

**DEVELOPMENT OF AN INSTITUTIONAL-BASED  
COMMUNITY POWER POOLING MODEL FOR  
SEAMLESS RENEWABLE ENERGY INTEGRATION**

**BY**

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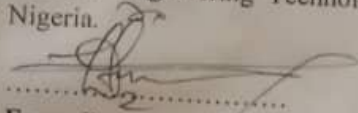
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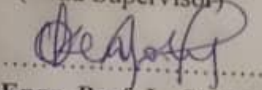
CERTIFICATION

This is to certify that this thesis entitled "Development of Institutional-based Community Power Pooling Model for Seamless Renewable Energy Integration" was carried out by Raymond Okechukwu Opara (20104834488) in partial fulfillment for the requirements for the award of the degree of Doctor of Philosophy (Ph.D) in Electrical Power System Engineering, Department of Electrical and Electronic Engineering, School of Electrical Systems Engineering Technology, Federal University of Technology Owerri, Imo State, Nigeria.



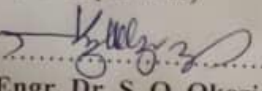
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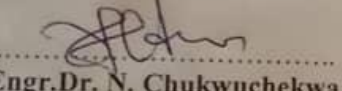
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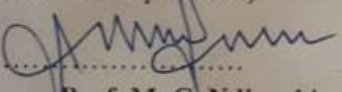
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## **DEDICATION**

This work is dedicated to God Almighty

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## **LIST OF EQUATION NUMBERS**

2.1 Loss of Power Supply Probability

2.2 Measure of System Reliability

2.3 Maximization of the total Production Cost

## LIST OF ABBREVIATIONS

1. AC	Alternating Current
2. PV	Photo Voltaic
3. NIE	New Institutional Economies
4. WPT	Wavelet Pocket Transform
5. NWP	Numerical Weather Prediction
6. EDCNN	Efficient Deep Convolution Neutral Network
7. DSM	Demand Side Management
8. SSA	Sub-Saharan Africa
9. UN	United Nation
10. CO <sub>2</sub>	Carbon dioxide
11. CB-LEM	Community Based Local Energy Market
12. CM	Community Manager
13. VPPs	Virtual Power Plants
14. EI	Environmental Impact
15. IoT	Internet of Things
16. ICT	Information Communication Technology
17. AMI	Advanced Metering Infrastructure
18. DR	Demand Response
19. MILP	Mixed Integers Linear Programming
20. RECs	Regional Economic Communities
21. SAPP	Southern African Power Pool
22. SADC	Southern African Community Development
23. WAPP	West African Power Pool
24. CAIP	Central African Power Pool

25. EAPP	East African Power Pool
26. NBI	Nile Basin Initiative
27. PSC	Planning Sub Committee
28. ECCAS	Economic Community of Central African States
29. MOU	Memorandum of Understanding
30. NWPP	Northwest Power Pool
31. SOL	System Operating Limits
32. NPP	Nordic Power Pool
33. DC	Direct Current
34. PDEs	Partial Differential Equations
35. TLCs	Thermostatically Controlled Loads
36. ST-2D	Spatio-Temporal Dual Decomposition
37. QoS	Quality of Service
38. DSR	Demand Side Response
39. DGS	Distributed Generation Supply
40. STATCOM	Static Synchronous Compensators
41. CAN	Controlled Area Network
42. PLL	Phase-Locked Loop
43. STLF	Short-Term Load Forecasting
44. CSP	Concentrated Solar Power
45. GUUD	Geographical Urban Units
46. CA	Cellular Automata
47. CHP	Combined Heat and Power
48. MGCC	Model of a Micro-grid with Controller
49. HRES	Hybrid Renewable Energy Systems
50. FITs	Feed-In-Tariffs

- 51. PLF            Probabilistic Load Forecasting
- 52. PLC           Programmable Logic Controller
- 53. SCADA       Supervisory Control and Data Acquisition
- 54. HOMER       Hybrid Optimization of Multiple Energy Resources
- 55. ETAP          Electrical Transient Analyser Program
- 56. EEDC          Enugu Electricity Distribution Company
- 57. UL            Underwriters Laboratories

## ABSTRACT

In recent times, educational institutions were provided with sources of power, that were able to cater for their needs, cognizance of the low demand for knowledge economy was not high. As a result, the available energy was able to suffice for the limited schools, departments, and units within the university system that was available as at that time. As technology continues to improve, the quest for knowledge increases thereby giving needs for expansion in the educational institutions, which cut across creating of more administrative sections, departments and courses. This expansion came with the need for more energy consumption, which calls for a more robust technology with enabling energy integration. The universities were not taking into consideration using energy resources within their operating environments for optimal utilization. And even when there is any consideration to the use of renewable energy resources, standalone energy systems were readily attracted without consideration to network, and integration model, with a fear of un-seamless nature of renewable energy resources. To mitigate the aforementioned shortcoming, this project proposes an institutional-based community power pooling model with seamless renewable energy integration. This involves the formulation and development of an institutionalized local distribution network forming a mini – grid. Then appropriate dc and ac Load Flow (LF) model were applied to determine an optimal balance between locally available distributed energy resources (DERs) and co – located load centers with the referenced institution – in this case, FUTO. The model simulations reveal that the system is capable of synchronizing the renewable energy resources within the university in a single network bus, alongside with public power supply and diesel generators. This could guarantee efficient and optimal utilization of the energy potentials within the university community, with excess energy of 8,603,334 KWh/yr. available for sales to the neighbouring energy users from the formulated model. This model could be utilized in other universities across the nation with the view of tailoring its architecture to suit each institutions special peculiarities in terms of energy resources and load demand.

