45minutes schedule. During the first 45minutes (6:00 am to 6:45 am), the public power supply was available and supplied 300W, while the renewable energy and the generator set was not available during this period. By 6:45 am the public power supply (Grid) and renewable energy went OFF, and the generator set restored and delivered 475W to the community until 7:30am. By 7:30 am the public power supply (Grid) and renewable energy was still OFF, therefore the generator set continues and delivered 360W to the community until 8:15am. The

public power supply was restored by 8:15am and it produced a power supply of 250W, thereby relieving the renewable energy supply smartly. By 9:00am there was an outage in the public power supply again and the intelligent master controller scanned the power sources and renewable energy was not available for use. Therefore, it initiated the generator, starting to load the community with 340W. The renewable energy was stored by 10:30am as the public power supply went OFF and the stored renewable energy took over and delivered 180 W to the community until 11:15am when the PV was at its peak with increased the energy delivery to 220W at 12:00pm and the exchange of energy supply was done smartly.

The sequence of operation continued and the data were collected and deposited on the cloud. These energy changes were viewed from the developed panel on the hardware basis as well as on a mobile device. The design followed the prioritized sequence; the energy sensor actuates the public power supply first, followed by the renewable energy supply and lastly the generating set supply.

The system was demonstrated for 6 hours, with 45minutes' intermittent checks, the result shows when the grid, renewable and generating set energy was available and their respective loads that were applied for the five communities.

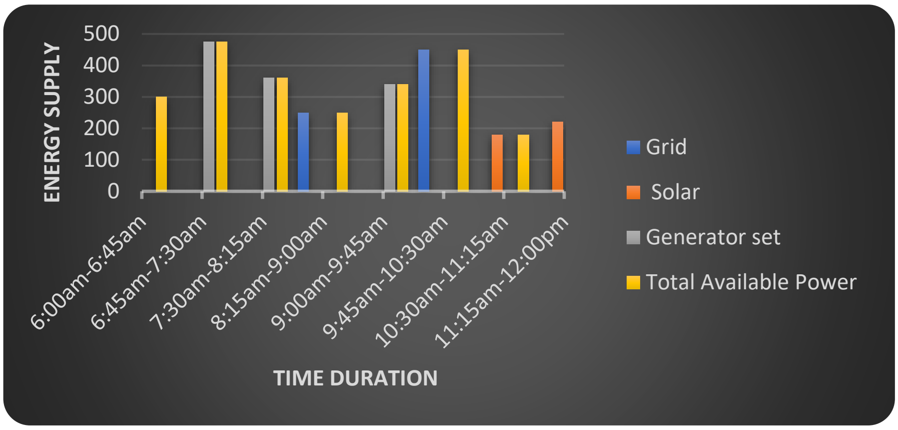


Fig. 4.21: Energy Supply Against Time Duration

In Table 4.4, the database size was estimated in section 3.2.2(g.) and the storage size was computed to be 0.16kb for the generated source information. The aggregated data size occupied by both the generated sources and the energy consumed power was 0.28kb.

Table 4.4 : The consumed power for Five community within 6-hour demonstration Period

Communities and Time Durations (45Mins)	**Afikpo (W)**	**Enohia (W)**	**Amaziri (W)**	**Oziza (W)**	**Unwana (W)**	**Total Load (W)**
6:00am-6:45am	60	50	40	80	70	**300**
6:45am-7:30am	30	60	40	0	50	**180**
7:30am-8:15am	35	40	45	50	50	**220**
8:15am-9:00am	50	50	50	50	50	**250**
9:00am-9:45am	70	80	75	45	70	**340**
9:45am-10:30am	85	95	85	97	88	**450**

10:30am- 11:15am	95	100	90	100	90	**475**
11:15am-2:00pm	85	50	60	75	90	**360**

In Table 4.5, the database size was estimated in section 3.2.2(g.) and the storage size was computed to be 0.12kb for the generated source information.

Table 4.5: Estimated Daily data trend for 10 days

Days	Hours in days	Data (KB)
1	24	0.28
2	48	0.56
3	72	0.84
4	96	1.12
5	120	1.4
6	144	1.68
7	168	1.96
8	192	2.24
9	216	2.52
10	240	2.8

Fig. 4.22 shows data trend for one day of 6 hours during which time the data size increased to as much as 0.28kb. The projection for ten days, as shown in the figure is about 2.8kb. This demonstrates that the data size will significantly increase as the energy market grows. The generated and individual consumed energy in the five

communities shows that their data were becoming large, hence, some of the consumers reduced their energy usage from their communities by isolating some of the energy devices remotely. The data gathered from this experiment from the five cohabited dwellers shows that big data handling by cloud computing was possible.

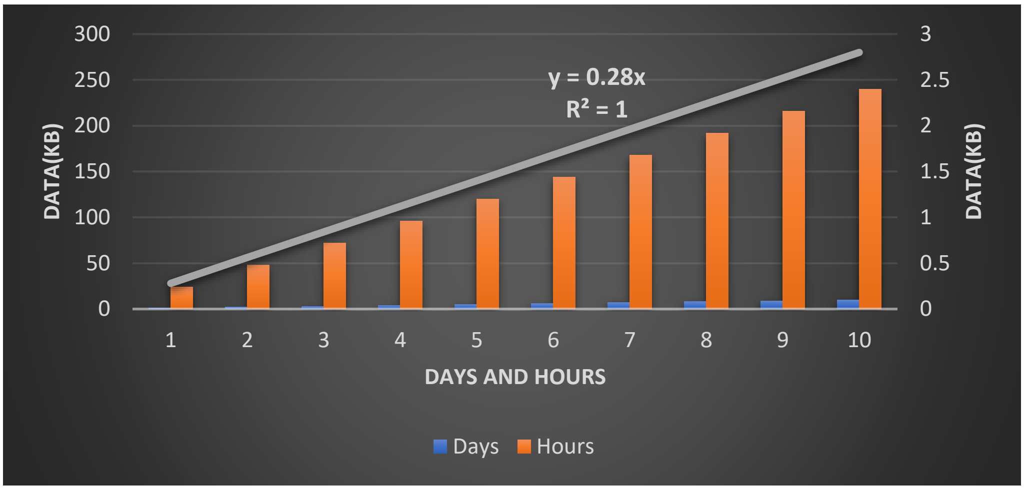


Fig. 4.22: Daily Data estimate for the energy data monitoring from integrated Power Pool system

4.3 Result and discussion for software program developed for the unified sequences of operation design

4.3.1 Result and discussion for sequences of operation design with general Relay Logic for the three Input at default operations.

The program logic is the main concept in this research, providing the sequence of energy prioritization in the order of Grid(X), Renewable energy (Y) and Generator supply(Z) to provide the output(O). The software simulation and the hardware program in the Arduino ATMega 328 was coded to give the system sequence of operations with its priority source.

The three inputs (Grid, Ren, and Gen) were simulated, compiled, and uploaded to the system as considered in the logic Table 4.6. At the system default setting, when the three inputs were not available, the system detects the non-availability of supply in each of the sources. Secondly, the software simulation with three inputs (Grid, Ren, and Gen), where the first two inputs were unavailable and the generator input was ON, gives a logical output of the system to be one (1). Thirdly, the three inputs (Grid, Ren, and Gen) where two inputs were unavailable, and the renewable input was ON, gives a logical output of the system to be one (1). Fourthly, when any one of the three inputs (Grid, Ren, and Gen) are available, the system smartly gives an output of one (1). Conclusively, if all three inputs are ON, the system automatically disengage generator and renewable energy sources, and allow only the grid energy supply.

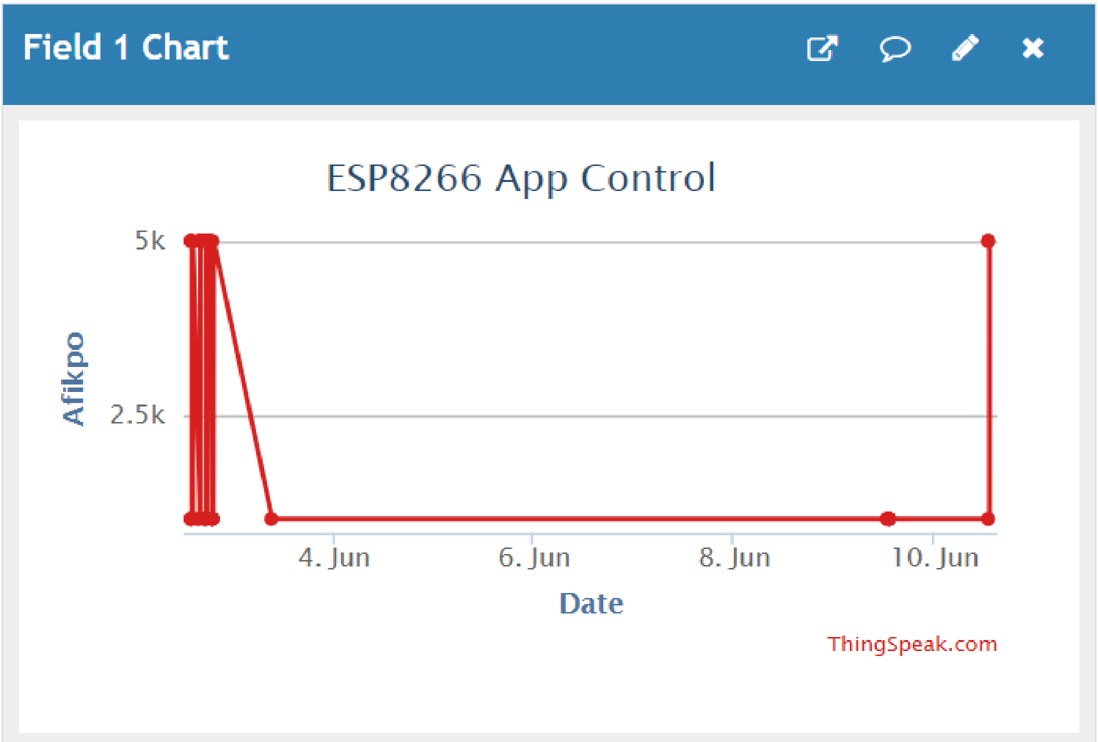
The communication logic between the admin and individual community operator determines the activities and the sequence of operation for this intelligent master controller. The system comprises of physical controller (master or admin control), and app controller (admin and community operator control), as they aid in remote switching operation priority.

The load consumption in this experimental model is monitored and controlled using android application via WIFI. With the android app, the trend of the energy consumed by individual communities are displayed and analyzed using ThingSpeak.

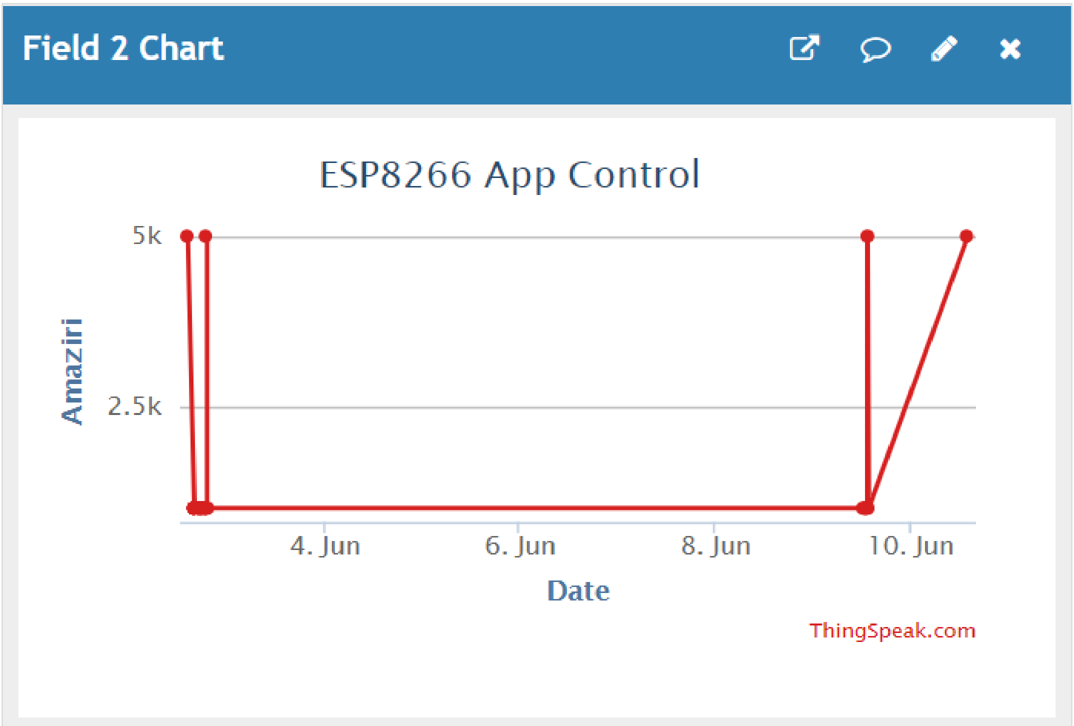
Table 4.6: Simulation result for the Intelligent Master Controller Logic Scheme

	X (Grid)	Y (Ren)	Z (Gen)	Output(O)
0	0	0	0	0
1	0	0	1	1
2	0	1	0	1
3	0	1	1	1
4	1	0	0	1
5	1	0	1	1
6	1	1	0	1
7	1	1	1	1

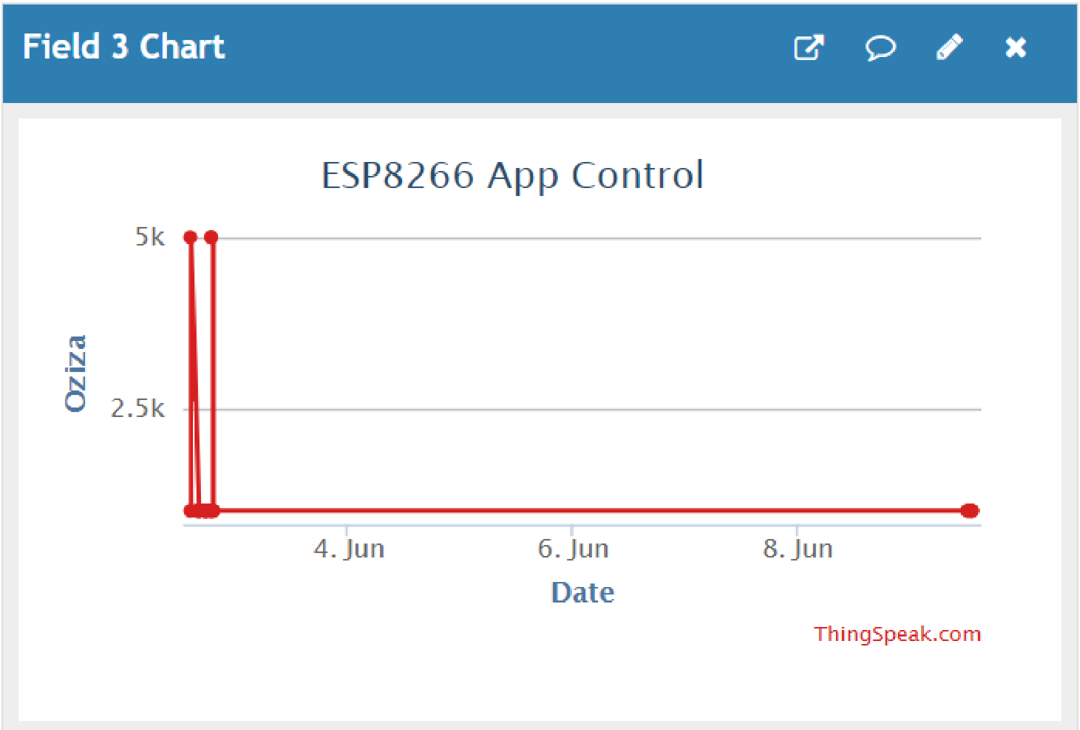
Fig.4.23 and 4.24 shows that when the grid source was available for use and other sources where unavailable, the sources available supplied power recorded at 5000 which logically means (1) and serve the five community, while 1000 logically means (0). Although priority is given to the communities with much sited industries in order not to affect their production through grid energy and generator sources. But when the renewable energy source is ON, priority then goes to communities with low energy demand first. The energy management system considers load shading and load sharing from data gathered and also gave the forecast of the individual energy requirements for the near future.


Field 1 Chart
ESP8266 App Control
5k
2.5k
Afikpo
4. Jun
6. Jun
8. Jun
10. Jun
Date
ThingSpeak.com

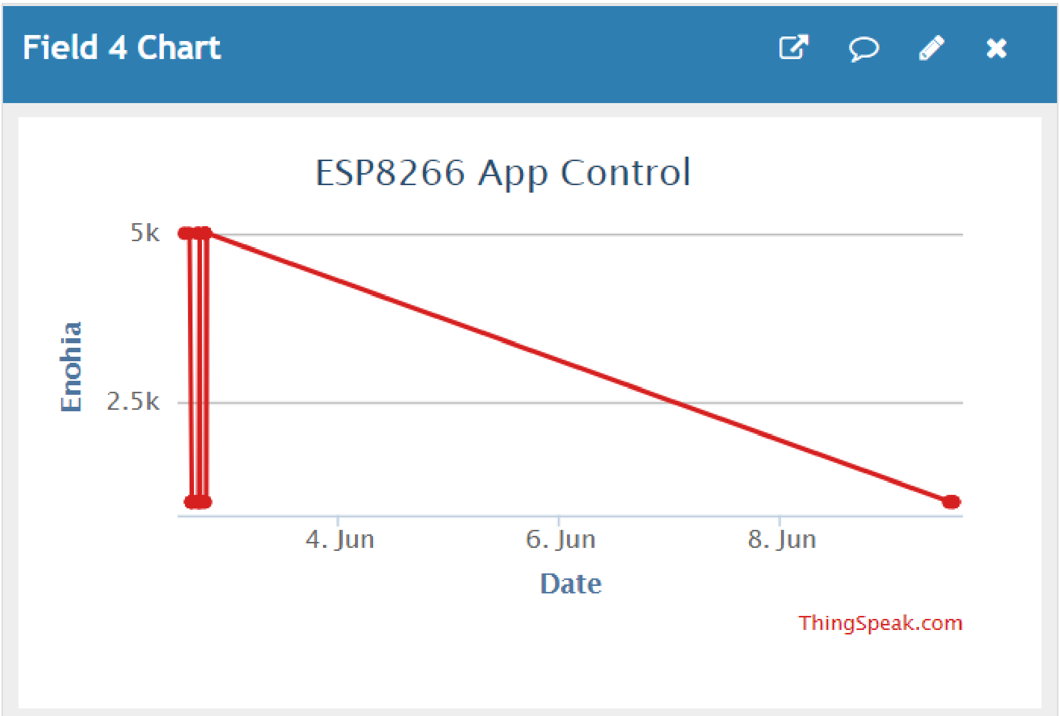
(a.)


Field 2 Chart
ESP8266 App Control
5k
2.5k
Amaziri
4. Jun
6. Jun
8. Jun
10. Jun
Date
ThingSpeak.com

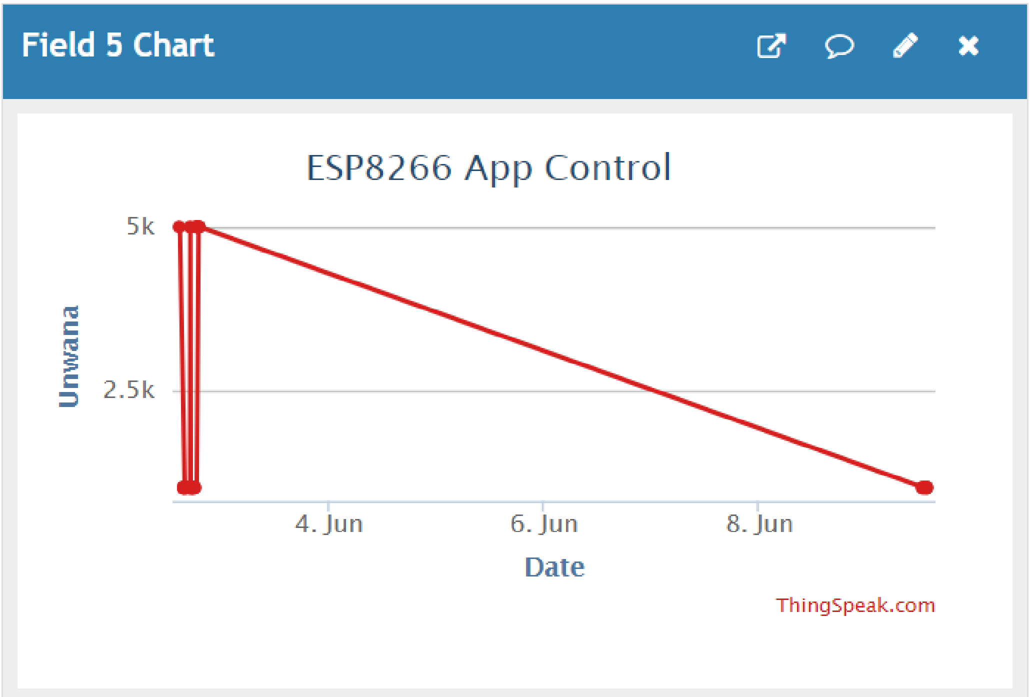
(b.)


Field 3 Chart
ESP8266 App Control
5k
2.5k
Oziza
4. Jun
6. Jun
8. Jun
Date
ThingSpeak.com

(c.)

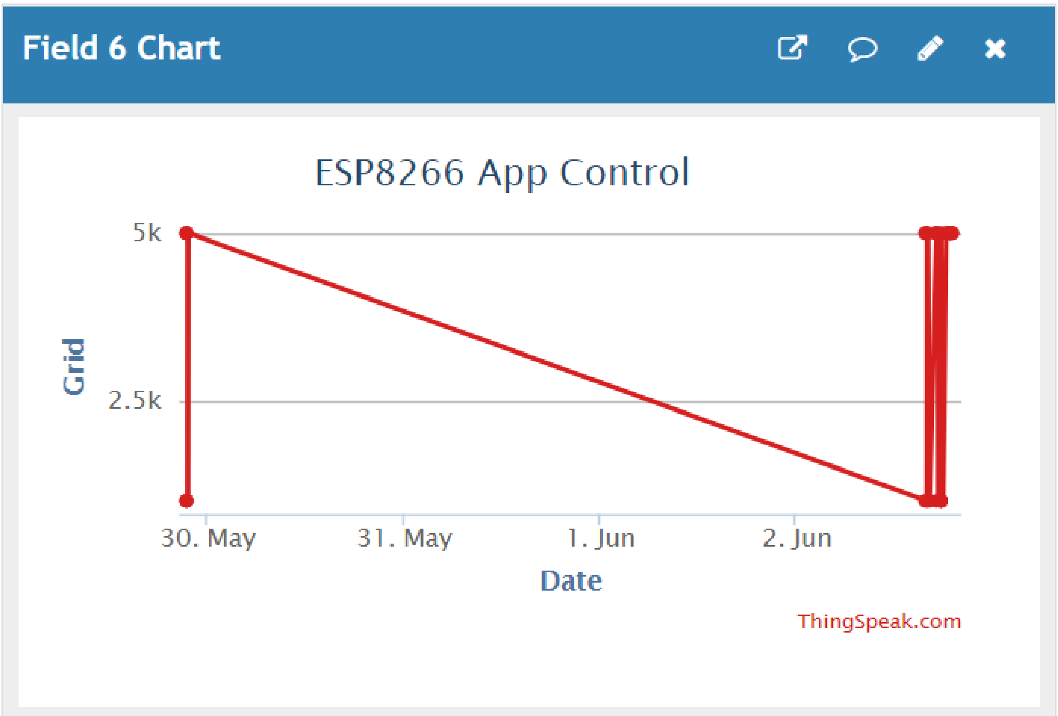

Field 4 Chart
ESP8266 App Control
5k
2.5k
Enohia
4. Jun
6. Jun
8. Jun
Date
ThingSpeak.com

(d.)

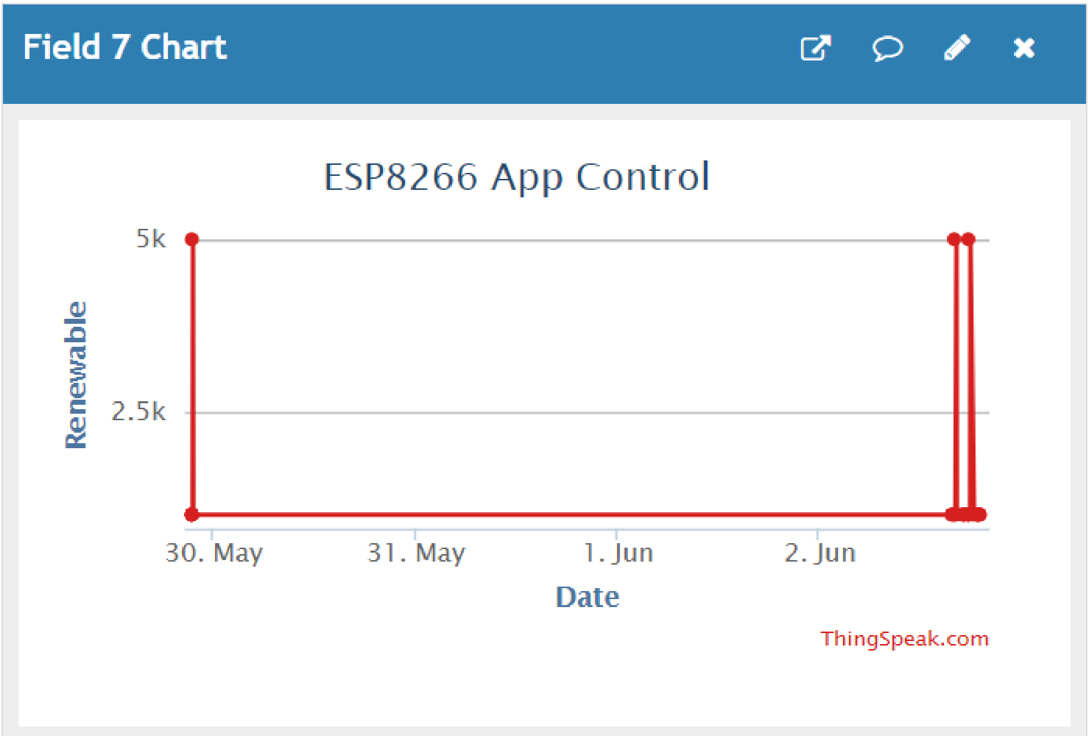


(e.)

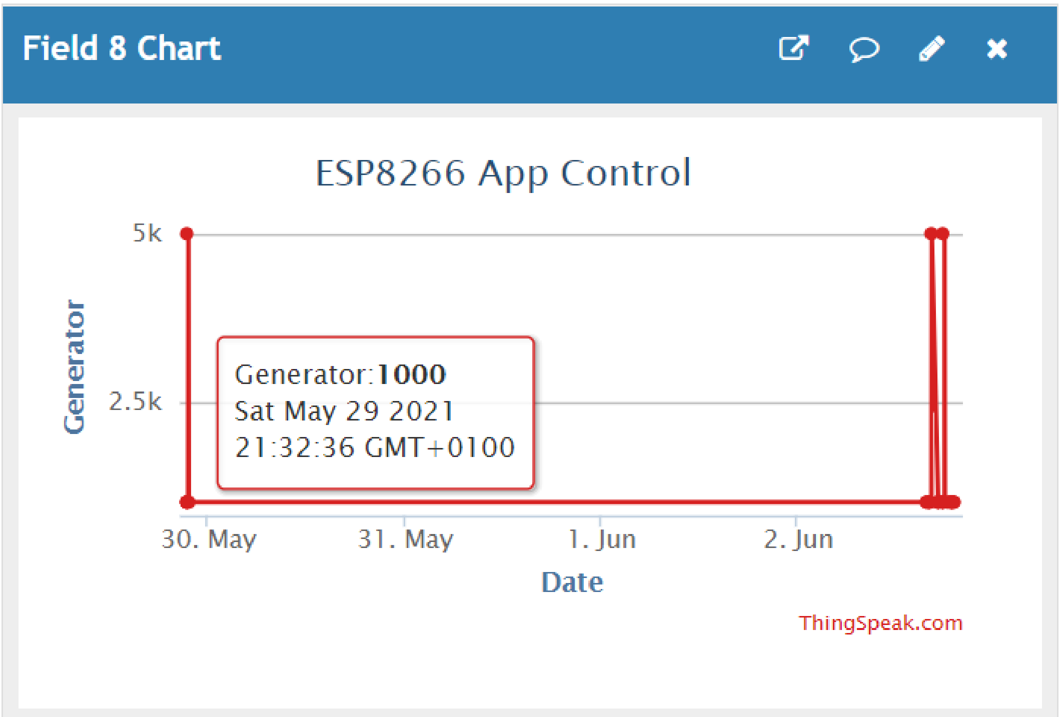
Fig. 4.23: Apps Control for five community with IoT Device



(a.)



(b.)



i.

Fig. 4. 24: Apps Control for three input sources with IoT Device

Fig. 4.25 shows the graphical view of the consumption and generated energy on PC screen and applications. This documents the monthly historical trends of the power produced and consumed.

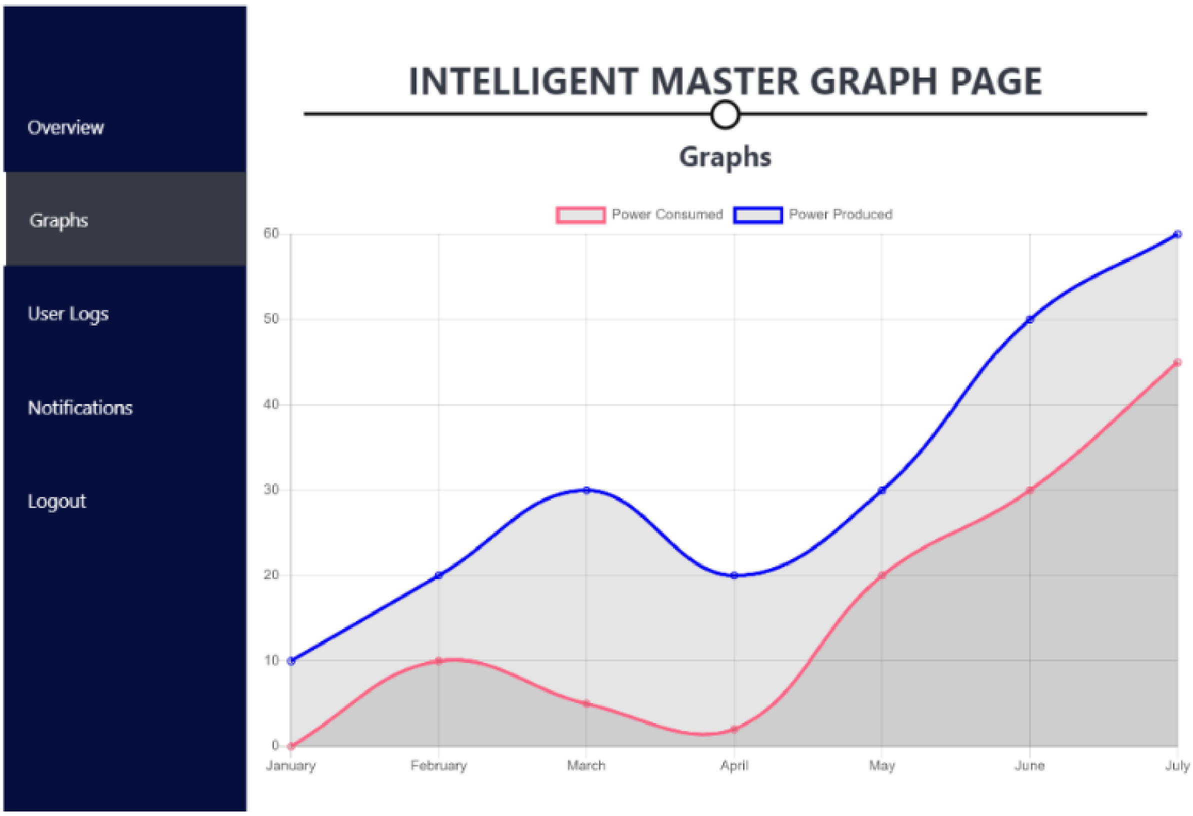


Fig. 4.25: Graphical View of the consumption and Generated energy on PC screen

4.3.2 Results and discussions for sequence of operation design with priority relay logic for three input at default operations.

Fig 4.26 and Table 4.7 shows the simulation result of the relay logic control state for the three input from grid, renewable and generator. This design set up the priority scheme for the intelligent master controller operations. The grid supply is designed as the default state and is connected in a normally close (NC) format. Group A relay with 2 designated relays, RL3 & RL4 with pins labeled a,b,c & d; where b & d are for grid configuration and a & c are for the renewable energy configuration. The renewable energy source is connected in a normally open (NO) format. The output of Group A relay is connected to the NC format in Group B relays RL5 & RL6 labelled e,f,g & h, with pin f & h the output from Group A relay which are b & d. Generator source is connected to the NO contact of Group B relay which are e & g terminals. The energized terminals for Group A relay were designed to be low their defaults state likewise Group B relays.

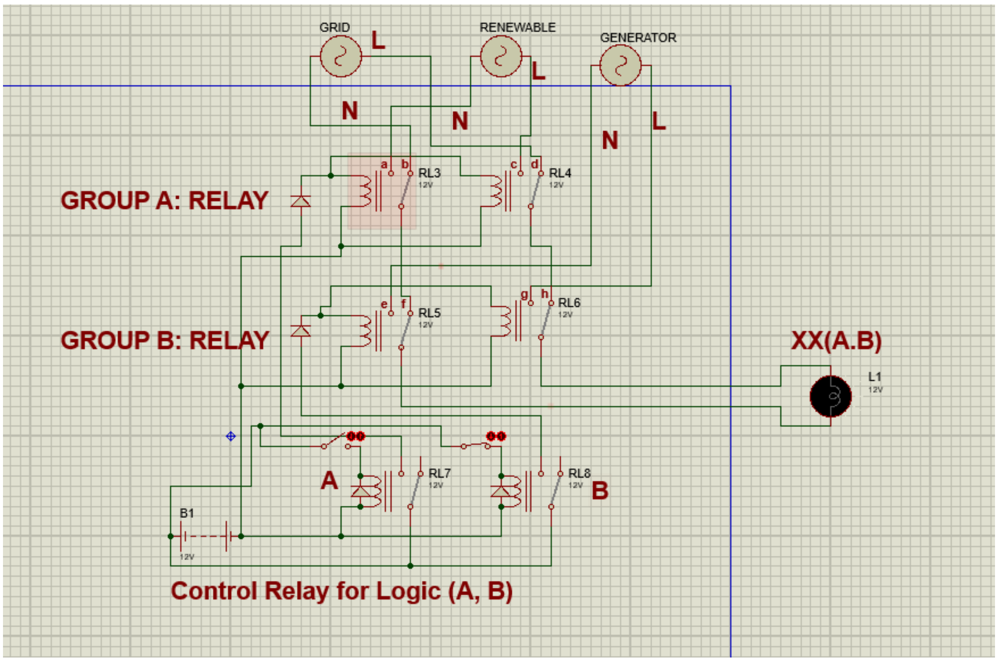


Fig. 4.26: Priority Relay Logic Control for the three input operations.

This result in Table 4.7 shows that the grid supply system is at its default ON state. There are two control designated relays, A(RL7) and B(RL8), such that whenever the energized terminal A is high and deenergized terminal B remains low, the results shows that the renewable energy source is at ON state and high. Whenever the energized terminals of B are high, the result in the generator source is at ON state. This configuration provides the priority scheme for the developed intelligent master controller.

Table 4.7: Simulation Result for the Priority Relay Logic State of the Intelligent Master Controller

	A	**B**	**(State) XX**
0	0	0	GRID
1	0	1	GEN
2	1	0	REN
3	1	1	GEN

The prioritize of the grid energy supply over the renewables even when the latter is the almost free resource, is in consideration of the load capacities available in the five communities as at when needed. Although it would have reduces the high cost of bill from the pay as you consumed grid power supply. The renewables supply was incorporated to support the system as an alternative source. The renewables would have been prioritizing instead as alternatives but for load demand's sake.

4.3.3 Result for sequence of operation design with Multiple Automated Generator Starting System.

From section 3.2.3: F and Fig. 3.19 and Fig. 3.20, the grid and renewable energy power supply are the primary sources of power to the five communities as integrated. Whenever there is power failure from both sources, the system delays for 10 seconds to see if power would be restored. If power is not restored after the delay time, the microcontroller provides signal to turn ON the generator which serves as the auxiliary power source. However, when either of the grid or the renewable energy supply are restored, the system also delays for 10 seconds to see if the power has been restored properly, if power has not been restored effectively, the generator is left **ON** and keeps powering the communities but if the supply is steady, the microcontroller sends information to turn **OFF** the generator and the power supply to the communities' load is automatically switched from the generator back to the public power supply.The switching OFF for the generators are one after the other in 5sec sequence.

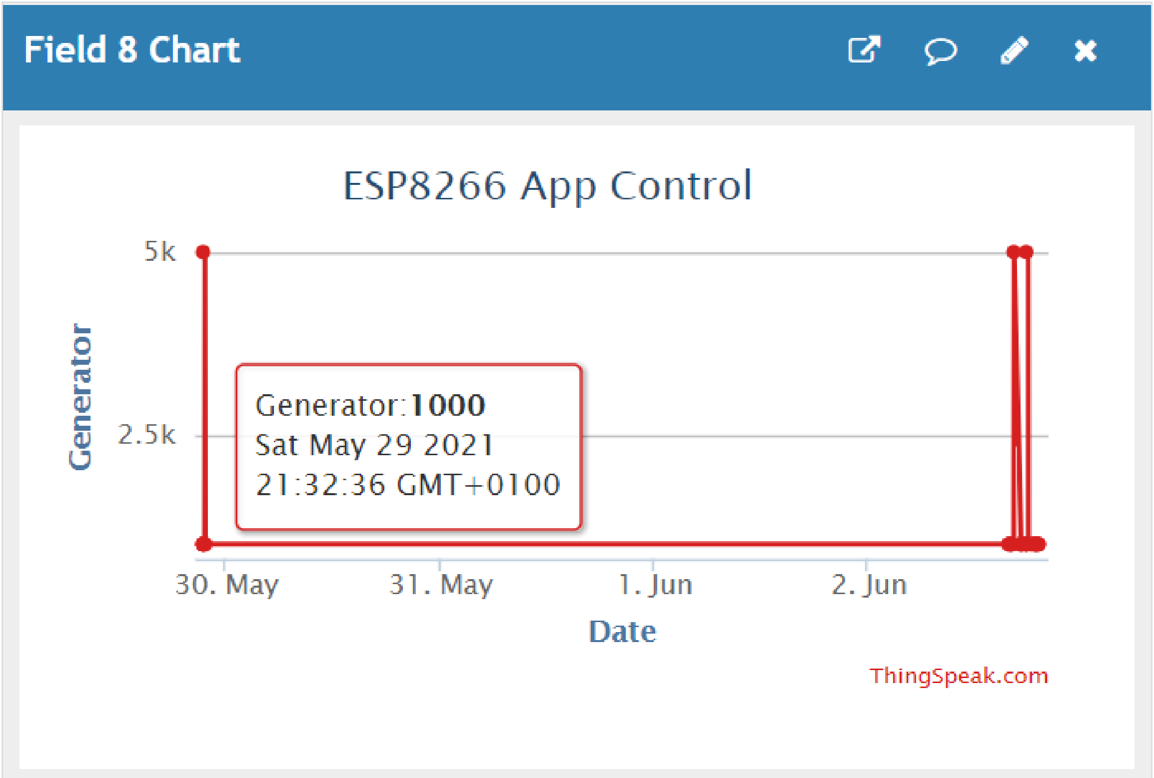


Fig. 4.27: Graph to show generator starter system communication with main circuit

At each operation, the voltage level of the power supply and consumed energy are documented in cloud and displayed on the liquid crystal screen. This is achieved using NRF Modules wirelessly.

4.3.4 Results and discussions of the Hardware Implementation, Data Acquisition and Analysis

Table 4.8 presents the results from Fig. 3.14, 3.15, 3.16, 3.17 and 3.18 corresponding to Section 3.2.3: A to 3.2.3: E shows the various design approach applied to realize the design, ranging from circuit diagram, flow chart and feedback design. The following associated tools were used to actualize the hardware of the intelligent master controller system: panels, frames, switches, relays, push buttons, lights, display and metering devices. The panels and frames formed the design casing for the developed system whereas switches, push buttons and relays were designed to switch **ON/OFF** the energy generated from Afikpo, Amasiri, Enohia, Oziza and Unwana line respectively done automatically. For the incorporated grid, renewable and generating set energy sources, the master controller scans through the three-energy supply platform and pay premium to the grid source first. Second priority is given to the renewable energy resources after the priority scan has revealed the absence of power in the grid energy source. But on account of the absence of both grid and renewable energy input, the intelligent master controller switches the generating set **ON** to keep the co-located community energized. Programme code from the slave via the master controller interaction, facilitates the power pool system control. The metering devices display the individual energy pooled by each contributor in term of voltage, current and power. In each of the activities, the soft touch human machine interface screen displays the action for the operator to see. In case of any unit malfunctioning, there is an alarm, but after 5sec if the operator pays no attention to the system behaviour, the system will automatically initiate an emergency shut down action. When each of the energy sources connects to the pool system, the generated power is indicated in the metering system.