**Keywords:** Institutional-based System, Distribution Energy Network, Seamless Energy Integration, Power Pool Model, Renewable Energy System

# CHAPTER 1

## INTRODUCTION

### 1.1 Background of Study

Energy pooling entails collections of energy potentials available in respective location for collective utilization. These utilizations are not without a cost; this is because the collaborative energy management require adequate maintenance. The barrier to optimal power system reliability in renewable energy system is the integration. This could result from poor state of energy network architecture and infrastructures, as these infrastructures are key requirement for development in energy creation sector (Liu, et al, 2014). Energy production, distribution and its management using information technology has been made easy with adoption of smart grid technology. The integration of several energy resources into smart grid system has created a lot of challenges in power sector (Mohamed, et al, 2015). The inclusion of both renewable and non-renewable energy system was to eliminate intermittent power supply. Satisfaction of energy demand calls for uninterrupted integration of renewable energy resources in the power production system (Shahid, 2018). An effective integration of renewable energy in power pool requires implementation of smart grid automation, monitoring and management. The deployment of microgrid system includes the collection of loads to be supplied, and the integration of renewable energy in the system has made energy supply more reliable. More so, inverter operation to supply AC power elicits power supply interruption. The integration of renewable energy systems into the power pool poses wide benefits to the participants (Reddy, et al, 2020). The benefit strongly depends on the tightness of the pools; and cost saving, reliable supply, substantial management are achievable in a tightly coordinated power pool system. Furthermore, smart grid integration has upgraded the energy sector to remote monitoring, renewable energy management for the advance forecast of resources, and automatic control. This encourages consumer utility interaction management (Mohamed et al., 2015). The system of hybrid energy

supply is built on a goal to defeat power grid failure by ensuring continuous supply that necessitates the use of automatic transfer switching. This enables switching from the power grid when out of supply to the battery system for short-term use then to the generator set for long-term supply with zero interruption (Cui, et al, 2018). However, the development and operation of reliable energy system has been a great challenge resulting from irregularity in nature of energy source and unforeseen load variations with unreliable grid. Hence, there is need for an advanced technique to enable optimal integration of renewable energy system (Dwari, Arnedo, and Blasko., 2014). Integration of renewable energy into distributed energy resources could pose an immense challenge to power production ranging from its stability, reliability and protections (Altaf, et al, 2020).

Adequate system stability and load flow assessment will be carried out on various load bus as to guarantee effective utilization of the network (Vijayvargia, et al, 2016). Distributed energy resources solution is undoubtedly feasible with block chain model. Safe and secured electricity marketing which is adequately managed between the user and the production sector without any intermediary is also achievable with the block-chain model (Burchi, et al, 2018).

## **1.2 Problem Statement**

Before now, institutions were operating on either public power supply or stand by generator, regardless of abundance and dispersed renewable energy resources within their localities. Recently, many institutions have realized that these scattered resources can be put to use, but were hampered by lack of unified local energy network model and scattered uncoordinated unit generator. Institutional based community is dense with several faculties, units, and sections that require optimal energy access for its daily operations, but lack of institutional distribution Network system deprive the schools from harnessing its potentials. Considering some environmental factors existing within most academic communities, renewable energy resources

may vary, random, and even uncertain. Some institutions have considerable intensity of sun, which could permit solar energy production, some have a running micro-river within their environment, which would have encouraged hydro energy generation. Institutions in coastal and desert areas have wind energy potentials, but the absence of energy integration model to assist in the effective use and synchronization of the resources jeopardizes its utilisation. Different faculties, units and sections have varying energy demand. This variation in load demand may pose instability to the modelled distribution network, as well as imbalances to load supply (Gersema & Wozabal, 2018). There is absence of a known load flow model to manage the proposed institutional-based power system model. Power systems must include power flow analysis. It is necessary for a comprehensive description of power systems to be possible. It can be used to track voltages, active and reactive power flows, and bus bars in the power system, among other things. Moreover, it is possible to find active and reactive losses in transmission lines. In order to determine if the system is working in a healthy state or not, we can assess its general health. There are numerous commercial computer programs available for load flow analyses and simulations (Shahzad, 2017). In view of the aforementioned problem, there is a need to develop an institutional based power system with seamless energy integration model.

### **1.3 Aim and Objectives**

The aim of this research is to develop an institutional-based community power pooling model for seamless renewable energy integration. This aim is achieved with the aid of the following specific objectives:

- i. To develop institutional distribution network system;
- ii. To develop an integrating model for the renewable system.
- iii. To design the system equilibrium model for sources and load balancer

- iv. To develop system sequence of operations for the model.
- v. To carryout load flow analysis for institutional distribution Network Model.

#### **1.4 Justification of the Study**

The introduction of power pool system for academic community use would aid the institution to attain their energy demand. In that, it would reduce the over dependence on public power supply and stand-by generators, thereby reducing the cost of operations in the Schools. Networking of all the scattered abundant energy resources within the operational confinement of the university will engender optimal energy harvest. These various renewable energies within the academic communities such as wind, sun, and hydro can be synchronized with the aid of the developed network model. The developed model will have an ability to handle system imbalances, given that the network substation is cited within the community.