Table 4.8: Hardware Implementation Data Acquired from ThingSpeak on real time

Data Creation Dates	Entry_ ID	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8
2021-05-11 18:57:36	1	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-11 18:58:08	2	5000	5000	5000	5000	5000	5000	1000	1000
2021-05-12 08:54:52	3	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-12 08:55:23	4	5000	5000	5000	5000	5000	5000	1000	1000
2021-05-12 09:14:42	5	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-12 09:19:34	6	5000	5000	5000	5000	5000	5000	1000	1000
2021-05-12 09:22:23	7	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-12 09:22:41	8	5000	5000	5000	5000	5000	5000	1000	1000
2021-05-12 09:25:14	9	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-12 12:03:24	10	5000	5000	5000	5000	5000	5000	5000	5000
2021-05-12 12:33:04	11	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-12 12:45:51	12	5000	5000	5000	5000	5000	5000	5000	5000
2021-05-12 12:46:49	13	5000	5000	5000	5000	5000	5000	5000	5000
2021-05-12 12:47:34	14	1000	1000	1000	1000	1000	1000	1000	1000
2021-05-12 18:16:50	15	5000	5000	5000	5000	5000	5000	5000	5000
2021-05-12 18:17:32	16	1000	1000	1000	1000	1000	1000	1000	1000

Fig. 4.28 and Table 4.8 shows hardware implementation data acquired from ThingSpeak on real time within 16 sampling time and shows the number of times the system was tested ON and OFF sequence of operation from Fig. 4.28 and Table 4.8.

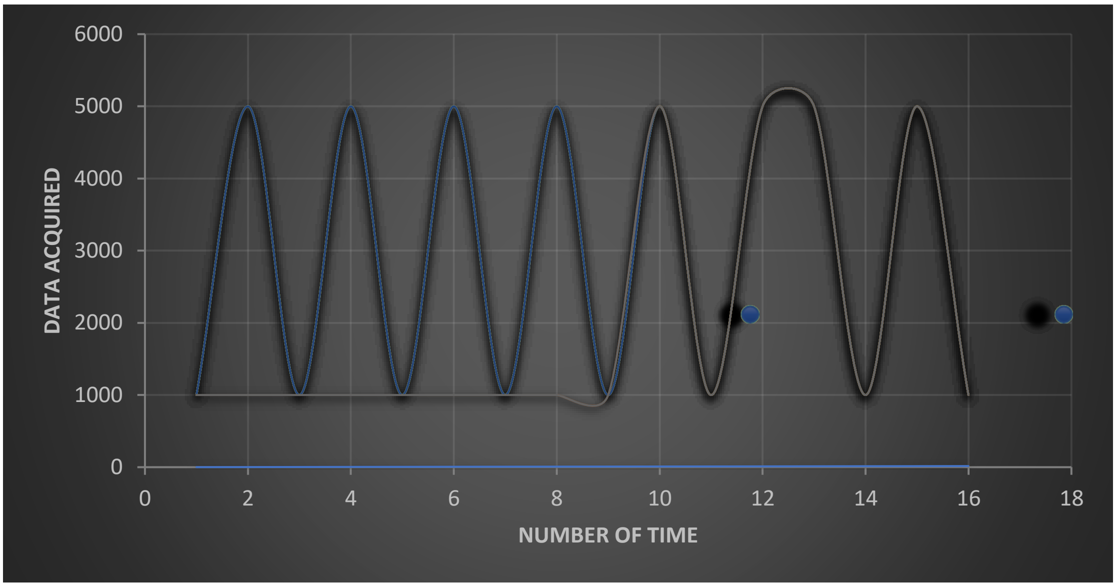


Fig. 4.28: Real Time Data Acquired from ThingSpeak

4.4 Result and discussion for the performance validation test on different system conditions

4.4.1 Result on the hardware performance validation test with three inputs from same power supply source

This is where the overall tests were carried out with the software and hardware separately and concurrently with varying loads at different system conditions. For the software test; Proteus schematic environment has virtual measuring instruments such as voltmeters, ammeters and oscilloscope and the design test were validated using this virtual instrument. The validation test was also carried out on the master PC and operator's android app via the design hardware. At the same time the slave controllers were also enabled and all the operation simultaneously observed.

Performance validation test for the hardware, software and IoT system were carried out in 6 (six) hours within the three-input power supply and the 5(five) experimented communities powered. The data was analyzed with MATLAB in real time through ThingSpeak platform. The ThingSpeak analytical tools validates the system design performance by providing the system function trend (graph) of voltage and current. Changes from one source to the other were displayed in real time basis.

Table 4.9: Performance Validation Test

	Communities	**Voltage (V)**	**Current (A)**	**Power (W)**
1.	Afikpo Load Line	220	0.909	200
2.	Amaziri Load Line	220	0.682	150
3.	Enohia Load Line	220	0.455	100
4.	Oziza Load Line	220	0.182	40
5.	Unwana Load Line	220	0.273	60

From Table 4.9 and Fig. 4.29, 220V AC was introduced to represent the three energy sources, and validation test was carried out on hardware design at various power values; 200W, 150W, 100W, 40W and 60W. The integrated system output current varies from the metering unit as 0.909A, 0.682A, 0.455A, 0.182A and 0.273A, respectively. The level of the system performance was ascertained, before the hardware test, the software-based test was conducted.

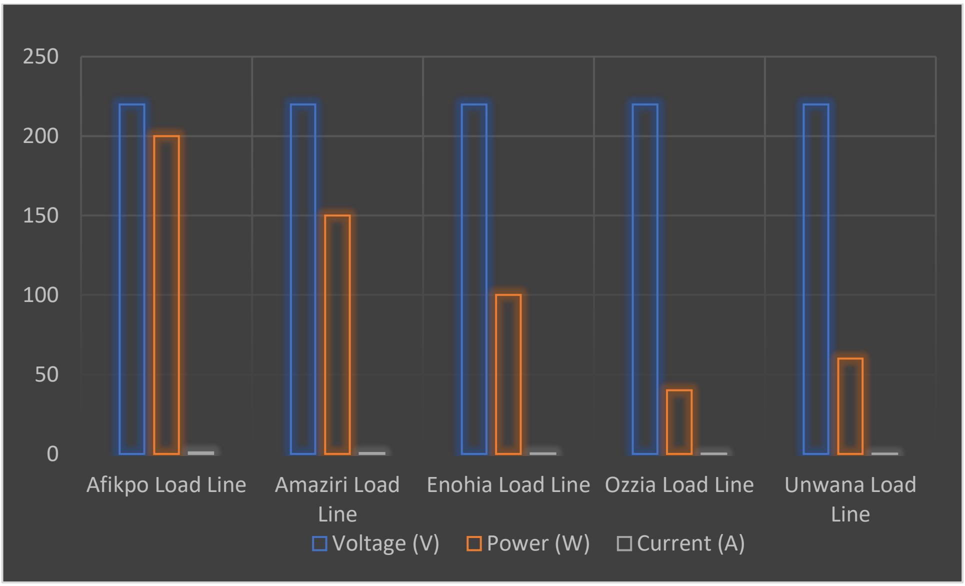
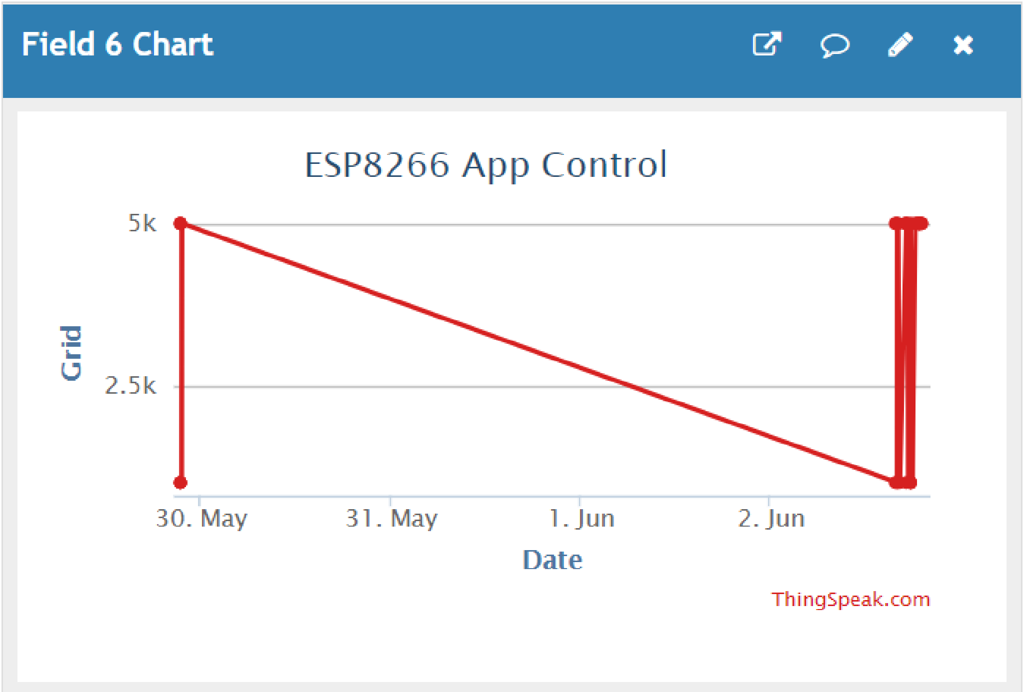


Fig. 4.29: Graph of Power, Voltage and Current

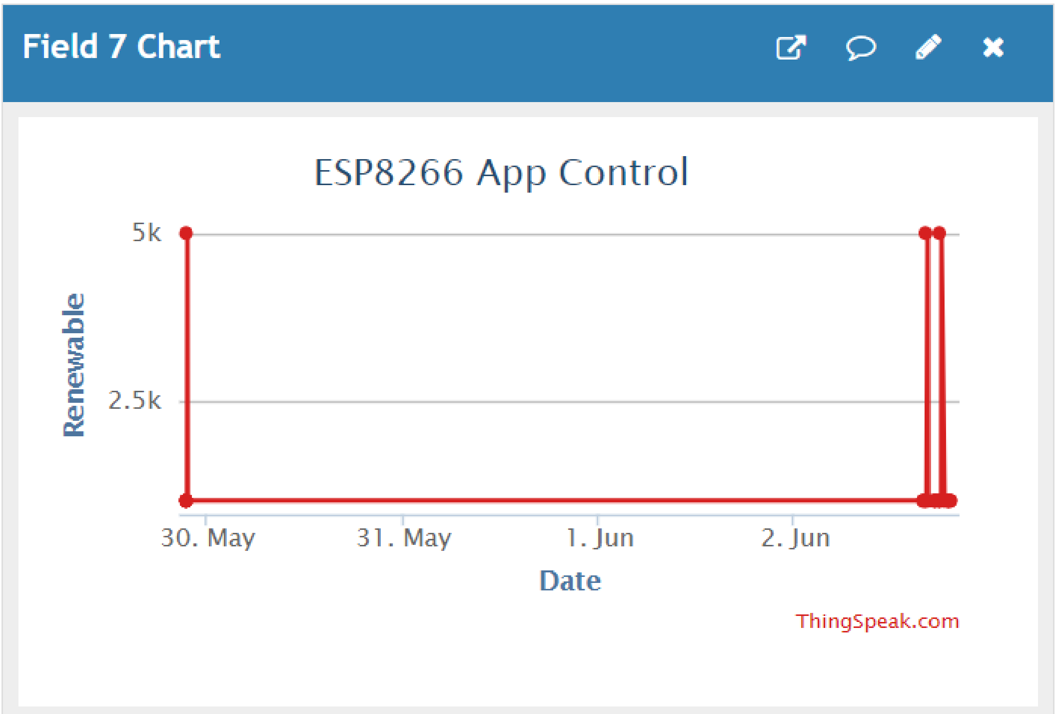
The validation test carried out on the master PC via the design hardware. At the same time, the slave controllers were also enabled to observe their performance and all the operation simultaneously validated.

4.4.2 Results and discussions on the Hardware Performance Validation Test with Three input from different power supply source at the same voltage level

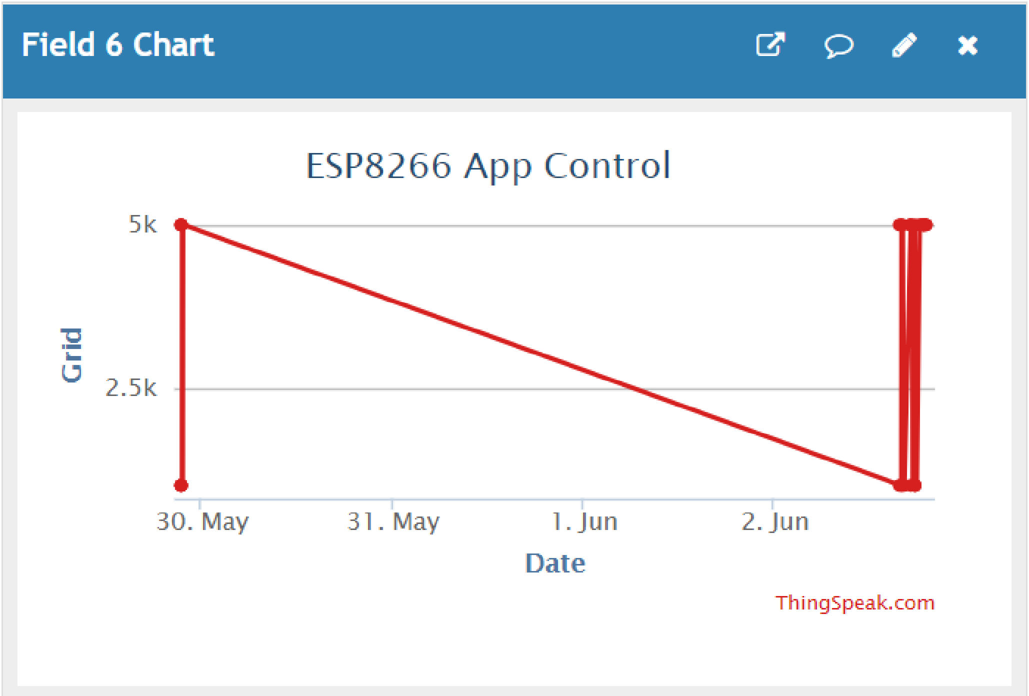
From fig.4.30, three input from different power supply source (public, renewable and generator) with same voltage level were connected and tested simultaneously. The result gives the same voltage level of 5000 representing HIGH or ON (1) and 1000 representing LOW or OFF (0) respectively.


Field 6 Chart
ESP8266 App Control
5k
2.5k
Grid
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(a.)


Field 7 Chart
ESP8266 App Control
5k
2.5k
Renewable
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(b.)

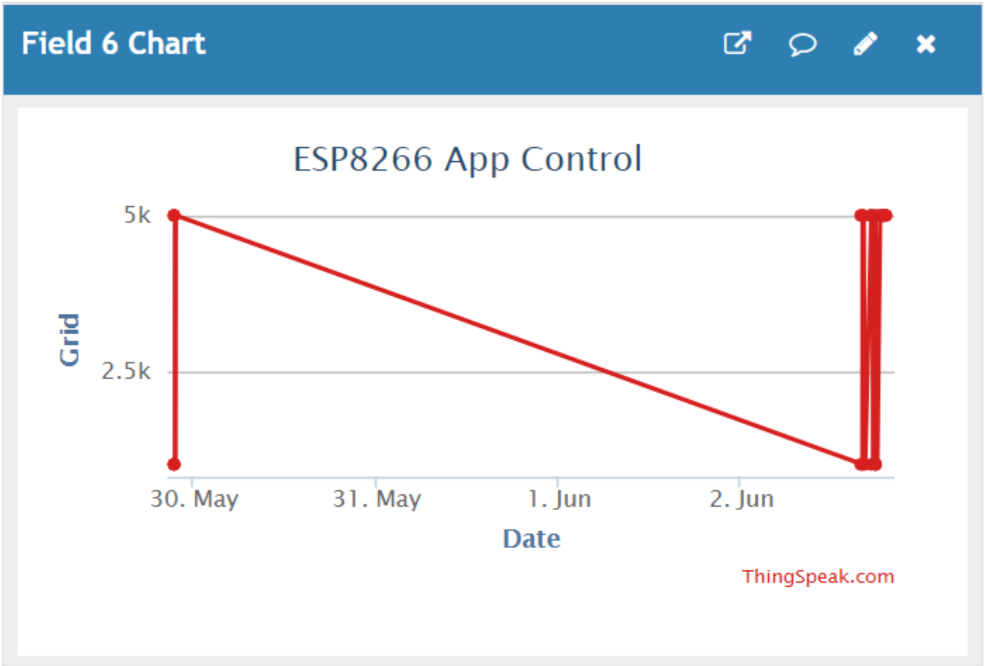


(c.)

Fig. 4.30: Hardware Performance Validation Test with Three input from difference power supply source at same voltage level

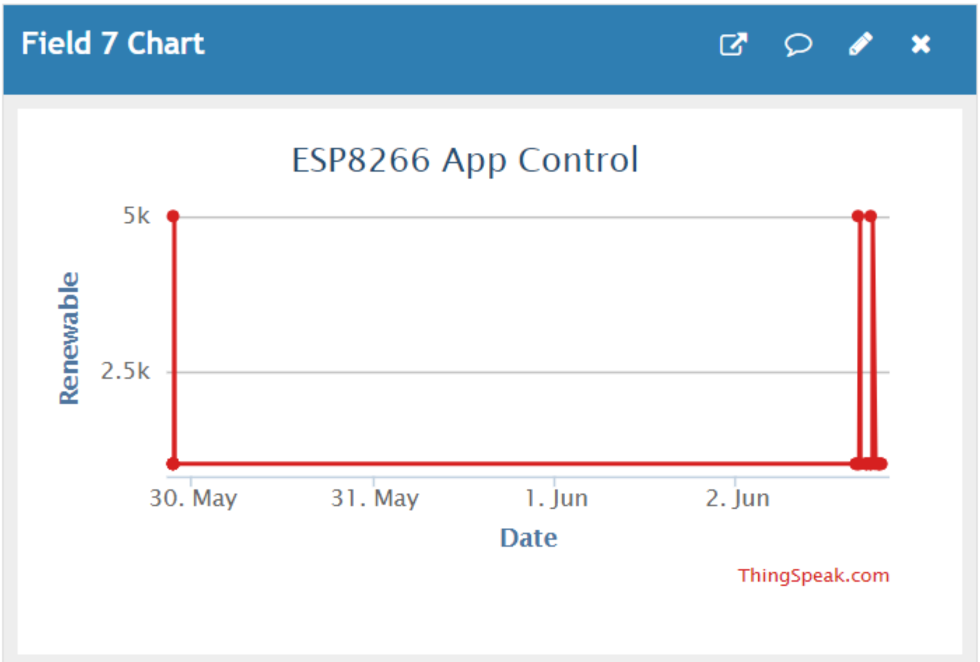
4.4.3 Results and discussions on the hardware performance validation test with three input from different power supply source and difference voltage level

From Fig.4.31. three input from different power supply sources (public, renewable and generator) with different voltage level were connected and tested simultaneously. The result gives the same voltage level of 5000 representing HIGH or ON (1) and 1000 representing LOW or OFF (0), respectively.