#### **1.5 Scope of the Study**

This research work considers institutional-based community for energy pooling with emphasis on Universities. Its specific attention is given to developing institutional distribution Network system. In addition to developing the system architecture, it provides seamless integration model with the available renewable system. The system also designs an equilibrium model for both the sources and load demands within the university community. This system is implemented by simulation. The load flow models and Power simulation were undertaken. The interfaces for seamless integration of the different renewable energy resources within an institution in focus will be considered. System synchronization checks will be handled digitally. An overall system implementation flow chart will be developed and simulated.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Energy System Model (Theoretical and Historical Framework)

A systematic framework is proposed to estimate the impact on operating costs due to uncertainty and variability in renewable resources (Widergren, 2016). The framework quantifies the integration costs associated with sub-hourly variability and uncertainty as well as day-ahead forecasting errors in solar photovoltaics (PV) power. (Wu, et al, 2015) conducted an extensive sensitivity analysis under different assumptions about balancing reserves, system flexibility, fuel prices, and forecasting errors. The result shows that high solar PV penetrations may lead to operational challenges, particularly during low-load and high solar periods. Furthermore, increased system flexibility is essential for minimizing integration costs and maintaining reliability.

In sub-Saharan Africa in 2009, about 585 million people lacked access to electric power services. Contrary to several other parts of the world, that number is anticipated to increase rapidly to around 652 million by 2030, which is an unsustainable and undesirable condition (Bent, et al, 2015). Governments and regional organizations have recognized the urgent need for rapid electrification rates because they are aware of the fundamental connections between development and access to energy services. Some of the well-known and cutting-edge theories, frameworks, and methods referred to as "Smart Grids" may make a significant contribution to ensuring that everyone has access to power (Welsch, et al, 2013). The authors contended that these Smart Grid developments could help governments in sub-Saharan Africa advance electrification efforts and skip several steps in traditional power networks

Specialists throughout the world have extensively researched and used the microgrid idea. IEC/ISO 62264 standards should be used with virtual power plants and microgrids, according to

(Palizban, et al, 2014) proposal. The authors also examined market involvement, energy storage devices, and cutting-edge control methodologies for both island and grid-connection operations (Palizban et al., 2014). With decentralized energy systems, cities can create more efficient energy systems that work better for everyone in the community(Adil and Ko, 2016);(Schoor and Scholtens, 2015);(Robert et al., 2018). The key determinants of the local network strength include the emergence of a common vision, the intensity of activity, and the nature of the organization(Schoor & Scholtens, 2015). Most urban planning research has focused on the impact of physical urban energy utilization. (Adil and Ko, 2016) reviewed the co-evolution of technology and social dynamics related to distributed generation and microgrids. A comprehensive analysis of urban elements, particularly physical, institutional, and social ones that become relevant as energy decentralization and democratization proceeds is necessary to understand how Micro-Grids, (MGs) and Smart Micro-Grids (SMGs) have come to be favoured arrangements for municipal energy infrastructure. The ability of urban energy infrastructure to withstand calamities linked to climate change is crucial to this issue as they become more imminent(Adil and Ko, 2016). This has greatly impact communities who want to achieve electricity self-sufficiency and environmental benefits through microgrids, users and service providers(Gui, et al, 2017).