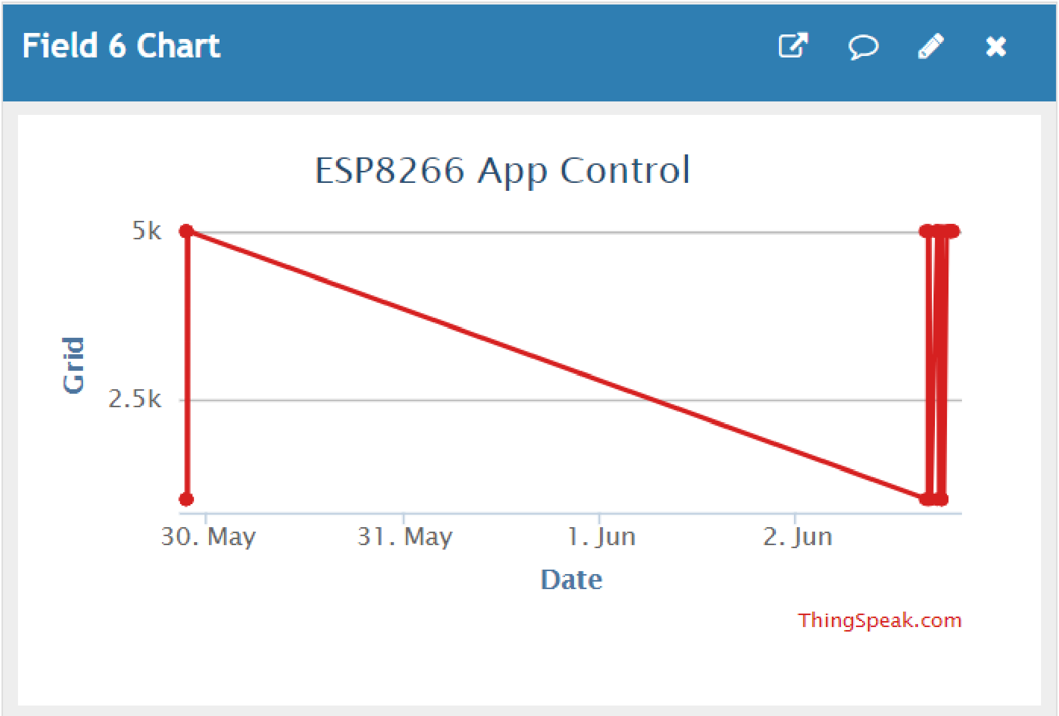
Field 6 Chart
ESP8266 App Control
5k
2.5k
Grid
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(a.)



Field 7 Chart
ESP8266 App Control
5k
2.5k
Renewable
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(b.)

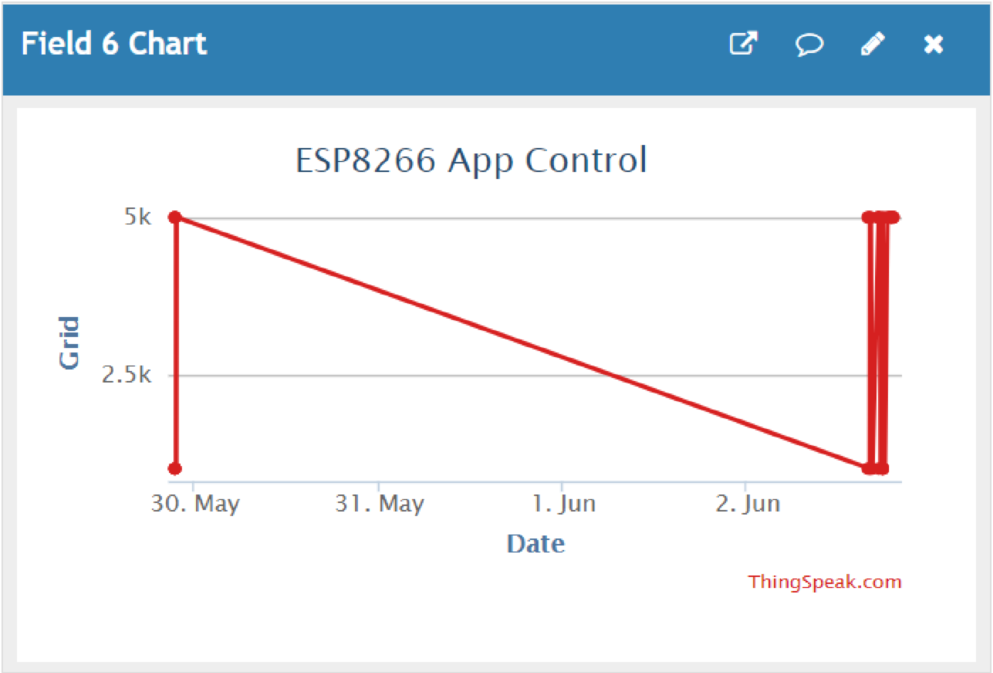


(C.)

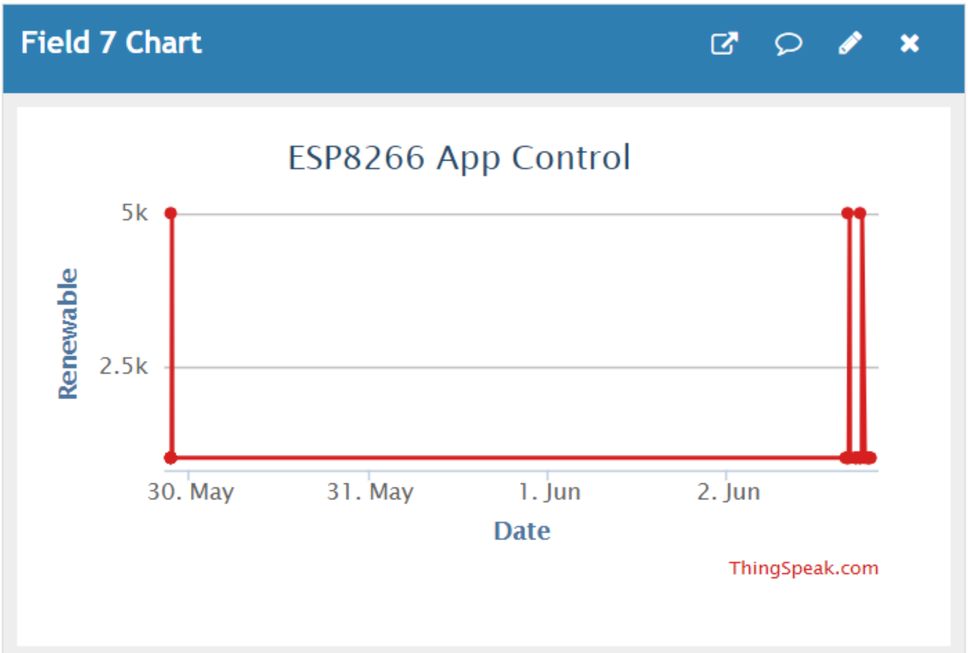
Fig. 4.31: Performance Validation Test with Three input from difference power supply sour3ce and difference voltage level

4.4.4 Results and discussions on the hardware performance validation test having three inputs from different power supply sources with voltage level below the threshold introduced

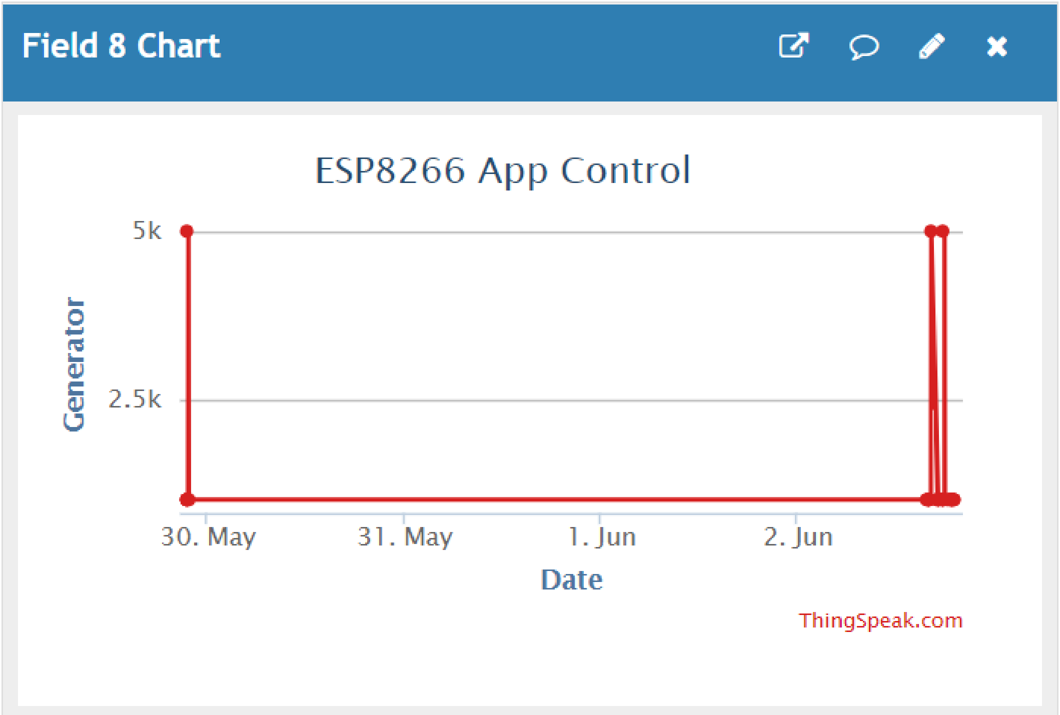
From Fig.4.32. three inputs from different power supply sources (public, renewable and generator) with voltage level set to 200V AC were connected and tested simultaneously. The result gives the same voltage level of 5000 representing HIGH or ON (1) and 1000 representing LOW or OFF (0), respectively.


Field 6 Chart
ESP8266 App Control
5k
2.5k
Grid
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(a.)


Field 7 Chart
ESP8266 App Control
5k
2.5k
Renewable
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(b.)

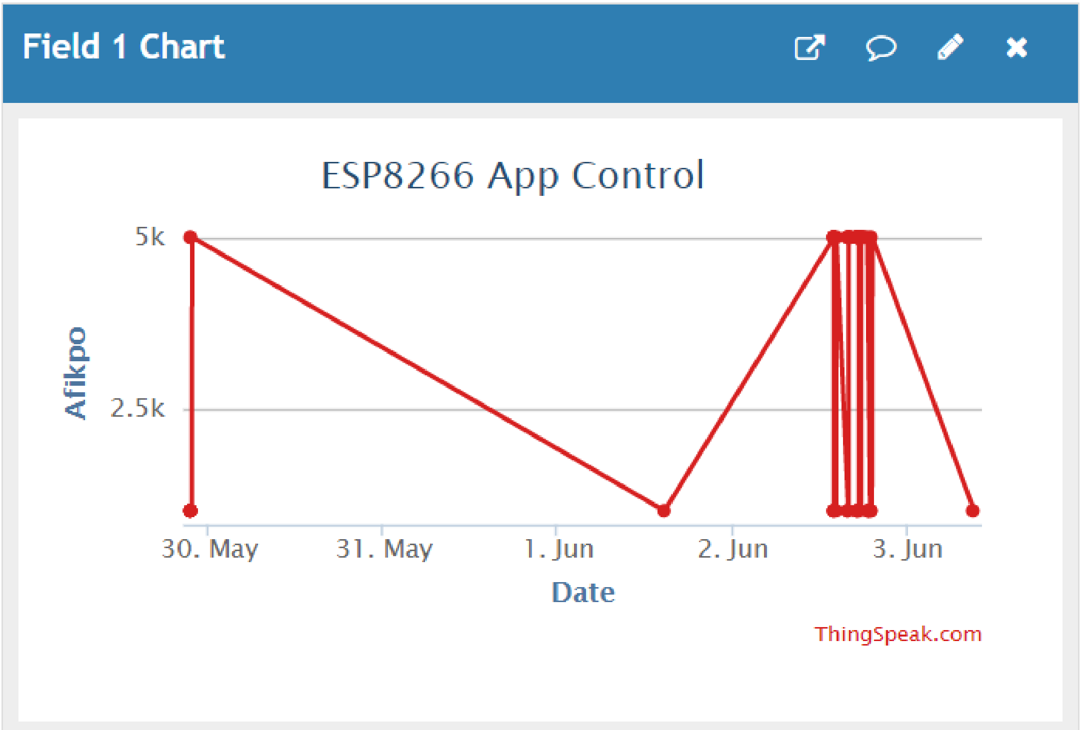


(C.)

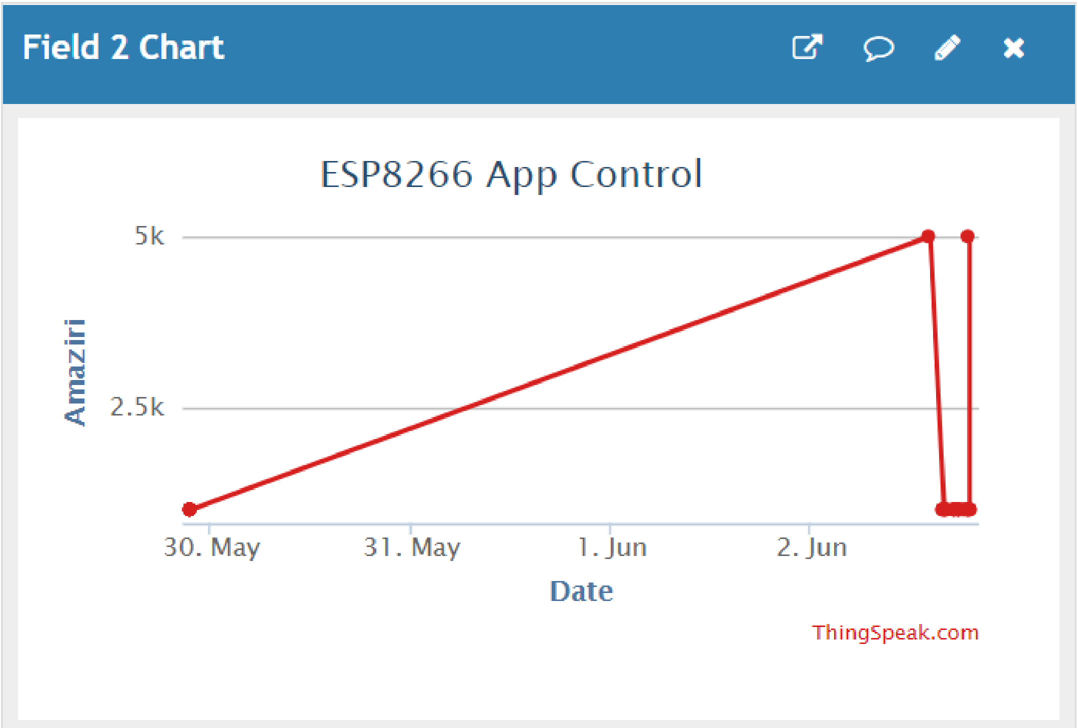
Fig. 4.32 Performance Validation Test having three inputs from difference power supply source with level below the threshold

4.4.5 Result and discussions on performance validation test for the five communities with any available power supply source

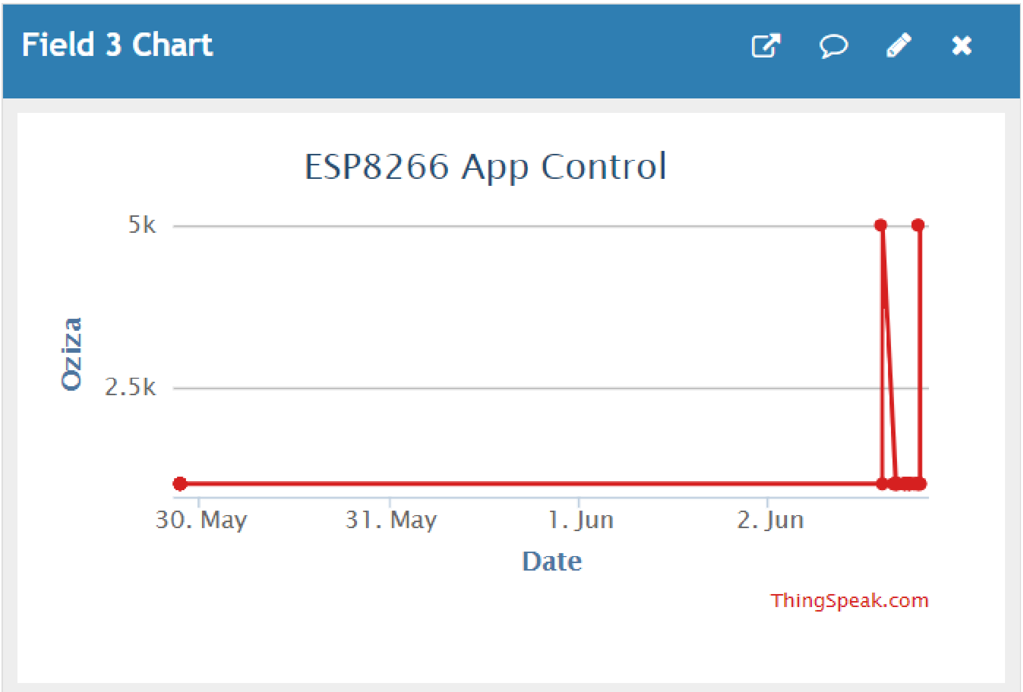
From Fig.4.33, five communities were powered from any of the available sources (public, renewable and generator) with any available voltage level connected and tested simultaneously. The result gives the same voltage level of 5000 representing HIGH or ON (1) and 1000 representing LOW or OFF (0) respectively. This is in validation of the design digital concept of zeros (0) and one (1) for a ON/OFF state.


Field 1 Chart
ESP8266 App Control
5k
2.5k
Afikpo
30. May
31. May
1. Jun
2. Jun
3. Jun
Date
ThingSpeak.com

(a.)

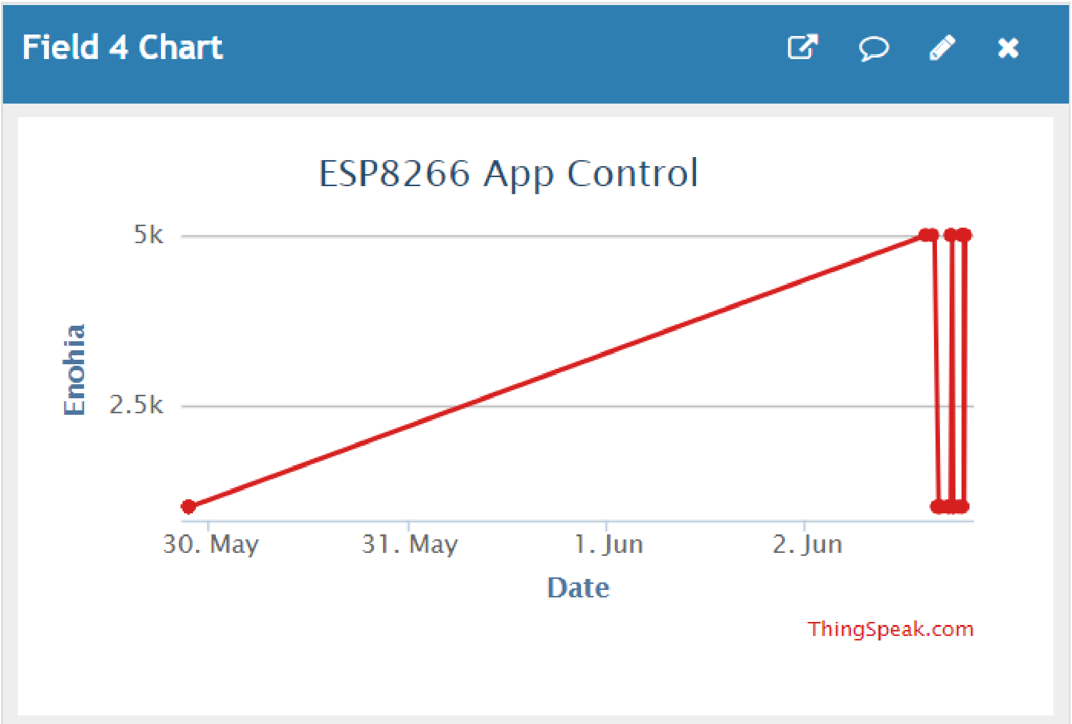

Field 2 Chart
ESP8266 App Control
5k
2.5k
Amaziri
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(b.)



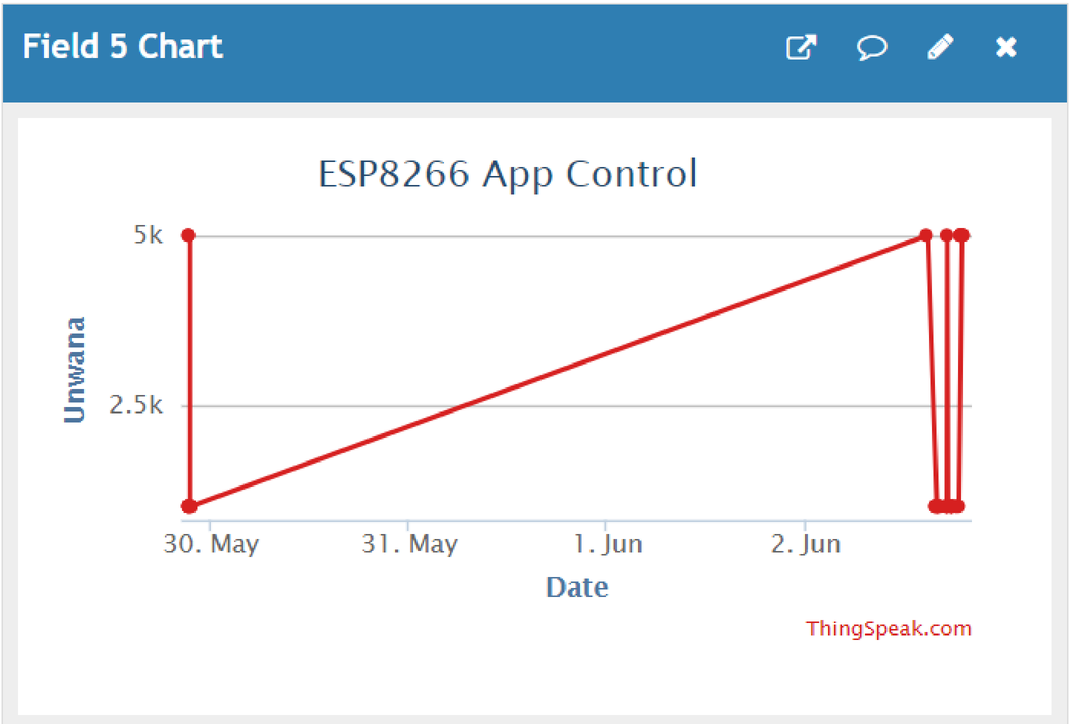
Field 3 Chart
ESP8266 App Control
5k
2.5k
Oziza
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(c.)



Field 4 Chart
ESP8266 App Control
5k
2.5k
Enohia
30. May
31. May
1. Jun
2. Jun
Date
ThingSpeak.com

(d.)

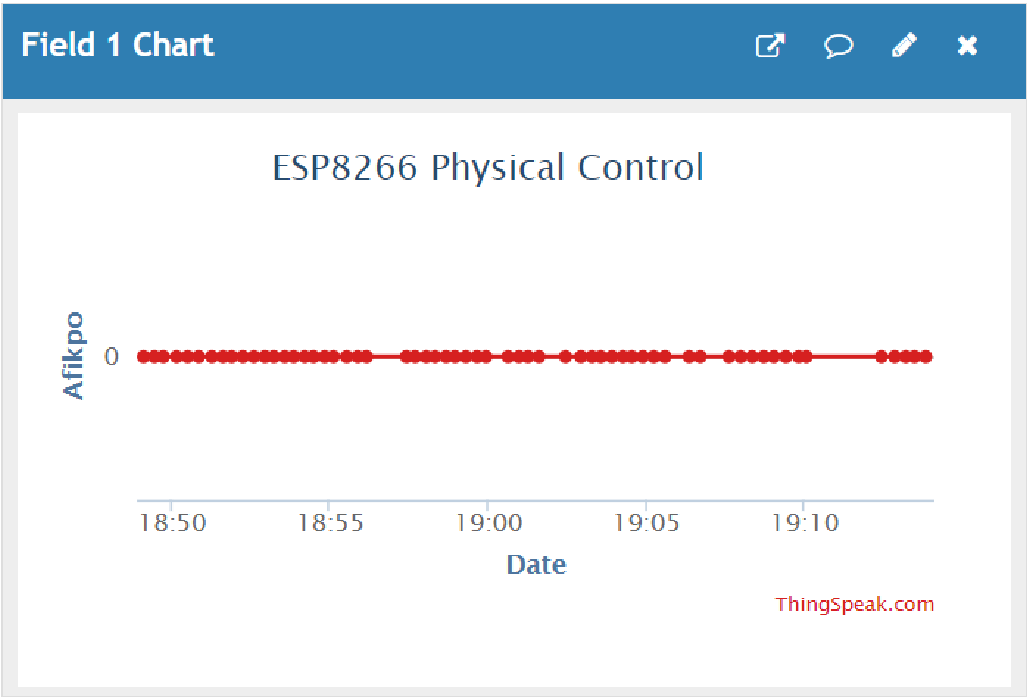


(e.)

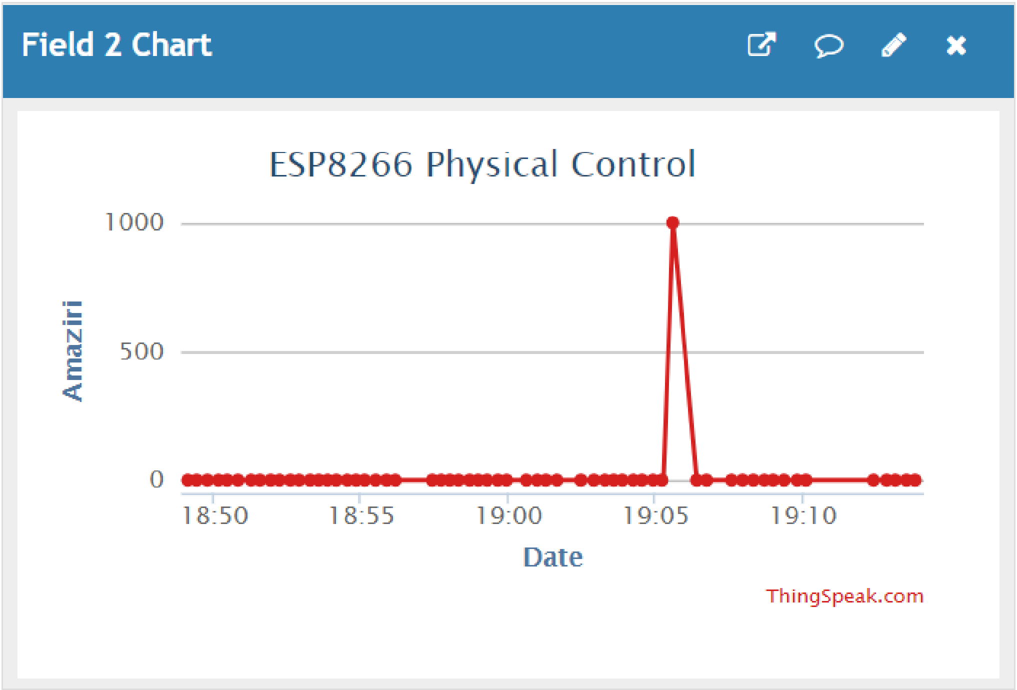
Fig. 4.33 Performance Validation Test for five communities from any available power supply source

4.4.6 Results and discussions on the hardware performance validation test with three inputs from different power supply source at same voltage level (Physical Control)

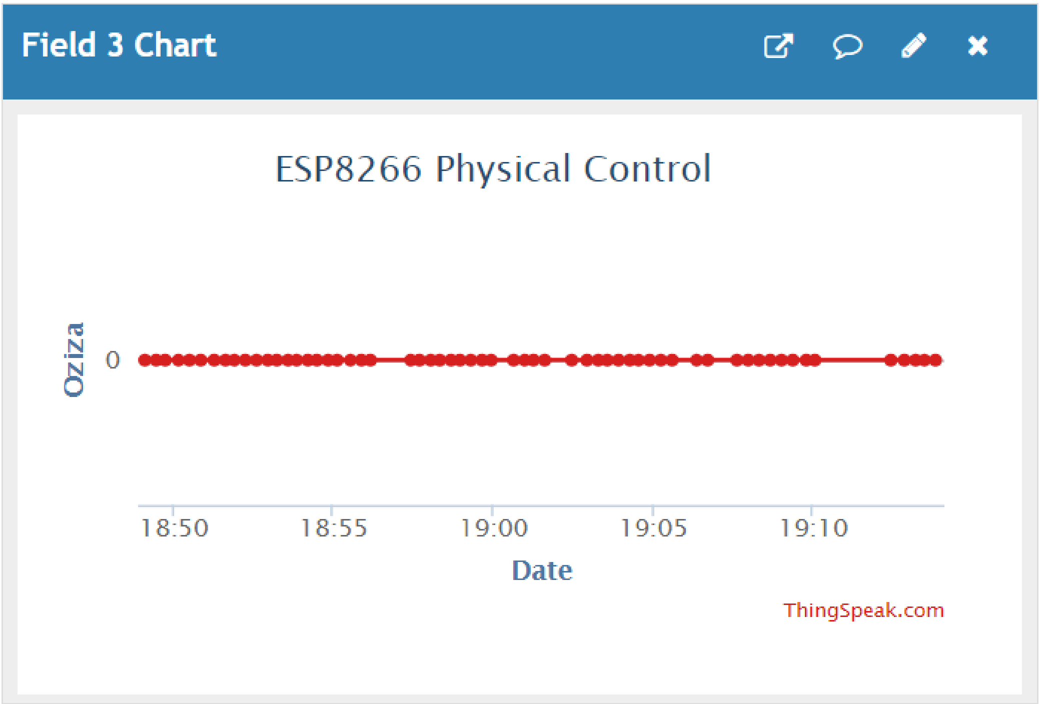
From Fig.4.34, whenever there is power in any of the three input (f,g,h) from which (public, renewable and generator) and the hardware is switched ON/OFF, it will be displayed on the physical control platform simultaneously for remote monitoring. Similarly, as the power in any of the three input (f,g,h) are ON/OFF the communities (a,b,c,d and e) gives the corresponding display of 5000 representing HIGH or ON (1) and 1000 representing LOW or OFF (0) respectively.


Field 1 Chart
ESP8266 Physical Control
Afikpo
0
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

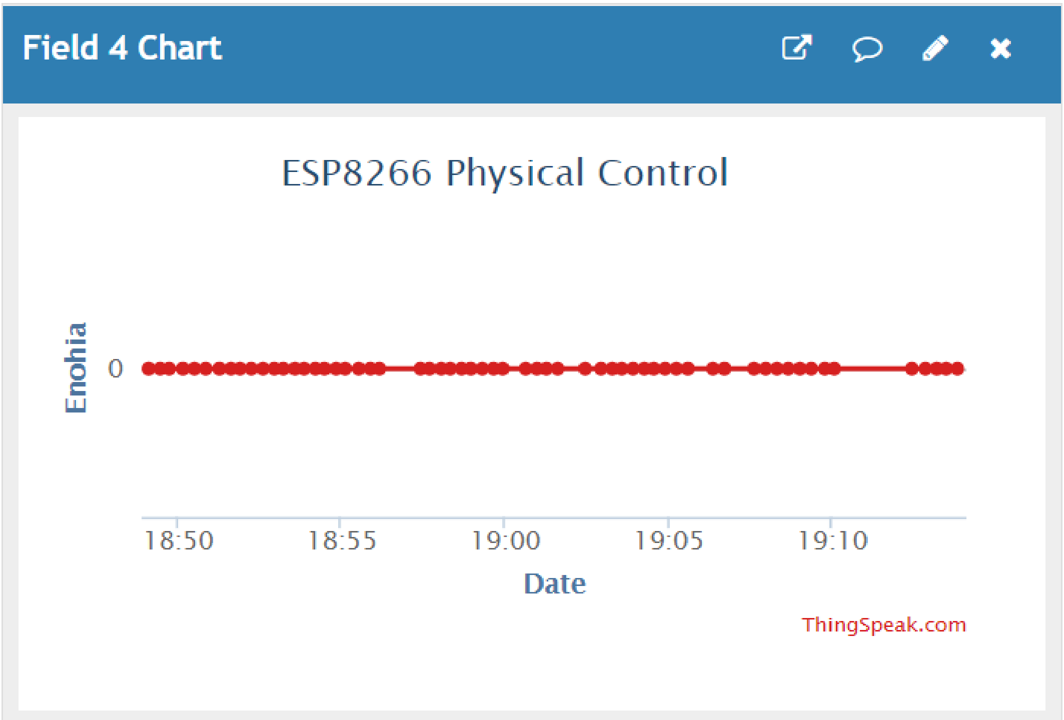
(a.)


Field 2 Chart
ESP8266 Physical Control
1000
500
0
Amaziri
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

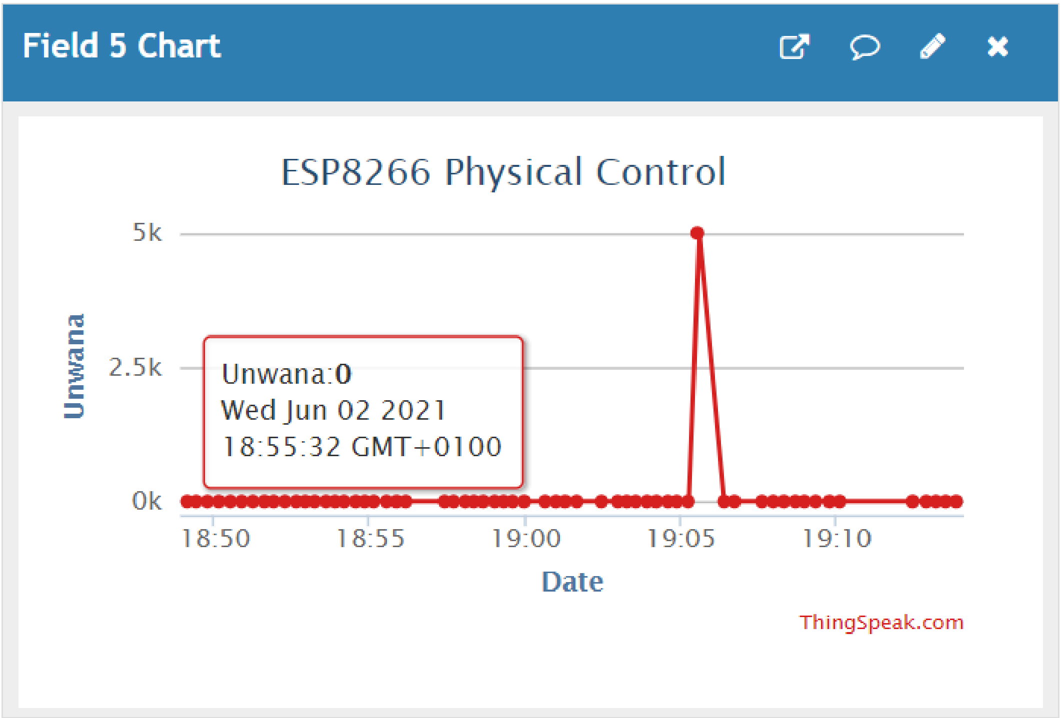
(b.)


Field 3 Chart
ESP8266 Physical Control
Oziza
0
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

(c.)

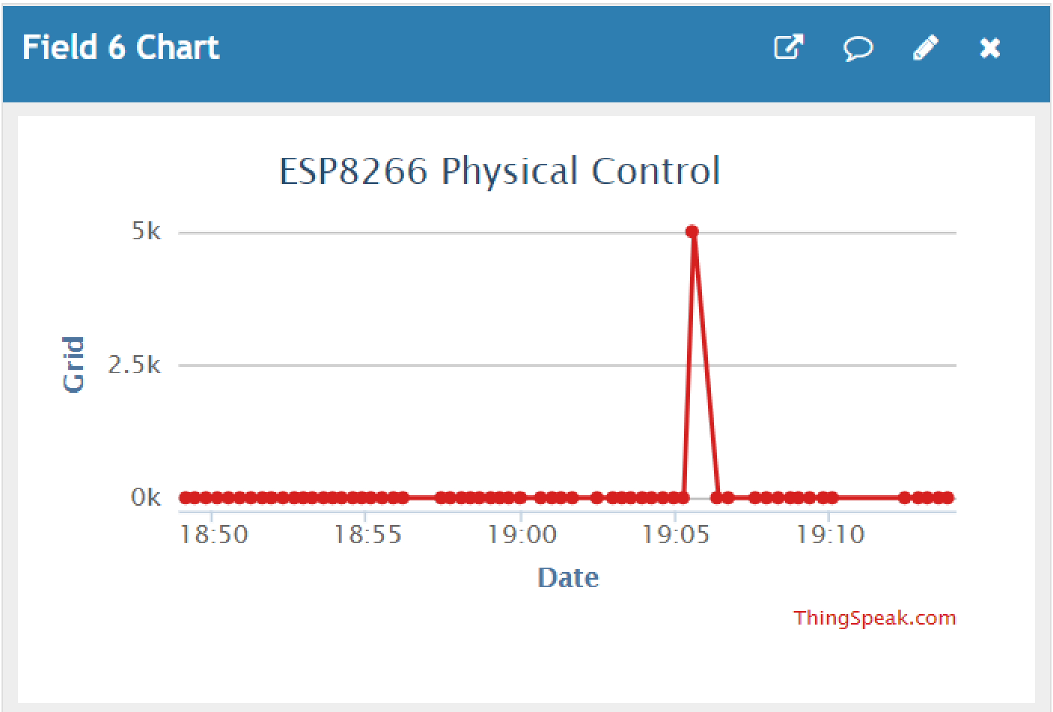

Field 4 Chart
ESP8266 Physical Control
Enohia
0
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

(d.)



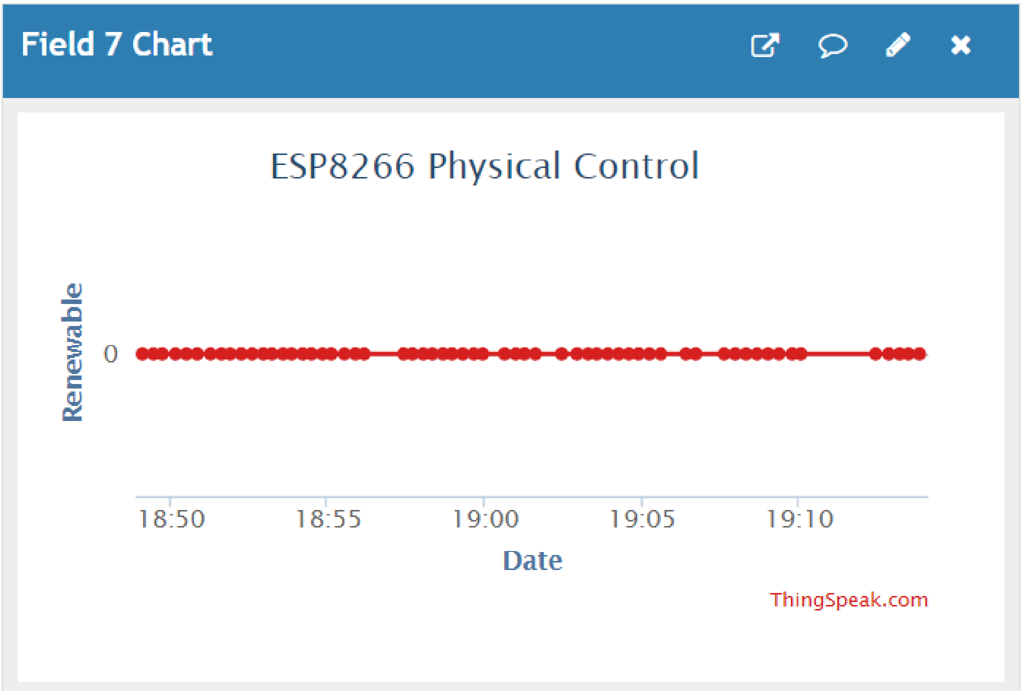
Field 5 Chart
ESP8266 Physical Control
5k
2.5k
0k
Unwana
Unwana:0
Wed Jun 02 2021
18:55:32 GMT+0100
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

(e.)

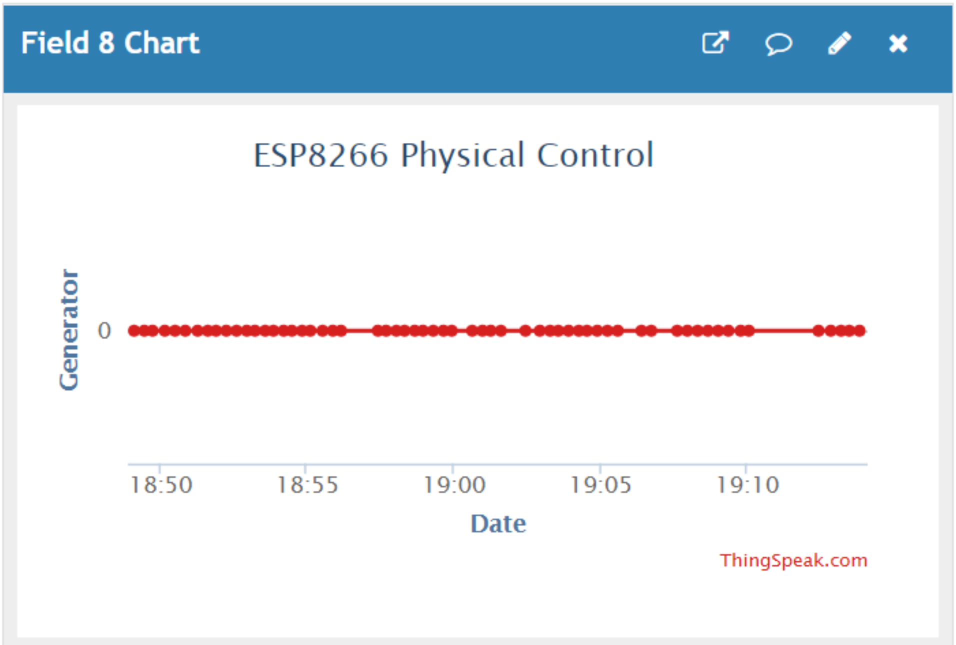


Field 6 Chart
ESP8266 Physical Control
5k
2.5k
0k
Grid
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

(f.)