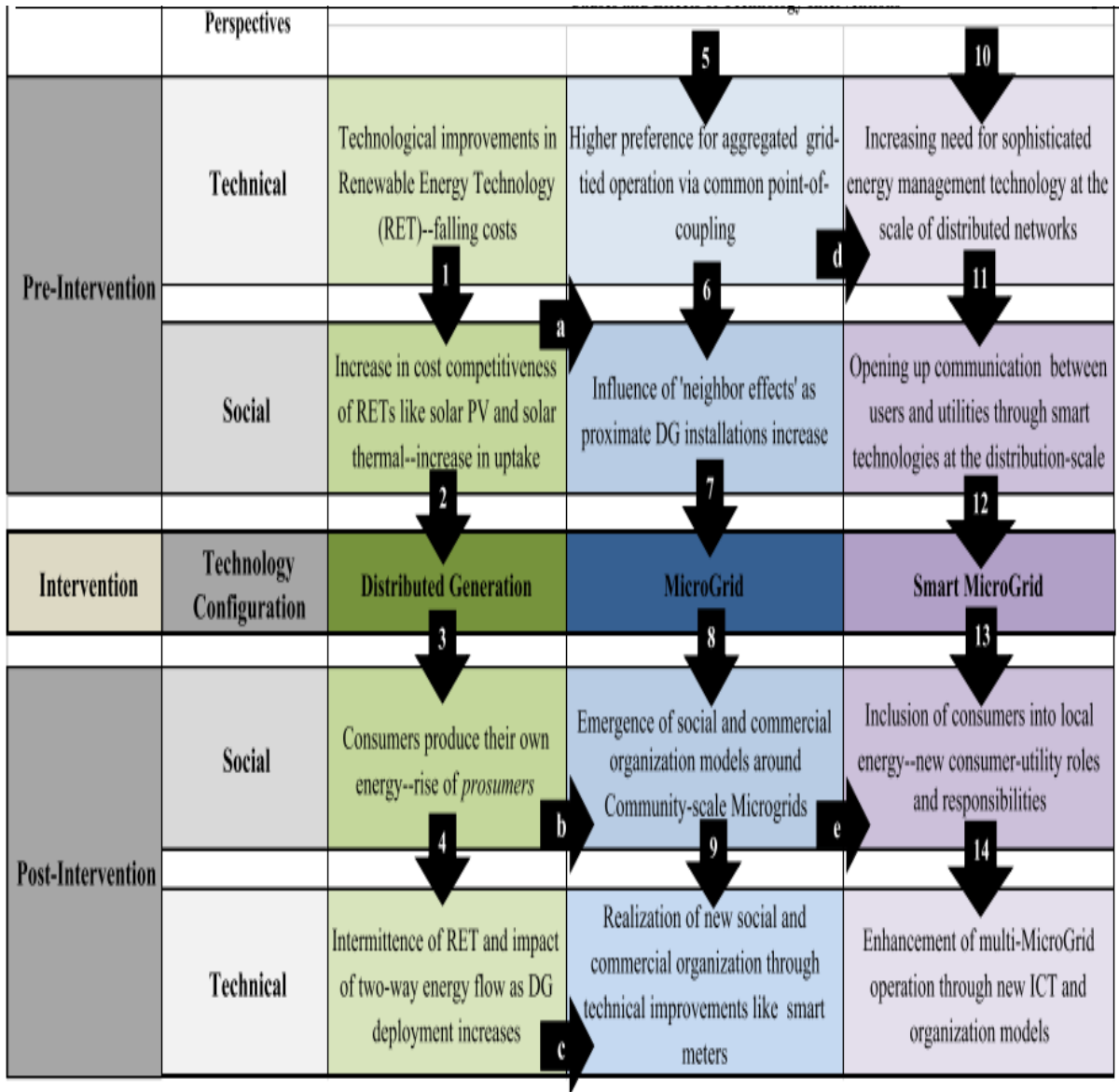


Figure 2.1: Decentralized energy system socio intervention (Gui et al., 2017).

(Gui et al., 2017) as shown in Figure 2.1, provides a guide to developing community microgrids based on concepts from New Institutional Economics (NIE). The authors looked at how energy systems can be used to improve public infrastructure and utility services and drew on empirical studies and experiences from other public/community infrastructure projects. The efficiency of an ownership and governance structure can be linked to the transactional characteristics of assets, such as their unique characteristics and how often they are traded ( Flores-espino, Giraldez, & Pratt., 2020). The key role of customers in the microgrid market and their relationship with

service providers is important to understand. This relationship gives customers a ‘monopoly’ on the grid, which can have important consequences for the choice of institutional structure. Different ways people can own financial assets, and how they can be governed over time were checked on. This allows for investment uncertainty and appropriation risks to be efficiently managed. The study found that factors such as long-term contract completeness, future demand for electricity, and the level of uncertainty are important when choosing an institutional structure (Gui et al., 2017).

Due to the fact that, 67% of the global energy consumption is a result of intensive urbanization, governments as well as analysts have paid close attention to how much energy is used in cities. This has led to the emergence of energy interactions among customers as the spreading of distributed energy systems has intensified over time. A novel method based on the complex network theory has been devised to take into account the energy transfers resulting from such interactions. The complex mathematical tool divides the urban region into interconnected territorial units with an energy demand and an energy producing potential ( Leaders, et al, 2015) and ( Amjad, et al, 2011). To ascertain the ideal energy flows occurring in the produced urban energy network, the process is evaluated for a hypothetical region. As a result, the created model serves as a valuable tool for the creation of urban energy action plans that are focused on the use of renewable resources and the installation of energy-efficient equipment (Fichera, Volpe, and Frasca., 2016).

Community support of a micro-grid development can be for a mix of economic, environmental and social reasons, for example, for access to cheaper electricity, for control and certainty over their long-term electricity supply, and to create a greener community and local employment. While various international studies provide case studies in the successful development and implementation of community micro-grid projects worldwide, major deficiencies have been acknowledged in creating incentives and commercial models for maximizing economic benefits

to the customer, the utility, and society as a whole (Rickerson and Strategies, 2022). Also some community micro-grid projects disappoint due to lack of effective governance and management, and lack of adequate compensation and incentive mechanisms to renew customers' interests and withstand economic uncertainties and challenges in these projects (Cook, et al, 2018).

Community micro-grids need to be managed and operated in a lean and flexible manner suited to the interests and capabilities of the key stakeholders. In particular, they will be unsustainable if heavily burdened by inefficient governance, complex legal requirements and high transaction costs. Environmental initiatives from some communities have led to the development of community micro-grids with high share or 100% of renewable energy (Rathnayaka and Potdar, 2015),(Communities and Directions, 2018). Furthermore, a typically key social objective of community micro-grids is to provide affordable electricity to the entire local community, and they may be required to provide service on a non-economic price basis to vulnerable customers (Rathnayaka and Potdar, 2015),(Gui et al., 2017). The socio-economic and socio-technical nature of community micro-grids, thus require novel approaches to bring together goals and interests of all stakeholders, particularly the community, the investor and the service provider, fostering community participation and equity, and encouraging long term investments, all while balancing social and economic objectives to achieve better outcomes for the community (Minghui et al., 2016).

## **2.2 Renewable Energy Systems Models**

As a consequence of rapidly increased CO<sub>2</sub> emissions, humanity is facing global warming. Electricity generation accounts for almost half of the emission; besides, conventional electrical production based on fossil fuel is becoming more and more expensive. (Markovic et al., 2013) came out with Cloud computing model which was used for developing Smart Grid solutions. The Cloud computing model is based on the delivery of computing as a service, whereby storage,

software and information are provided to computers and other devices as a commodity over the Internet. Furthermore, the Cloud computing helped to reduce costs, increased storage, on-demand performance, and better flexibility – have motivated many companies in recent years to move their IT operations to the cloud.

Over the years, power systems are facing the challenges of growing power demand, depleting fossil fuel and aggravating environmental pollution (caused by carbon emission from fossil fuel based power generation). Mujeeb et al., (2019) developed an efficient deep learning-based prediction model for wind power forecasting. The model made up of Wavelet Packet Transform (WPT) which helped to decompose the past wind power signals rather than decomposed signals and lagged wind power, multiple exogenous inputs (such as, calendar variable and Numerical Weather Prediction (NWP) are also used as input to forecast wind power. Furthermore, Efficient Deep Convolution Neural Network (EDCNN), was employed to forecast wind power. The results proved that the proposed Demand Side Management (DSM) method successfully distribute the load, making load profile almost normally distributed. Moreover, the proposed DSM algorithm effectively reduces the consumption cost. However, the model could not determine the impact of current conditions on wind power for a short forecasting period of time.

A concept known as "sustainable energy transition" refers to the development of strong, effective, and efficient energy sectors in a certain nation or region without jeopardizing the socio-environmental security of the present and the future. In light of this, several nations have made outstanding attempts to realize this crucial goal in accordance with contemporary energy wants and supply requirements. More than half of the world's estimated poor people live in sub-Saharan Africa (SSA), and Nigeria, the most populous nation in Africa, is home to a substantial fraction of these people (up to 400 million). The strength of a country's energy industry has a significant impact on its social and economic development. Adewuyi et al., (2020) study on the significance of an equal right to the adoption of sustainable energy in Nigeria and other African

nations. This was clearly highlighted in relation to reaching the deadline for Sustainable Development goals SDGs set by the UN.

Driving our civilization to entirely adopt renewable energy sources like solar and wind energy and less rely on fossil fuel is one strategy to dramatically slow down global warming (Markovic et al., 2013). Communities and neighborhoods are changing as a result of the shift toward renewable and sustainable energy. This change might have a significant impact on society as a whole. In order to reach 100% sustainable energy, energy neutrality, zero carbon emissions, or zero impact on their communities, many cities, towns, and villages are developing ambitious plans (Schoor & Scholtens, 2015).

Between 2000 and 2012, the amount of electrical energy needed in sub-Saharan Africa increased by nearly 35%, or 352 terawatt hours (TWh). According to the IEA, until 2040, the continent's overall demand for electricity will grow at an average rate of 4% each year. By 2040, it's anticipated that more than half a billion people would still lack access to power, and it won't be fully achieved until 2080, according to estimates. Due to this complicated and ongoing electricity imbalance, sub-Saharan Africa is burdened. The term "electricity gap" refers to both the imbalance between supply and demand in grid-connected regions and the absence of access in off-grid locations. It is a complex challenge to close the power gap in sub-Saharan Africa, and how it is framed has significant ramifications for the region's overall energy issue. The region has struggled to expand economically and has been unable to meet many of its goals for the improvement of health and education due to persistent electricity constraints.

Dearth of electricity production capacity to provide power to grid-connected regions, inadequate grid infrastructure to deliver this power, regulatory barriers to providing steady revenue to maintain and invest in new generation capacity, and population dispersion in remote areas are some of the causes of this scarcity. Avila, et al, (2017) developed an open-access power system model and examine the best approaches to increase supply capacity in Kenya and Nigeria, the

two case study nations. In order to achieve reliable and affordable power by 2035, the authors compared the average costs of various expansion scenarios and investigated issues like the integration of variable renewable resources, increased access to electricity, the effects of reliability, and the function of decentralized energy resources. The case studies demonstrated that until grid storage costs come down, fuels like natural gas can help provide system flexibility. Renewable energy sources are now cost-competitive. The analysis demonstrates that it is important to choose fuels carefully, especially coal, which is demonstrated to be an expensive route to electrification in Kenya and Nigeria(Avila et al., 2017). These countries are two case study countries on the path to improving their electricity systems by 2035. The scale of centralized generation expansion required is significant compared with historical investments in power systems. Current investment in sub-Saharan electricity systems is about US\$8 billion a year. Analysis shows that fuel choices should be considered cautiously, particularly coal, which is shown to be a costly pathway(Naveen et al., 2016). The problem of energy balancing is particularly important in microgrids fueled by renewable energy sources.

Renewable energy sources are often supplemented with fossil fuel generation; however, storage and demand response may be more flexible and economical. Use of precise and detailed models is required if renewable energy sources are to be utilized on a broad basis( Robert, Sisodia, and Gopalan., 2018).

The existing body of literature review on community micro-grids is concentrated on the technical and economic dimensions; academic publications on institutional design and business models are rare. In possibly the first attempt to interpret institutions of community micro-grids from a social science perspective, Wolsink (2012) narrated a ‘common pool resource’ approach to address the institutional character of governance, social acceptance and innovation related to sustainable management of social-technical systems such as micro- grids (Wolsink, 2012 and 2017). He argued that to effectively establish such systems requires institutions that unite currently separate

and poorly coordinated decision-making, support mutual trust, and generate suitable governance framework and policies to cultivate favourable conditions for new technologies (Gui et al., 2017)(Minghui, Diesendorf, and Macgill., 2016). Community acceptance of these systems is crucial, while acceptance by all actors either public or private is largely determined by the institutional arrangements of ownership and control. The degree of acceptance that drives the transformation from a visionary plan into financial commitment is closed linked to the level of trust between the actors and the institutions, and between different groups of actors (Gil and Joos, 2006).