(g.)

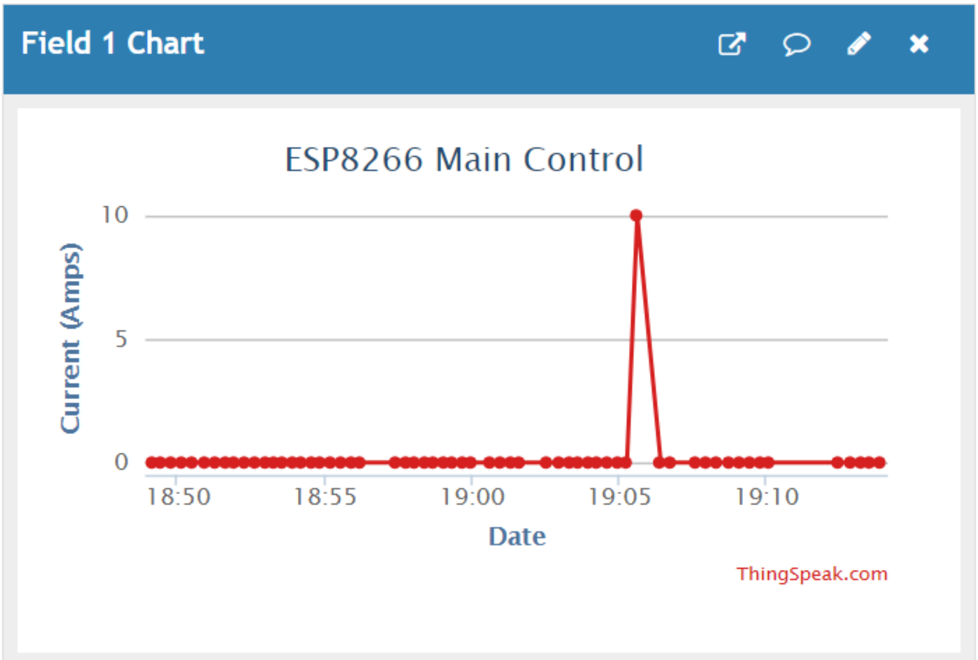


(h.)

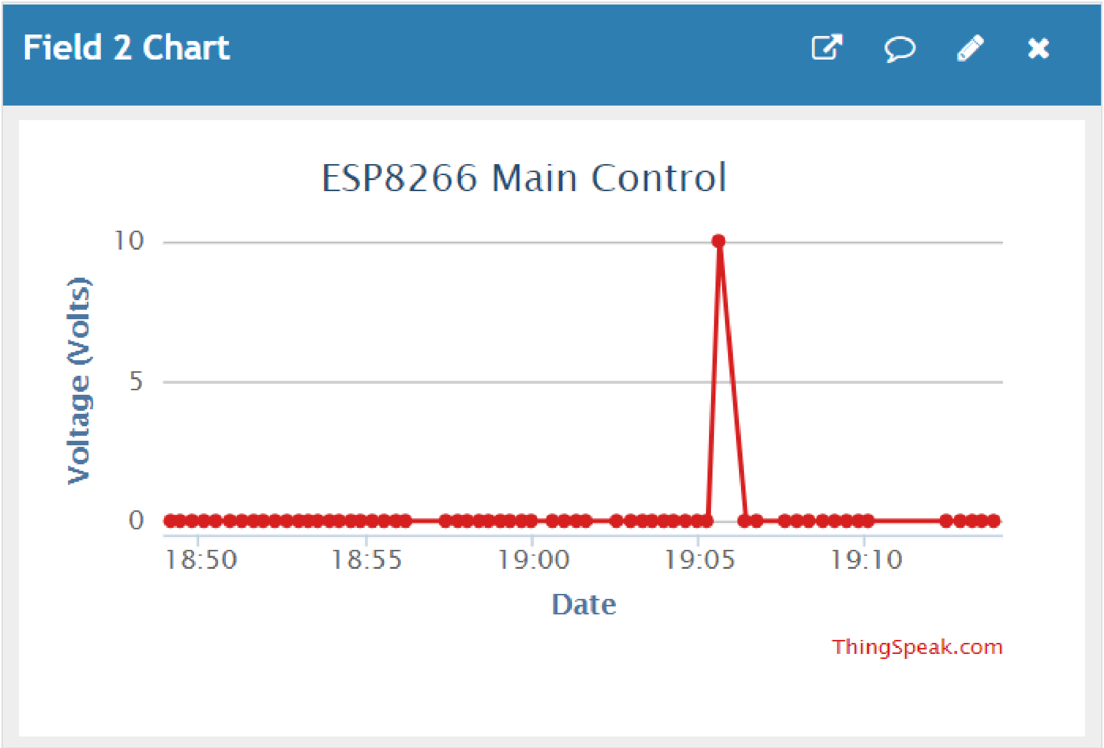
Fig. 4.34: Hardware Performance Validation Test with three inputs for five communities supply (Physical Control)

4.4.7 Results and discussions on the hardware performance validation test with three input from any available power supply source with Master/Main Control operations

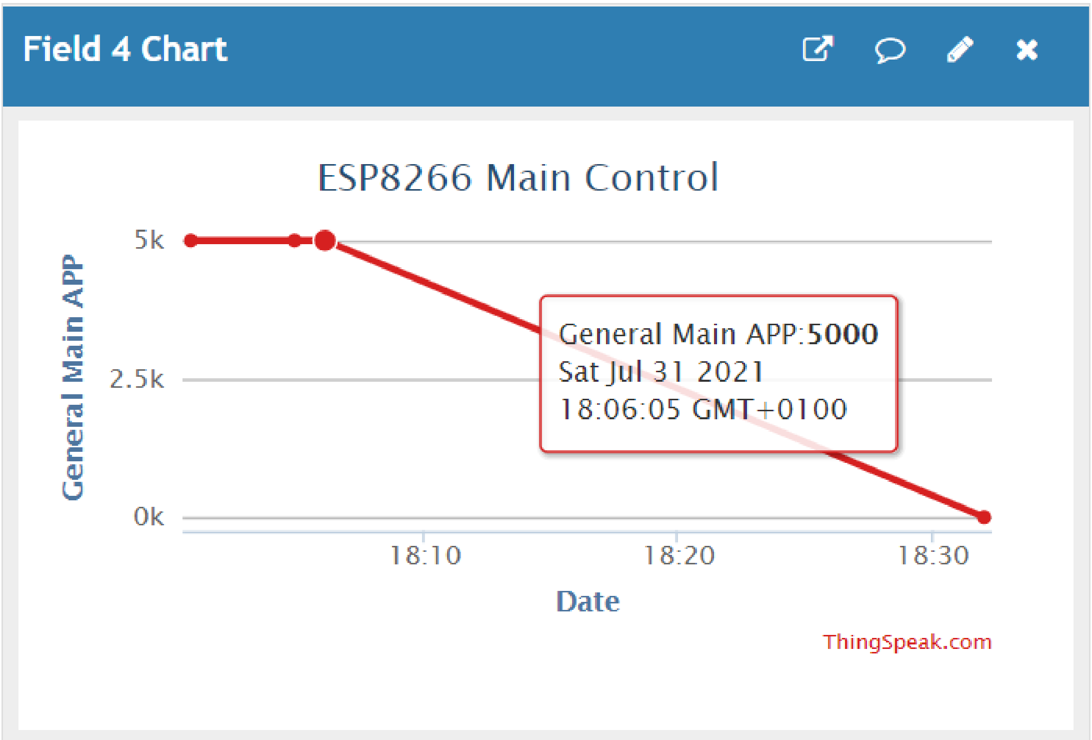
From Fig.4.35, Main control platform with the current and voltage value display (a.) & (b.) as well as the General Main/Master control for both Apps and physical system (c.) & (d.). The available inputs from any power supply source (public, renewable and generator) when controlled/switched remotely is monitored in (c.) & (d.) simultaneously. The current and voltage value during any operation is visible viewed remotely from (a,) & (b.)



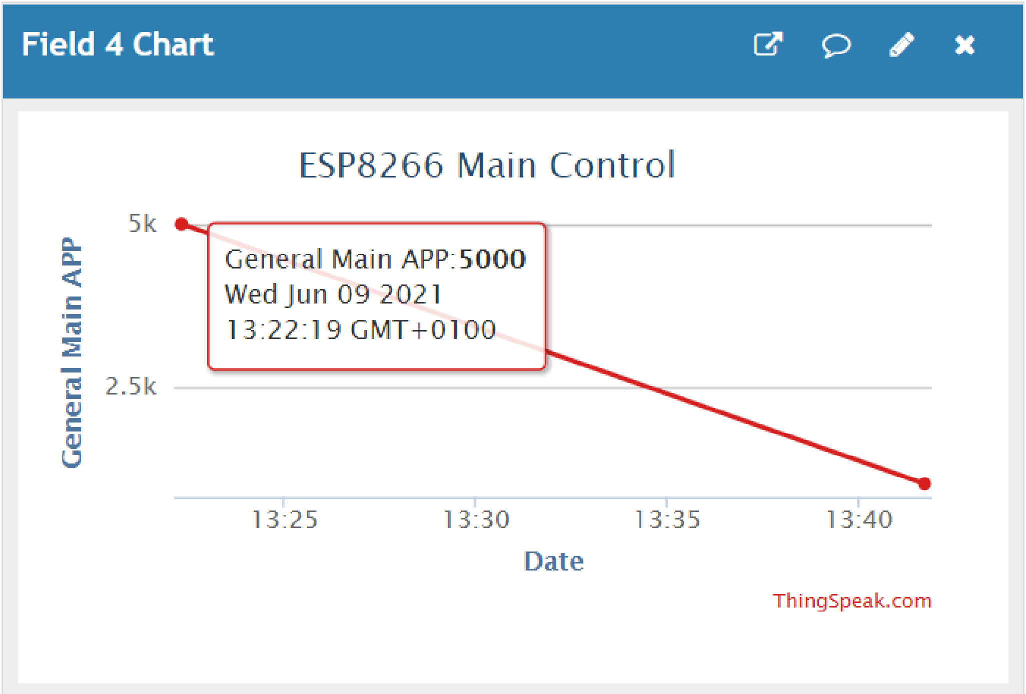
(a.)


Field 2 Chart
ESP8266 Main Control
Voltage (Volts)
10
5
0
18:50
18:55
19:00
19:05
19:10
Date
ThingSpeak.com

(b.)


Field 4 Chart
ESP8266 Main Control
General Main APP
5k
2.5k
0k
General Main APP:5000
Sat Jul 31 2021
18:06:05 GMT+0100
18:10
18:20
18:30
Date
ThingSpeak.com

(c.)



(d.)

Fig. 4.35: Hardware Performance Validation Test with input from any difference power supply source for Main/Master Control operations

4.5 Result and discussion of System Control Stability Model and Cost Benefit Report

4.5.1 Result and discussion of the Intelligent Master Controller Control System Model

(a.) Transfer function and characteristic equation for the model

The transfer function model stated in equation (3.7), was deduced from a closed loop feedback control model for intelligent master controller as given in Fig.3.22 & Fig. 3.23.

$$\frac{Y(s)}{R(s)} = \frac{G_1G_2G_3}{(1+G_1H_1)(1+G_2G_3H_3) - G_1G_2H_3}$$

The equivalent transfer function equation in the s domain with reference to all initial condition parameters inputted resulted to the equation described in equation (3.11) having a characteristic equation of six poles and a zero equation in the second order form.

$$\frac{Y(s)}{R(s)} = \frac{S^2}{2.5S^6 + 6S^5 + 10.5S^4 + 10S^3 + 7.5S^2 + 3S + 1}$$

(b.) Controllability and Observability Test for Intelligent Master Controller using State Space Model

i. ***Controllability***: The system Controllability test was carried out on the intelligent master controller model using MATLAB and the results shows that the develop system was stable. This result in Table 4.10, validates the Controllability Matrix condition in equation 3.12.

Table 4.10: Matrix Array of the Intelligent Master Controller System Controllability

```
Controllable Matrix is Co =
         0         0         0         0         0    1.0000
         0         0         0         0    1.0000   -2.4000
         0         0         0    1.0000   -2.4000    1.5600
         0         0    1.0000   -2.4000    1.5600    2.3360
         0    1.0000   -2.4000    1.5600    2.3360   -5.5584
    1.0000   -2.4000    1.5600    2.3360   -5.5584    3.2890

Given System is Controllable.
```

ii. ***Observability***: The system observability test was carried out on the intelligent master controller model using MATLAB and the results shows that the develop system was observable. This result in Table 4.11 validates the observability Matrix condition in equation 3.13.

Table 4.11: Matrix Array of the Intelligent Master Controller System Observability

```
Observable Matrix is Ob =
     1     0     0     0     0     0
     0     1     0     0     0     0
     0     0     1     0     0     0
     0     0     0     1     0     0
     0     0     0     0     1     0
     0     0     0     0     0     1

Given System is Observable.
```

(c.) Intelligent Master Controller Step Unit Response

The unit step input response model in equation 3.14 presents the transient, steady state and disturbance status of the intelligent master controller. Fig.4.36 shows the output step response for a higher order system model, which is the time domain performance characteristic of the intelligent master controller model. The following parameters were deduced from the response, settling time of 29.5s, rise time of 0s, peak overshoot of infinite value at a time 6.91s, peak amplitude of -0.213 and a final steady state time of 0s. The stated data as collated from the figure 4.36, indicates the property of the system model to attain a settling time due to a delay in the transient response of the system. In conformity with the condition of critical dampness, the system roots.

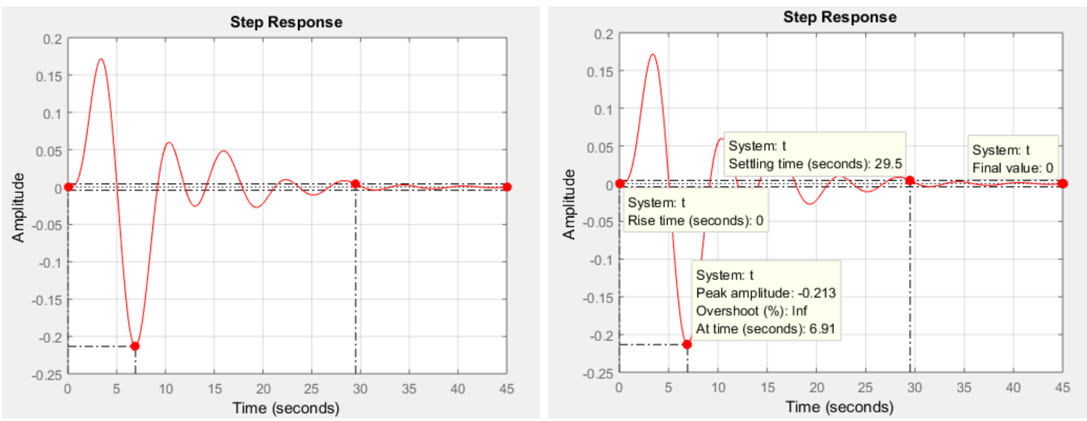


Fig. 4.36: Intelligent Master Controller Unit Step Response

(d.) Intelligent Master Control Stability Result

The denominator from the transfer function is the higher order polynomial as its characteristic equation for the intelligent master controller model. The Routh

Hurwitz (RH) stability test with the higher order polynomial equation (3.11) below gives the results in the Array in Table 4.19, this shows that the system is stable.

$$2.5S^6 + 6S^5 + 10.5S^4 + 10S^3 + 7.5S^2 + 3S + 1 = 0$$

All the coefficient of characteristic polynomial has same sign; thus, the equation has fulfilled the RH criterion for stability assessment.

Table 4.12: The Routh Hurwitz Array

S^6	**2.5**	**10.5**	**7.5**	**1**
S^5	6	10	3	0
S^4	6.33	6.25	1	0
S^3	4.08	2.05	0	0
S^2	3.06	1	0	0
S^1	0.72	0	0	0
S^0	1	0	0	0

The plot of zero and poles from Table 4.11 is shown in Fig 4.37., this validates the system stability status, the solution to the root of the characteristic equation shows that the entire root of the polynomial lie on the left half plane of the plot. Further justification to the intelligent master controller stability was that the set of the algebra combined coefficient all have the same sign.

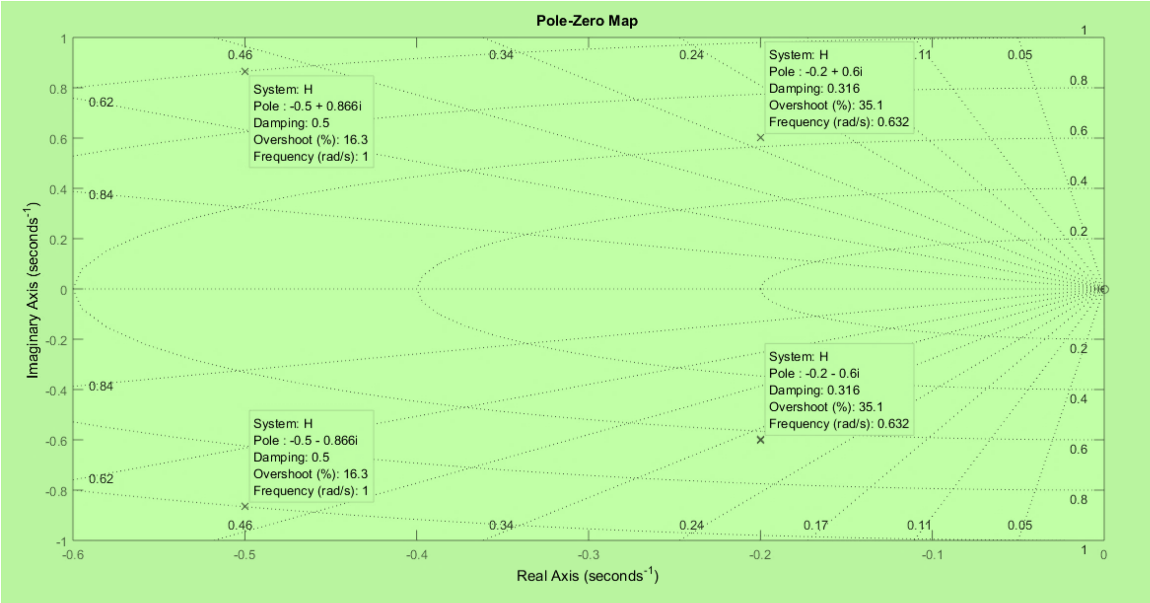


Fig. 4.37: Poles and zero Plots

Fig. 4.37 shows the location of the poles, the system has 6 poles. The first set of 4poles with -0.5 value and the damping of 0.5 at the overshoot of 16.3%. The second set of 2 poles with 0.2 value and damping value of 0.316 at the overshoot of 35.1%.

4.5.2 Result and discussion of Cost Benefit Report for the System

The principle of cost benefit analysis is of the essence as its application in determining strength, weakness, opportunity and threat (SWOT) in design prototype evaluation cannot be over emphasized. Therefore, cost benefit analysis simply suggests that a project is expected to have a higher value of benefits than the cost of undertaking such project. Further to this, it informs the opinion of a researcher on the right decision to take, having assessed the opportunities, weaknesses, strengths and even threats that the estimated project offers. In light of the above, the developed intelligent master controller was selected due to its cost benefit analysis potentials. This is explained in the designed components prototype of the developed system. For instance, this system was designed to serve five co-located communities in Afikpo metropolitan city in Ebonyi State at a cost of two hundred and sixty-six thousand and seventy-five naira (N266,075.00) only which cannot be equated to power transformer being installed in the respected communities with its attendant and relative high cost of each transformer summed together at fifteen million naira only (N15,000,000.00) translating to about three million naira (N3,000,000.00) each. This in no small way translates that in the development of this system, every resource employed were optimally allocated and maximized. To this end, the researcher in a bid to explain the cost benefit analysis, adopted the SMART analytical tools for the system evaluation and explanation.

i. **Simplicity/Specific**: The developed system was experimentally confirmed to be user friendly, simple, specific, easy to understand and needs little or no explanation to the users.

ii. **Measurability:** The developed system proves its potential in measuring and registering the generated and consumed power values in real time basis and as well visible for the user to access remotely.

iii. **Affordability:** As the name suggests, the developed system proves that it is affordable in energy monitoring and control within the hours of operation. From Table 3.1 and Section 3.2.5, the cost of actualizing the intelligent master controller for this Hybridized power pool system application was aggregated. An estimated cost of the design prototype was two hundred and sixty-six thousand, seventy-five naira only (**N266,075.00**) with low maintenance requirements. The design for mass production would in no doubt bring the cost to two hundred and sixty-six thousand, seventy-five naira only (**N266,075.00)**

iv. **Reliability:** The developed system demonstrates its ability and dependability in coordinating the overall energy activities within its hours of demonstrations under normal environmental conditions while holding other conditions constant. In section 3.2.4(d.), the system performance was validated simultaneously with its three-input power supply and the reliability probability test within 6(six) hours. The result shows that the system performance attained a reliability of 0.84(84%) and unreliability of 0.16(16%) within the demonstration period of 6(six)hours. This implies that for six (6) hours of demonstration translating to 21600seconds; the 0.84 reliability attainment show the power was available for (5.04 hours) 18144seconds, while the power outage witnessed an unreliability value of 0.16 representing 16% failure, about 3456seconds unavailability of power supply.

v. **Time-sensitive/Bond**: The developed system demonstrates efficient time management in switching from one source to another without wasting time and unnoticed to the users.