This paper offers an institutional development framework for community micro-grids using a New Institutional Economics (NIE) approach (Lasseter, 2007) to address non-technical properties in the development of community micro-grids, including property rights, asset characteristics, customer-provider relationship, ownership, governance and contractual arrangements. The framework is intended to aid in enabling adaptation to future uncertainties and fostering dynamic efficiency and innovation for community energy self-sufficiency. Its development however, requires new social-technical and social-political relationships in which government policies, stakeholder incentives, and community and consumer motivations have to converge to drive this transition (Nye and Whitmarsh, 2010).

Forecasting solar energy generation is a challenging task due to the variety of solar power systems and weather regimes encountered (Alonso and Batlles, 2014). Forecast inaccuracies can result in substantial economic losses and power system reliability issues Zhang et al., (2013) carried an experiment using a suite of generally applicable and value-based metrics for solar forecasting for a comprehensive set of scenarios which included instances like different time horizons, geographic locations, and applications. Furthermore, a comprehensive framework was developed to analyze the sensitivity of the proposed metrics to three types of solar forecasting improvements using a design of experiments methodology, in conjunction with response surface

and sensitivity analysis methods. The approach successfully shows that the developed metrics could efficiently evaluate the quality of solar forecasts, and assess the economic and reliability impact of improved solar forecasting.

### **2.3 Power Pool Models**

The decentralization of energy supply and demand can contribute decisively to protecting the environment and climate of the planet by consuming electricity in the proximity of the generation source and avoiding losses in transmission and distribution ( Pinson, et al, 2017.) and ( Petri, et al, 2021) developed an Ethereum-Blockchain framework with an application scenario from the fish industry to demonstrate how energy transactions can be coordinated through the use of smart contracts. And also, how Blockchain can enable energy prosumers to monetize any surplus of energy and register its ownership by supporting their integration into a more competitive energy market. However, the work could not investigate the trustworthiness of smart meters with methods for behaviour modelling and prediction for appliances and controllers. In order to lower cost of generation, utilities share electricity in formal groups known as power pools. A framework for evaluating the effects of various pooling arrangements on production costs and emissions was presented by (Brodsky and Hahn, 1986). The framework was built upon a collection of economic dispatch models that simulate the strategies used by various kinds of pools when negotiating short-term energy exchanges. Constraints on emissions, system demand, spinning reserve, and unit production are included in the models. Trade-offs between expenses and carbon emissions for various kinds of pools can be measured by changing the constraint set (Figure 2.2). An illustrative computation was provided for the current pool to showcase the effectiveness of this approach(Brodsky *et al*, 1986).

Several South Asian nations are currently reforming their power industries. Which was primarily in the altered ownership and investment patterns as well as the growing importance of both

domestic and international private investment. These nations continue to be distinguished by low energy consumption per person, subpar energy infrastructure, unequal distribution, and difficult to access and expensive energy prices. The coordination of the power systems of adjacent nations and their interconnection offers significant technical and financial advantages. The primary concern is to operate the system in a free and just way, guaranteeing that consumers receive high-quality power at the most reasonable cost through the safe, secure, and dependable functioning of the power system leading to transparent price discovery(Saroha & Verma, 2013).

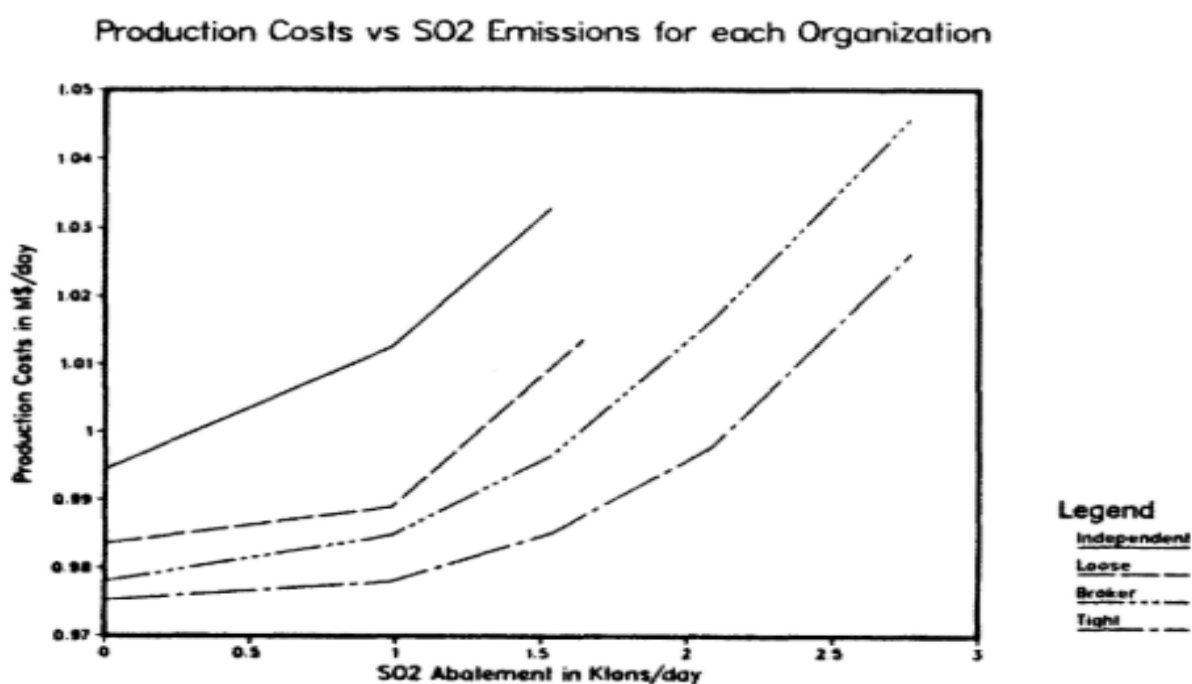


Figure 2.2: Trade-off curve (Saroha & Verma,2013)

With the deregulation of the electricity industry in many nations, the aim is to provide market participants greater freedom and choice while fostering competition in the power market as much as feasible. Shrestha, Kai, and Goel., (2000) described the creation of a power pool simulator that includes elements that increase market participants' options and freedom while also fostering more competition. The simulation system's key components were explained. A few issues relating to the impact of the power suppliers' bid data on their benefits and system operation are discussed and analyzed. That is anticipated. Power suppliers will change their

bidding data to maximize their benefits and recoup their costs in a competitive market (Shrestha et al., 2000).

In order to determine optimal generating schedules that reduce energy payments by power pool customers, a new approach for centralized optimization is presented in this study. The calculation of market clearing prices, bid assessment, recovery of generator start-up and no-load costs, operational restrictions on individual generating units, and market structure-related concerns are all covered in this essay. The approach given here reduces payments by power pool customers as opposed to traditional Unit Commitment algorithms, which minimize overall energy production costs. Lower market clearing prices and a modified unit commitment and dispatch strategy are the results of a payment reduction target. Additionally, the bid assessment procedure incorporates the best distribution of generator start-up and no-load costs across the scheduling period, resulting in a further decrease in consumer payments (Hao, et al., 1997).

To improve the effectiveness and sustainability of energy systems, shifting to a user-centric paradigm is viewed as a crucial paradigm shift. There was a suggestion to create a community-based local energy market (CB-LEM) in which participants are free to exchange energy through a neighborhood pool in the community, starting with day-ahead clearing and ending with a settlement that is based on real energy transactions. A community manager oversees the day-ahead price setting process (CM). The created framework was tested using a real-world case study of a residential area in Amsterdam, the Netherlands. The community's members would gain from the adoption of such an LEM framework since it would give them a price signal to manage and decide regarding their own possessions (Crespo-vazquez, et al, 2021).

A community micro-grid may serve a small community of ten households, and may serve a municipality up to hundreds of thousands of households and business customers, covering a wide geographic area and a variety of load types, including residential, commercial, and other non-critical or critical loads in a remote town or part of a city (Bunker, et al, 2015). A community

micro-grid may comprise prosumers, defined as “an energy user who generates renewable energy in its domestic environment and either stores the surplus energy for future use or vends to the interested energy buyers”, and/or prosumer-community groups, connecting a set of prosumers through dedicated technical infrastructures such as Virtual Power Plants (VPPs) or micro-grids. Socio-technical challenges in relation to goal-sharing and diverse energy-sharing preferences and behaviors’ of individual prosumers have been identified as key barriers to build effective prosumer-community groups in achieving optimal economic and social outcomes (Wolsink, 2017), (Aoife, Haney, and Pollitt., 2013).

Considering the social dimension, a ‘community micro-grid ’ can be viewed as a micro-grid with the key objectives of achieving economic, social and environmental benefits in community electricity supply and distribution (Künneke and Finger, 2009). These may include: energy autonomy and self-sufficiency; promotion of cleaner and more sustainable electricity; more reliability; retained economic benefits in the community; job creation in the community; provision of alternative competitive electricity supply compared to their current supply, such as grid electricity. A community micro-grid can involve multiple classes of assets, and can be owned by single or multiple parties, including the community, a utility, or other public or private companies (Bolton and Foxon, 2014). Depending on their purpose and operational characteristics, we categorize these assets into three classes - generation assets, distribution assets and micro-grid assets. Generation assets may include residential or commercial solar.

Electricity infrastructure comprises complex techno-economic systems whose development is influenced by the interactions between a wide range of social, political and institutional factors (Bolton and Foxon, 2015). Most national economies continue to recognize electricity generation, transmission and distribution as critical public infrastructure (Mendes, et al, 2011), and the right of each citizen to access electricity, clean water and other basic utilities under the ‘Universal Service Obligation’ policy (Partnership and Authority, 2012). Before the wave of restructuring

(including the introduction of market competition, partial deregulation and privatization) of electricity industries in many key jurisdictions at the end of the 20th century, electricity infrastructure was mostly managed by state companies or local government enterprises and funded through standardized electricity tariffs, or sometimes through general taxes or local taxes. Private sector involvements have increased since then, and new forms of funding can now come from user charges based on market prices, and involve public-private partnership, private investors, cooperatives, community trustee and other not-for-profit organizations. All these innovations have unlocked the potential in reducing infrastructure construction costs and addressing barriers to private sector financing (Laufer, 2019).