Above all, it is SMART in nature by being, simple, measurable, affordable, reliable and time bound.

4.6 Summary of Result, Discussion and Major Research Findings

The major findings in this research reveals that the co-located community-based hybridized renewable system alongside with its alternative sources can be monitored and controlled remotely using an intelligent master controller. Locally available energy resources can be harnessed, power pooled and put to use efficiently, reliably and sustainably when proper energy management scheme is in place. A developed soft touch android operated human machine interface proved its applicability in remote renewable energy management as it visibly shows each of the energy sources and its associated contribution in the community level which is a focus of this research. This is because all the standalone, hybridized and optimized renewable energy sources were wasted without power pool system at the local community level. The integration of these locally contributed energy resources (unified energy system) with this formidable monitoring and control scheme eliminated the energy wastage. With this design many generators can be started automatically and at the same time synchronized to a common bus for central utilization. Energy input in use can be monitored and controlled remotely using mobile application. The information on energy generation and consumption can be documented real time in cloud. The system transfer function was deduced, state space model developed and the system stability model was formulated and validated.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An intelligent master controller for management of the integrated hybridized energy resources in a smart micro-grid system was developed. The excess energy from one community serves other communities by effective and efficient management of the pool resources; remote monitoring and control of these integrated micro-grid system was achieved with an intelligent master controller with an incorporated human machine interface. In this work, software program and mobile application was used in developing the monitoring platform of the system and it observes the system changes with time. The design offers a touch screen human machine interface that helps to centrally manage all the (unified) pool resources thus, eliminating energy wastage. Five different communities in Ebonyi South senatorial zone were selected for this prototype experiment. In the result, it was revealed that the operators and machine efficiently interacted for optimum energy utilization. The contributions to knowledge in this research are enumerated thus: the research reveals that it was feasible to achieve the interconnection of the co-located community-based hybridized energy system with available renewable energy resources within Afikpo metropolis for the purpose of power pooling; it showed the likelihood of controlling and monitoring of the power pool system with the aid of a personal computer (intelligent master Controllers), touch screen HMI implementable by Arduino and mobile App. The developed model was experimented on the hybridized power pool system monitoring and control. The research was achieved through, modelling, simulation and implementation. The system stability, controllability and observability were achieved. The data collected from this design were stored and analyzed in cloud.

5.2 Recommendations for future Work

The development of intelligent master controller for hybridized power pool system applications used in few co-located communities in Afikpo North Local Government Area, Ebonyi State, was the focus of this research work. From the design model and simulation, the design has demonstrated a huge potential from the available renewable energy resources in our locality and needs to be further worked on thus, these recommendations:

i. In other to promote efficient energy management and waste free economy, the renewable energy resources from all the local communities should further be designed to coordinate, hybridize and pooled with their central controllers situated around their local government headquarters.

ii. Further steps should be taken to implement the screen touch human machine interface design on its hardware basis for monitoring and control to cover the entire local government area.

iii. Further research should consider carrying out similar research design for many communities.

iv. The researcher should be encouraged to design a hybrid system from locally available renewable energy resources so as to promote power pool system in our local areas which will later metamorphose into state affairs with the view to eliminating energy wastages.

v. Future improvement should consider quality, quantity and cost power before embarking on its controller design. The rating of the generator and load assessment from the study location should be investigated as it will give a redesign model the capability to handle the whole load within the study area.

vi. Energy storage and compensation device maybe introduce to improve the system performance.

vii. Federal Government should enact an enabling law that will enhance renewable energy power pooling at local government level.

5.3 Contribution to knowledge

The prime contribution to the body of knowledge in this research work is that the intelligent master controller was designed, simulated, built and tested. First known developed local controller for community energy management. This contribution was made possible with the following sub-achievements:

i. The intelligent master controller architecture was designed and validated. The results revealed that it is feasible to achieve the interconnection of community-based hybridized system with available renewable energy resources within the Afikpo metropolitan city for the purpose of power pool control.

ii. The remote monitoring and control using web and Android application with soft touch HMI was designed and implemented. The results uncovered the possibility of monitoring and controlling the power pool system with the aid of PC and mobile touch screen HMI implementable by the intelligent master controller. This engenders efficient, reliable and stable energy supply to our teeming communities as its foster wasteless energy management system. The database was designed and implemented, data documentary for energy in this remote location in Nigeria was computed, analysed and used for energy forecast within the area. The system states, behavioral performance and dynamic characteristics were determine using suitable stability analytical tools.

iii. The Software was developed to handle the system sequence of operations, this provides the system switching based on the feedback and prioritized program. The results obtained revealed that if remote areas in all the state of the federation embrace community-based power pool systems, it will decongest our national grid thereby reducing the problem of overload in our grid system. Also, automatic generator starting scheme was designed and implemented, the results shows that it is possible to put ON/OFF several generators (Multiple Generator Starter) at the same time within a co-located community and integrate their output energy to a common miniature bus within the Afikpo metropolis for power pool purpose.

iv. The Prototype (Hardware) was built and tested to validate its performance and analyzed using ThingSpeak. This model was used to determinee the unified energy system with full utilization of the abundant renewable resources available in zone that was unexploited.

v. The controller control model was developed for the system and the cost benefit template was formulated, and it gives the estimated cost of producing a single unit. The renewable energy resources within the remote location that was wasted, ignored and poorly managed was integrated, monitored and controlled for efficiently at affordable price.

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APPENDICES

Appendix A: Hypertext Mark-up Language (HTML) Code for soft touch Human Machine Interface design

```
<html>
<head>
		<meta charset="utf-8">
		<title>IMC Power Pool System</title>
		<meta charset="utf-8" />
		<link rel="stylesheet" type="text/css" href="CSS/index.css">
   <meta name="format-detection" content="telephone=no" />
   <meta name="msapplication-tap-highlight" content="no" />
   <meta name="viewport" content="user-scalable=no, initial-scale=1, maximum-scale=1, minimum-scale=1,
width=device-width" />
</head>
<body>
		<main>
				<header>
						<h2 class="power">IMC Power Pool System</h2>
						<h3 class="dev">Development of Intelligent Master Controller for Hybridized Power
Pool System Applications</h3>
				</header>
		<section class="container">
						<section class="source">
								<div class="grid">
										<h2>GRID SOURCE </h2>
								<a href="info.html">Grid</a>
								<a href="#" id="grid">Grid Off</a>
								</div>
								<div class="solar">
										<h2>RENEWABLE ENERGY SOURCE</h2>
										<a href="info.html">renewable</a>
										<a href="#" id="solar">Renewable Off</a>
								</div>
								<div class="gen">
												<h2>GENERATOR SOURCE</h2>
												<a href="info.html">Gen</a>
												<a href="#" id="gen">Gen Off</a>
								</div>
						</section>
								<section class="leds">
										<div class="led-yellow  led" >
								  </div>
										<div class="led-red  led" >
								  </div>
										<div class="led-blue  led">
								</div>
						</section>
						<section class="cont">
								<div class="display">
										<p id="display">GENERATED ENERGY DISPLAY</p>
```

```
                    </div>
            <div class="master">
                    <a href="#" id="master">INTELLIGENT MASTER CONTROLLER [ON]</a>
            </div>
            <div class="note">
 <p id="display2">CONSUMPTION ENERGY DISPLAY</p>
            </div>
            </section>

            <section class="load">
            <div class="load1">
              <h2> AFIKPO LOAD</h2>
              <a href="#" id="load1">AFIKPO ON</a>
              <a href="info.html">AFIKPO</a>
            </div>
            <div class="load2">
              <h2>AMAZIRI LOAD</h2>
              <a href="#" id="load2">AMAZIRI ON</a>
              <a href="info.html">AMAZIRI</a>
            </div>
            <div class="load3">
              <h2>OZZIA LOAD</h2>
              <a href="#" id="load3">OZZIA ON</a>
              <a href="info.html">OZZIA</a>
            </div>
            <div class="load4">
              <h2>ENOHIA LOAD</h2>
              <a href="#" id="load4">ENOHIA ON</a>
              <a href="info.html">ENOHIA</a>
            </div>
            <div class="load5">
              <h2>UNWANA LOAD</h2>
                    <a href="#" id="load5">UNWANA ON</a>
                    <a href="info.html">UNWANA</a>
            </div>
        </section>
            <section class="led2">
                            <div class="led-red2" id ="led1" >
                     </div>

                            <div class="led-red2" id = "led2" >
                     </div>

                            <div class="led-red2" id = "led3">
                    </div>
                     <div class="led-red2" id = "led4">
                    </div>
<div class="led-red2" id = "led5">
                    </div>
                     </section>
             </section>
        </main>
        <script src="js/jquery.js"></script>
```

```
<script type="text/javascript">
        $(document).ready(function() {
                $("#grid").click(function() {
                        var grid = $("#grid");
                        var gridval = grid.html();
                        if(gridval == "Grid Off") {
                                grid.html("Grid On");
                        } else {
                                grid.html("Grid Off");
                        }
                });

        });
        $(document).ready(function() {
                $("#solar").click(function() {
                        var solar = $("#ren");
                        var solarval = ren.html();
                        if(solarval == "Ren Off") {
                                solar.html("Ren On");
                        } else {
                                solar.html("Ren Off");
                        }
                });
        });
    $(document).ready(function() {
                $("#gen").click(function() {
                        var gen = $("#gen");
                        var genval = gen.html();
                        if(genval == "Gen Off") {
                                gen.html("Gen On");
                        } else {
                                gen.html("Gen Off");
                        }
                });
        });
$(document).ready(function() {
    $("#load1").click(function() {
                        var load1 = $("#load1");
                        var load1val = load1.html();
                        if(load1val == "AFIKPO ON") {
                                load1.html("AFIKPO OFF");
                        } else {
                                load1.html("AFIKPO ON");
                        }
                });
        });
    $(document).ready(function() {
    $("#load2").click(function() {
                        var load2 = $("#load2");
                        var load2val = load2.html();
                        if(load2val == "AMAZIRI ON") {
                                load2.html("AMAZIRI OFF");
                        } else {
                                load2.html("AMAZIRI ON");
```

```
					}
				});
			});
			$(document).ready(function() {
		$("#load3").click(function() {
					var load3 = $("#load3");
					var load3val = load3.html();
					if(load3val == "OZZIA ON") {
						load3.html("OZZIA OFF");
					} else {
						load3.html("OZZIA ON");
					}
				});
			});
	$(document).ready(function() {
		$("#load4").click(function() {
					var load4 = $("#load4");
					var load4val = load4.html();
					if(load4val == "ENOHIA ON") {
						load4.html("ENOHIA OFF");
					} else {
						load4.html("ENOHIA ON");
					}
				});
			});
	$(document).ready(function() {
		$("#load5").click(function() {
					var load5 = $("#load5");
					var load5val = load5.html();
					if(load5val == "UNWANA ON") {
						load5.html("UNWANA OFF");
					} else {
						load5.html("UNWANA ON");
					}
				});
			});
	$(document).ready(function() {
		$("#master").click(function() {
					var master = $("#master");
					var masterval = master.html();
					if(masterval == "INTELLIGENT MASTER CONTROLLER [ON]") {
						master.html("INTELLIGENT MASTER CONTROLLER
[OFF]");
					} else {
						master.html("INTELLIGENT MASTER CONTROLLER
[ON]");
					}
				});
			});
		</script>
</body>
</html>
```

Appendix B: Cascading Styles Sheets (CSS) Code for soft touch Human Machine Interface design

```
*{
		margin: 0;
		padding: 0;
		outline: none;
}
header{
  font-family: Permanent Marker;
  text-align: center;
  width: 100%;
  height: 50px;
  background: blue;
}
.container {
		display: flex;
}
.source{
		margin-top: 100px;
}
.leds{
		margin-top: 100px;
}
.grid h2{
		text-align: center;
		width: 200px;
		padding: 10px;
		margin-top: 30px;
		margin-left: 110px;
		border: 1px solid #000;
		border-radius: 5px;
}
.solar h2{
		text-align: center;
		width: 200px;
		padding: 7px;
		padding-right: 35px;
		margin-top: 90px;
		margin-left: 100px;
		border: 1px solid #000;
		border-radius: 5px;
}
.gen h2{
   text-align: center;
   width: 200px;
   padding: 10px;
   margin-top: 120px;
   margin-left: 110px;
   border: 1px solid #000;
   border-radius: 5px;
}
```

```
.source a {
		display: inline-block;
		margin:10px;
		color: #000;
		font-size: 17px;
		text-transform: uppercase;
		text-decoration: none;
		background-color: #33ff33;
		padding: 10px 29px;
		border: none;
		border-radius: 6px;
}

.source a:hover{
		opacity: 0.6;
}

.led{
		margin-left: 110px;
		padding:4px;
		margin-bottom: 40px;
}
  .led-red {
		margin-top: 170px;
		width: 35px;
		height: 35px;
		background-color: #F00;
		border-radius: 50%;
		box-shadow: rgba(0, 0, 0, 0.2) 0 -1px 7px 1px, inset #441313 0 -1px 9px, rgba(255, 0, 0, 0.5) 0 2px 12px;
  }
  .led-yellow {
		margin-top: 170px;
		width: 35px;
		height: 35px;
		background-color: #FF0;
		border-radius: 50%;
		box-shadow: rgba(0, 0, 0, 0.2) 0 -1px 7px 1px, inset #808002 0 -1px 9px, #FF0 0 2px 12px;
  }
  .led-blue {
		margin-top: 200px;
		width: 35px;
		height: 35px;
		background-color: #24E0FF;
		border-radius: 50%;
		box-shadow: rgba(0, 0, 0, 0.2) 0 -1px 7px 1px, inset #006 0 -1px 9px, #3F8CFF 0 2px 14px;
  }

.load{
   margin-left: 500px;
}
.load1 h2{
		text-align: center;
		width: 200px;
		padding: 10px;
```

```
        margin-top: 50px;
        margin-left: 40px;
        border: 1px solid #000;
        border-radius: 5px;
}
.load2 h2{
        text-align: center;
        width: 200px;
        padding: 10px;
        margin-top: 50px;
        margin-left: 40px;
        border: 1px solid #000;
        border-radius: 5px;
}
.load3 h2{
        text-align: center;
        width: 200px;
        padding: 10px;
        margin-top: 50px;
        margin-left: 30px;
        border: 1px solid #000;
        border-radius: 5px;
}
.load4 h2{
        text-align: center;
        width: 200px;
        padding: 10px;
        margin-top: 50px;
        margin-left: 40px;
        border: 1px solid #000;
        border-radius: 5px;
}
.load5 h2{
        text-align: center;
        width: 200px;
        padding: 10px;
        margin-top: 50px;
        margin-left: 40px;
        border: 1px solid #000;
        border-radius: 5px;
}
  .led-red2 {
        margin-left: 50px;
        width: 35px;
        height: 35px;
        background-color: #F00;
        border-radius: 50%;
        box-shadow: rgba(0, 0, 0, 0.2) 0 -1px 7px 1px, inset #441313 0 -1px 9px, rgba(255, 0, 0, 0.5) 0 2px 12px;
  }
  #led1{
        margin-top: 56px;
  }
  #led2{
        margin-top: 130px;
```

```
 }
 #led3{
        margin-top: 120px;
 }
 #led4{
        margin-top: 120px;
 }
 #led5{
        margin-top: 130px;
 }
 .load a {
        display: inline-block;
        margin:10px;
        color: #000;
        font-size: 17px;
        text-transform: uppercase;
        text-decoration: none;
        background-color: #33ff33;
        padding: 10px 29px;
        border: none;
        border-radius: 6px;
}
#master {
        font-weight: bold;
        font-size: 20px;
        display: inline-block;
        margin:10px;
        color: #000;
        text-transform: uppercase;
        text-decoration: none;
        background-color: rgba(255, 1, 32, 0.3);
        padding: 40px 29px;
        border: none;
        border-radius: 8px;
}
}
```

Appendix C: JavaScript Code for soft touch Human Machine Interface design

```
    <script src="js/jquery.js"></script>

    <script type="text/javascript">
        $(document).ready(function() {
            $("#grid").click(function() {
                var grid = $("#grid");
                var gridval = grid.html();
                if(gridval == "Grid Off") {
                    grid.html("Grid On");
                } else {
                    grid.html("Grid Off");
                }
            });

        });
        $(document).ready(function() {
            $("#solar").click(function() {
                var solar = $("#solar");
                var solarval = solar.html();
                if(solarval == "Solar Off") {
                    solar.html("Solar On");
                } else {
                    solar.html("Solar Off");
                }
            });
        });
    $(document).ready(function() {
            $("#gen").click(function() {
                var gen = $("#gen");
                var genval = gen.html();
                if(genval == "Gen Off") {
                    gen.html("Gen On");
```

Appendix D: Hypertext Mark-up Language (HTML) Code for Sign IN/UP Page design

```
<!DOCTYPE html>
<html lang="en">
<head>
   <meta charset="UTF-8">
   <title> Sign In/Sign Up</title>
   <link rel="stylesheet" type="text/css" href="css/style.css">
   <meta name="viewport" content="width=device-width, initial-scale=1.0">
   <link href="css/fa/css/font-awesome">
   <meta http-equiv="X-UA-Compatible" content="ie=edge">
</head>
<body>
   <div class="container" id="container">
      <div class="form-container sign-up-container">
         <form action="#">
            <h1>
               Create Account
            </h1>
            <div class="images">
               <img src="images/gen.jpg">
               <img src="images/solar.jpg">
               <img src="images/grid.jpg">
            </div>
            <input type="text" placeholder="Name">
            <input type="email" placeholder="Email">
            <input type="password" placeholder="Password">
            <button>Sign Up</button>
         </form>
      </div>
      <div class="form-container sign-in-container">
         <form action="#">
            <h1> Intelligent Master Controller Interface</h1>
            <div class="images">
               <img src="images/gen.jpg">
               <img src="images/solar.jpg">
               <img src="images/grid.jpg">
            </div>
            <input type="email" placeholder="Email">
            <input type="password" placeholder="Password">
            <button>Sign In</button>
            <a href="#">Forgot Your Password?</a>
         </form>
      </div>
      <div class="overlay-container">
         <div class="overlay">
            <div class="overlay-panel overlay-left">
               <h1>Welcome Back</h1>
               <p>
                To keep connected with us, please login with your personal info
               </p>
```

```
                <button class="ghost" id="signIn">Sign In</button>
            </div>
            <div class="overlay-panel overlay-right">
                <h1>New IMC Operator</h1>
                <p>Enter your personal details to sign up</p>
                <button class="ghost" id="signUp">Sign Up</button>
                <p class="power">IMC Power Pool System Controller </p>
            </div>
        </div>
    </div>
</div>

<script type="text/javascript" src="main.js"></script>
</body>
</html>
```

Appendix E: Cascading Styles Sheets (CSS) Code for Sign IN/UP Page design

```
@import url('https://fonts.googleapis.com/css?family=Monserrat:400,800');
*{
	box-sizing: border-box;
}
body{
	font-family: 'Monserrat', sans-serif;
	background: #f6f5f7;
    display: flex;
    flex-direction: column;
    justify-content: center;
    align-items: center;
    height: 100vh;
    margin: -20px 0 50px;
}
h1{
	width:400px;
	padding-right:20px;
	padding-left:20px;
	font-weight: bold;
	margin: 0px;
}
p{
	font-size: 14px;
	font-weight: 100;
	line-height: 20px;
	letter-spacing: 0.50px;
	margin: 20px 0 30px;
}
.power{
	margin-bottom: 5px;
    text-transform: uppercase;
    color: #fff;
	font-size: 14px;
}
a{
	color: #333;
```

```
		font-size: 14px;
		text-decoration: none;
		margin: 15px 0;
}
.container{
		background: #fff;
		border-radius: 10px;
		box-shadow: 0 14px 28px rgba(0, 0, 0, 0.25), 0 10px 10px rgba(0, 0, 0, 0.22);
  position: relative;
  overflow: hidden;
  width: 768px;
  max-width: 100%;
  min-height: 480px;
}
.form-container form {
		background: #fff;
		display: flex;
		flex-direction: column;
		padding: 0 50px;
		height: 100%;
		justify-content: center;
		align-items: center;
		text-align: center;
}
.images{
		margin: 20px 0;
}
.images img {
		border: 1px solid #ddd;
		border-radius: 50%;
		display: inline-flex;
		justify-content: center;
		align-items: center;
		margin: 0 5px;
		height: 70px;
		width: 70px;
}
.form-container input{
		background: #eee;
		border: none;
		padding: 12px 15px;
		margin: 8px 0;
		width: 100%;
}
button{
		border-radius: 20px;
		border: 1px solid #ff4b2b;
		background: #ff4b2b;
		color: #fff;
		font-size: 12px;
		font-weight: bold;
		padding: 12px 45px;
		letter-spacing: 1px;
		text-transform: uppercase;
```

```
        transition: transform 80ms ease-in;
}
button:active{
        transform: scale(0.95);
}
button:focus{
   outline: none;
}
button.ghost{
        background: transparent;
        border-color: #fff;
}
.form-container {
        position: absolute;
        top: 0;
        height: 100%;
        transition: all 0.6s ease-in-out;
}
.sign-in-container{
        left: 0;
        width: 50%;
        z-index:  2;
}
.sign-up-container{
        left: 0;
        width: 50%;
        opacity: 0;
        z-index:  1;
}
.overlay-container{
        position: absolute;
        top: 0;
        left: 50%;
        width: 50%;
        height: 100%;
   overflow: hidden;
   transition: transform 0.6s ease-in-out;
   z-index: 100;
}
.overlay{
        background: #ff416c;
        background: linear-gradient(to right, #ff4b2b, #ff416c) no-repeat 0 0 / cover;
        color:#fff;
        position:relative;
        left:-100%;
        height: 100%;
        width: 200%;
        transform: translateX(0);
        transition: transform 0.6s ease-in-out;
}
.overlay-panel{
        position: absolute;
        top: 0;
        display: flex;
```

```
            flex-direction: column;
            justify-content: center;
            align-items: center;
            padding: 0 40px;
            height: 100%;
            width: 50%;
            text-align: center;
    transform: translateX(0);
    transition: transform 0.6s ease-in-out;
}
.overlay-right {
            right: 0;
            transform: translateX(0);
}
.overlay-left{
            transform: translateX(-30%);
}
.container.right-panel-active .sign-in-container{
            transform: translateX(100%);
}
 .container.right-panel-active .overlay-container{
            transform: translateX(-100%);
 }
 .container.right-panel-active .sign-up-container{
            transform: translateX(100%);
            opacity: 1;
            z-index: 5;
 }
 .container.right-panel-active .overlay{
            transform: translateX(50%);
 }
 .container.right-panel-active .overlay-left{
            transform: translateX(0);
 }
  .container.right-panel-active .overlay-right{
            transform: translateX(20%);
 }
```

Appendix F: Java Script Code for Sign IN/UP Page design

```
const signUpBottom = document.getElementById("signUp");

const signInBottom = document.getElementById("signIn");

const container = document.getElementById("container");

signUpBottom.addEventListener('click', () =>

container.classList.add('right-panel-active'));

signInBottom.addEventListener('click', () =>

container.classList.remove('right-panel-active'));
```

Appendix G: Code for Admin and Operators database design

```
<!DOCTYPE html>
<html>
<head>
            <title>Grid Info</title>
            <meta charset="utf-8" />
   <meta name="format-detection" content="telephone=no" />
   <meta name="msapplication-tap-highlight" content="no" />
   <meta name="viewport" content="user-scalable=no, initial-scale=1, maximum-scale=1, minimum-scale=1,
width=device-width" />
    <script src = "js/jquery.min.js"></script>
     <script src = "js/highcharts.js"></script>
</head>
<body>
   <div id="container" style="min-width: 310px; height: 400px; margin: 0 auto"></div>
        <script language = "JavaScript">
      $(document).ready(function() {
        var chart = {
          zoomType: 'x'
        };
        var title = {
          text: 'GRID ENERGY SOURCE TO POWER POOL SYSTEM'
        };
        var subtitle = {
          text: document.ontouchstart === undefined ?
          'Click and drag in the plot area to zoom in' :
          'Pinch the chart to zoom in'
        };
        var xAxis = {
          type: 'datetime',
          minRange: 1,
          title: {
                     text: 'MONTHS'
          }

        };
        var yAxis = {
          title: {
            text: 'POWER IN MW'
          }
        };
        var legend = {
          enabled: false
        };
        var plotOptions = {
          area: {
            fillColor: {
              linearGradient: { x1: 0, y1: 0, x2: 0, y2: 1},
              stops: [
                [0, Highcharts.getOptions().colors[0]],
                [1, Highcharts.Color(
                  Highcharts.getOptions().colors[0]).setOpacity(0).get('rgba')]
```

```
            ]
          },
          marker: {
            radius: 2
          },
          lineWidth: 1,
          states: {
            hover: {
              lineWidth: 1
            }
          },
          threshold: null
        }
      };
      var series = [{
        type: 'area',
        name: 'GRID TO PPL',
        pointInterval: 1,
        pointStart: Date.UTC(2019),
        data: [
          1, 2, 3, 4, 5, 6, 7, 8, 9, 10
        ]
      }];

      var json = {};
      json.chart = chart;
      json.title = title;
      json.subtitle = subtitle;
      json.legend = legend;
      json.xAxis = xAxis;
      json.yAxis = yAxis;
      json.series = series;
      json.plotOptions = plotOptions;
      $('#container').highcharts(json);
    });
  </script>
</body>
</html>
```

Appendix H: Code for Generated Energy database design

```
<!DOCTYPE html>

<html>

<head>

	<title>Grid Info</title>

	<meta charset="utf-8" />

  <meta name="format-detection" content="telephone=no" />

  <meta name="msapplication-tap-highlight" content="no" />
```

```
    <meta name="viewport" content="user-scalable=no, initial-scale=1, maximum-scale=1, minimum-scale=1,
width=device-width" />
     <script src = "js/jquery.min.js"></script>
      <script src = "js/highcharts.js"></script>
</head>
<body>
    <div id="container" style="min-width: 310px; height: 400px; margin: 0 auto"></div>
          <script language = "JavaScript">
        $(document).ready(function() {
           var chart = {
              zoomType: 'x'
           };
           var title = {
              text: 'GRID ENERGY SOURCE TO POWER POOL SYSTEM'
           };
           var subtitle = {
              text: document.ontouchstart === undefined ?
              'Click and drag in the plot area to zoom in' :
              'Pinch the chart to zoom in'
           };
           var xAxis = {
              type: 'datetime',
              minRange: 1,
              title: {
                         text: 'MONTHS'
              }


           };
           var yAxis = {
              title: {
                 text: 'POWER IN MW'
```

```
  }
};
var legend = {
  enabled: false
};
var plotOptions = {
  area: {
    fillColor: {
      linearGradient: { x1: 0, y1: 0, x2: 0, y2: 1},
      stops: [
        [0, Highcharts.getOptions().colors[0]],
        [1, Highcharts.Color(
          Highcharts.getOptions().colors[0]).setOpacity(0).get('rgba')]
      ]
    },
    marker: {
      radius: 2
    },
    lineWidth: 1,
    states: {
      hover: {
        lineWidth: 1
      }
    },
    threshold: null
  }
};
var series = [{
  type: 'area',
  name: 'GRID TO PPL',
  pointInterval: 1,
```

```
            pointStart: Date.UTC(2019),
            data: [
               1, 2, 3, 4, 5, 6, 7, 8, 9, 10
            ]
          }];

          var json = {};
          json.chart = chart;
          json.title = title;
          json.subtitle = subtitle;
          json.legend = legend;
          json.xAxis = xAxis;
          json.yAxis = yAxis;
          json.series = series;
          json.plotOptions = plotOptions;
          $('#container').highcharts(json);
        });
    </script>
</body>
</html>
```

Appendix I: Code for Consumption Energy database design

```
<!DOCTYPE html>
<html>
<head>
            <title>Grid Info</title>
            <meta charset="utf-8" />
   <meta name="format-detection" content="telephone=no" />
   <meta name="msapplication-tap-highlight" content="no" />
   <meta name="viewport" content="user-scalable=no, initial-scale=1, maximum-scale=1, minimum-scale=1,
width=device-width" />
    <script src = "js/jquery.min.js"></script>
     <script src = "js/highcharts.js"></script>
</head>
<body>
   <div id="container" style="min-width: 310px; height: 400px; margin: 0 auto"></div>
        <script language = "JavaScript">
      $(document).ready(function() {
```

```
var chart = {
  zoomType: 'x'
};
var title = {
  text: 'GRID ENERGY SOURCE TO POWER POOL SYSTEM'
};
var subtitle = {
  text: document.ontouchstart === undefined ?
  'Click and drag in the plot area to zoom in' :
  'Pinch the chart to zoom in'
};
var xAxis = {
  type: 'datetime',
  minRange: 1,
  title: {
          text: 'MONTHS'
  }

};
var yAxis = {
  title: {
    text: 'POWER IN MW'
  }
};
var legend = {
  enabled: false
};
var plotOptions = {
  area: {
    fillColor: {
      linearGradient: { x1: 0, y1: 0, x2: 0, y2: 1},
      stops: [
        [0, Highcharts.getOptions().colors[0]],
        [1, Highcharts.Color(
          Highcharts.getOptions().colors[0]).setOpacity(0).get('rgba')]
      ]
    },
    marker: {
      radius: 2
    },
    lineWidth: 1,
    states: {
      hover: {
        lineWidth: 1
      }
    },
    threshold: null
  }
};
var series = [{
  type: 'area',
  name: 'GRID TO PPL',
  pointInterval: 1,
  pointStart: Date.UTC(2019),
```

```
            data: [
              1, 2, 3, 4, 5, 6, 7, 8, 9, 10
            ]
          }];

          var json = {};
          json.chart = chart;
          json.title = title;
          json.subtitle = subtitle;
          json.legend = legend;
          json.xAxis = xAxis;
          json.yAxis = yAxis;
          json.series = series;
          json.plotOptions = plotOptions;
          $('#container').highcharts(json);
        });
    </script>
</body>
</html>
```

Appendix J: Code for Atmega Microcontroller (Arduino) design

```
#include <ezButton.h>

#include <LCDWIKI_GUI.h>

#include <LCDWIKI_KBV.h>

#include "font.h"

int T1,T2, T3, T4, T7,T5,T6,T8;

LCDWIKI_KBV my_lcd(ST7796S,40,38,39,43,41);

#define  BLACK   0x0000

#define BLUE    0x001F

#define RED     0xF800

#define GREEN   0x07E0

#define CYAN    0x07FF

#define MAGENTA 0xF81F

#define YELLOW  0xFFE0

#define WHITE   0xFFFF

char *aspect_name[] = {"PORTRAIT", "LANDSCAPE", "PORTRAIT_REV", "LANDSCAPE_REV"};

char *color_name[] = { "BLUE", "GREEN", "RED", "WHITE" ,"CYAN","MAGENTA","YELLOW"};

uint16_t color_mask[] = { 0x001F, 0x07E0, 0xF800, 0xFFFF,0x07FF,0xF81F,0xFFE0 };

String reqString = "src0=1000$src1=5000$src2=1000$src3=5000$src4=1000$src5=5000$src6=1000$src7=5000$";
```

```
unsigned long lastsenttime = 0;
String header;
int len = 0;
ezButton button2(2);
ezButton button3(3);
ezButton button8(8);
ezButton button4(4);
ezButton button11(11);
ezButton button5(5);
ezButton button7(7);
ezButton button6(6);
void show_string(uint8_t *str,int16_t x,int16_t y,uint8_t csize,uint16_t fc, uint16_t bc,boolean mode)
{
    my_lcd.Set_Text_Mode(mode);
    my_lcd.Set_Text_Size(csize);
    my_lcd.Set_Text_colour(fc);
    my_lcd.Set_Text_Back_colour(bc);
    my_lcd.Print_String(str,x,y);
}
unsigned long show_fill_circle(void)
{ button3.loop(); button2.loop();
   button4.loop();   button5.loop();
   button6.loop(); button7.loop();
  button8.loop(); button11.loop();
    uint16_t i;
    unsigned long time_start = micros();
int btn2State = button2.getState();
if(btn2State==0){T1=RED; reqString.setCharAt(5, '1'); my_lcd.Set_Draw_color(T1);}
else if(btn2State==1){T1=GREEN;  reqString.setCharAt(5, '5'); my_lcd.Set_Draw_color(T1);}
 my_lcd.Fill_Circle(80, 60,30);
 show_string("1 ",70,110,2,WHITE,BLACK,0);
 int btn3State = button3.getState();
 if(btn3State==0){T2=RED; reqString.setCharAt(15, '1'); my_lcd.Set_Draw_color(T2); }
```

```
 else if(btn3State==1){T2=GREEN; reqString.setCharAt(15, '5'); my_lcd.Set_Draw_color(T2);}
   my_lcd.Fill_Circle( 160,60, 30);
   show_string("2 ",160,110,2,WHITE,BLACK,0);
 int btn8State = button8.getState();
if(btn8State==0){T3=RED; reqString.setCharAt(25, '1'); my_lcd.Set_Draw_color(T3);}
else if(btn8State==1){T3=GREEN; reqString.setCharAt(25, '5'); my_lcd.Set_Draw_color(T3);}
 my_lcd.Fill_Circle( 240,60,30);
show_string("3 ",240,110,2,WHITE,BLACK,0);
int btn4State = button4.getState();
 if(btn4State==0){T4=RED; reqString.setCharAt(35, '1'); my_lcd.Set_Draw_color(T4);}
else if(btn4State==1){T4=GREEN; reqString.setCharAt(35, '5'); my_lcd.Set_Draw_color(T4);}
   my_lcd.Fill_Circle(320,60,30);
   show_string("4 ",320,110,2,WHITE,BLACK,0);
 int btn11State = button11.getState();
if(btn11State==0){T5=RED; reqString.setCharAt(45, '1'); my_lcd.Set_Draw_color(T5);}
else if(btn11State==1){T5=GREEN; reqString.setCharAt(45, '5'); my_lcd.Set_Draw_color(T5);}
 my_lcd.Fill_Circle(400,60,30);
 show_string("5 ",400,110,2,WHITE,BLACK,0);
int btn7State = button7.getState();
if(btn7State==0){T6=RED; reqString.setCharAt(65, '1'); my_lcd.Set_Draw_color(T6);}
else if(btn7State==1){T6=GREEN; reqString.setCharAt(65, '5'); my_lcd.Set_Draw_color(T6);}
my_lcd.Fill_Circle( 120,170,30);
show_string("GEN ",100,220,2,WHITE,BLACK,0);
int btn6State = button6.getState();
if(btn6State==0){T7=RED; reqString.setCharAt(75, '1'); my_lcd.Set_Draw_color(T7);}
else if(btn6State==1){T7=GREEN; reqString.setCharAt(75, '5'); my_lcd.Set_Draw_color(T7);}
 my_lcd.Fill_Circle(240,170,30);
 show_string("REN ",220,220,2,WHITE,BLACK,0);
int btn5State = button5.getState();
if(btn5State==0){T8=RED; reqString.setCharAt(55, '1'); my_lcd.Set_Draw_color(T8);//digitalWrite(22,LOW);
}
else if(btn5State==1){T8=GREEN; reqString.setCharAt(55, '5'); my_lcd.Set_Draw_color(T8);//digitalWrite(22,HIGH);
}
```

```
   my_lcd.Fill_Circle(360,170,30);
   show_string("GRID ",340,220,2,WHITE,BLACK,0);
      my_lcd.Set_Draw_color(RED);
 show_string("VOLTAGE: ",255,270,2,WHITE,BLACK,0);
  show_string("CURRENT: ",70,270,2,WHITE,BLACK,0);
 }
void setup() {
  Serial.begin(9600);
  pinMode(19,INPUT);digitalWrite(19,LOW);pinMode(18,OUTPUT);digitalWrite(19,HIGH);
  Serial1.begin(115200);
  len = reqString.length()+1;
  button2.setDebounceTime(50);
  button3.setDebounceTime(50);
  button4.setDebounceTime(50);
  button5.setDebounceTime(50);
  button6.setDebounceTime(50);
  button7.setDebounceTime(50);
  button8.setDebounceTime(50);
  button11.setDebounceTime(50);
  T1=T2= T3= T4= T7=T5=T6=T8=RED;
  my_lcd.Init_LCD();
  my_lcd.Fill_Screen(BLACK);
  my_lcd.Set_Rotation(3);
  unsigned long time_start = micros();
    my_lcd.Set_Draw_color(0, 0,128);
    my_lcd.Fill_Rectangle(0, 0, my_lcd.Get_Display_Width(), 20);
    my_lcd.Set_Text_colour(255, 255, 255);
    my_lcd.Set_Text_Size(1);
    my_lcd.Set_Text_Mode(1);
    my_lcd.Print_String("----< Engr. Kufre Project >----", CENTER, 3);


    my_lcd.Set_Draw_color(0, 0, 128);
```

```
    my_lcd.Fill_Rectangle(0, my_lcd.Get_Display_Height()-15, my_lcd.Get_Display_Width()-1, my_lcd.Get_Display_Height()-
1);
    my_lcd.Set_Text_colour(255, 255, 255);
    my_lcd.Set_Text_Size(1);
    my_lcd.Set_Text_Mode(1);
    my_lcd.Print_String("--------<http://futminna.ng.ed.com>--------", CENTER, my_lcd.Get_Display_Height()-11);
    my_lcd.Set_Draw_color(255, 0, 0);
    my_lcd.Draw_Rectangle(0, 20, my_lcd.Get_Display_Width()-1, my_lcd.Get_Display_Height()-16);
    my_lcd.Draw_Rectangle(0, 250, my_lcd.Get_Display_Width()-1, my_lcd.Get_Display_Height()-16);
    return micros() - time_start;
}
void loop() {
  header = "";
  char reqstring[len];
  while (Serial1.available()>0) {
    header = Serial1.readStringUntil(('\n'));
  }
  if(!header.equals(""))
    Serial.println(header);
  if((millis() - lastsenttime) > 5000){
    Serial1.flush();
    for (int l = 0; l < len-1; l++){
      reqstring[l] = reqString.charAt(l);
    }
    reqstring[len] = '\n';
    Serial1.write(reqstring);
    lastsenttime = millis();
  }
    show_fill_circle();
} alue
  if (val>=1023)
  {
    digitalWrite(ledPin,HIGH);
```

```
 }
  else{
  digitalWrite(ledPin,LOW);
  }
 }
```

Appendix K: Code for NRF (ESP8266) and ThingSpeak design

```
#include <ESP8266WiFi.h>
#include "secrets.h"
#include "ThingSpeak.h"
char ssid[] = "Airtel 4G MiFi_F665";
char pass[] = "00821902";
int keyIndex = 0;
WiFiClient  client;

unsigned long weatherStationChannelNumber = SECRET_CH_ID_WEATHER_STATION;
unsigned int temperatureFieldNumber = 1;
unsigned long counterChannelNumber = 1357378;
const char * myCounterReadAPIKey = "XK0YFMQDPAZU57C7";
unsigned int counterFieldNumber = 2;
void setup() {
  Serial.begin(115200);
  while (!Serial) {
  }
  Serial1.begin(9600);
  WiFi.mode(WIFI_STA);
  ThingSpeak.begin(client);
}
void loop() {
  int statusCode = 0;
  if(WiFi.status() != WL_CONNECTED){
    Serial.print("Attempting to connect to SSID: ");
    Serial.println(SECRET_SSID);
    while(WiFi.status() != WL_CONNECTED){
      WiFi.begin(ssid, pass);
      Serial.print(".");
      delay(5000);
    }
    Serial.println("\nConnected");
  }

  long count = ThingSpeak.readLongField(counterChannelNumber, counterFieldNumber, myCounterReadAPIKey);
  statusCode = ThingSpeak.getLastReadStatus();
  if(statusCode > 0){
    Serial.println(count);
    Serial1.print(String(count));
  }
  else{
  }

  delay(15000); // No need to read the counter too often.

}
```