The possibility to develop low-fuel, low-carbon power systems based on wind, geothermal, and photovoltaic technologies as well as to employ flexible and effective demand management techniques is presented by this difficult problem for sub-Saharan countries. There are plenty of fossil and renewable energy sources in the area (Avila et al., 2017). Digitalization and decentralization are the key enablers for a low-carbon transactive Energy Internet (EI) that will increase the share of renewable energy, empower a prosumer-centric transactive energy market, enhance the flexibility of smart energy systems, speed up the development of energy-aware services, and accelerate the modernization of EI. This will increase value for energy producers, end consumers, businesses, the economy, and the environment. In this work, significances are examined from three angles: Technology, society, and people all come first. The study explained how IoT promotes the interactive digitalization of EI and aids in the convergence and interoperability of diverse resources in terms of digitalization. Four different perspectives on energy digitization are presented: IoT architectures, a closed-loop energy automation framework, and fundamental ICT technologies enabling the adoption of digital (Rövekamp, et al, 2021).

(Wu et al., 2021) demonstrated how to implement digitalization and decentralization of transactive EI, a thorough discussion of the key infrastructures is given. These infrastructures

include the last mile "Advanced metering infrastructure" (AMI), the renewables integrator "smart inverter," the energy flow adjuster "energy router," and the coordinator "Microgrid." A wide range of topics are covered, including energy physical space, data cyber space, and human social space, while discussing challenges and future developments (Wu et al., 2021).

The percentage of renewable energy in the energy mix has been expanding steadily in recent years. Renewable generation is unpredictable and not entirely controlled. Therefore, it is harder to match erratic demand with supply, which is essential for maintaining grid stability. It is possible to reduce the amount of money invested in conventional power plants and the costs associated with power balancing by utilizing demand side flexibility and renewable generation portfolio design. To take advantage of demand flexibility from residential devices, (Gottwalt, et al, 2017) offered a thorough centralized scheduling model. By evaluating the capacity of various existing and potentially accessible future end user devices to lower the production cost of a functionality aggregator in a microgrid including a large part of Renewable Generation (RG), we estimate the monetary worth of homes for demand response (DR). Additionally, we pinpoint crucial elements influencing the worth of demand flexibility and generate suggestions for an aggregator's renewable generation portfolio structure, which shows that the potential of a device to directly exploit fluctuating RG is significantly impacted by the makeup of the renewable energy source portfolio and that electric cars, stationary batteries, and storage heaters are the most promising devices for residential DR (Gottwalt et al., 2017).

The built environment accounts for a significant portion of the world's energy usage. Concepts to properly integrate and manage renewable energy are required in order to minimize the energy consumption of urban metropolises. The energy-hub concept, which was employed by (Orehounig, et al, 2014) to optimize energy usage during planning and operation, explains the relationship between input and output energy flows. The idea was applied to assess several future energy scenarios for a Switzerland community that wants to completely stop using fossil fuels.

As a starting point, the current situation regarding the energy demand of the village was captured and assessed with regard to diverse purposes, various energy carriers, their origin, distribution, and networks. The feasibility for various decentralized energy production methods is assessed in the next stage. Building-integrated or localized renewable energy generation using photovoltaics, biomass, or small hydropower are examples of decentralized energy production. The third stage defines several energy future possibilities for an energy sustainable community. A model of the village's energy hub was created and utilized to assess the various energy situations and use the converter coupling matrix to set of different energy carriers. The model can be implemented to solve optimization issues such as optimal dispatch, optimal hub layout, optimal storage, etc (Orehounig et al., 2014).

The formulation of Investment Model for Renewable Energy System (IMRES) a static electricity generating capacity expansion model with specific unit commitment limitations, was described in (de Sisternes, 2013). Joint choices are made regarding investment, unit commitment, and energy dispatch. In systems with a large penetration of intermittent renewable energy sources, this model seeks to identify the minimal cost electricity production capacity mix while taking into consideration the operating dynamics of thermal units and their effects on the overall system cost. The model was designed as a 0-1 Mixed Integers Linear Programming (MILP), taking capacity decisions at the level of individual power generation, operational decisions with hourly time resolution, and considering techno-economic factors like ramp constraints, startup costs, and minimum stable outputs of thermal plants, among other things(de Sisternes, 2013).

### **2.3.1 Overview of Some International Power-Pool Schemes**

The security and reliability of electricity supply has been the driving force behind power system interconnections (power-pools) and promotion of cross-border power-pool. Indeed, countries and utilities have interconnected their power systems to provide for increased quality and reliability

of electricity service; lower electricity production costs among sub-regional trading partners; reduced levels of required reserve capacity in the connected grids, and improved national energy security, including mutual support in time of emergencies. In recent years, the development of interconnections (power-pools) between power systems as a means of electricity integration and power pooling within regional economic communities (RECs) has been encouraged in most developing regions.

In the last decade, a number of power pools have been set up in Africa, starting with the Southern African Power Pool (SAPP) created in August 1995 through a Southern African Community Development (SADC) treaty and aimed at optimizing the use of available energy resources in the SADC region (Tom-Hammons, 2005). Since then, other power pools have been created such as the West African Power Pool (WAPP), Central African Power Pool (CAPP), East African Power Pool (EAPP), and the Nile Basin Initiative (NBI).

#### **2.3.1.1 The South African Power Pool (SAPP)**

The SAPP Planning Sub-Committee (PSC) has developed a twenty-year generation and transmission expansion plan. This plan clearly shows the benefits of coordinated planning and cost reductions that can be achieved over individual utility expansion plans. The coordinated plan requires the expenditure of \$ US 8 billion while the sum of the individual utility expansion plans requires \$ US 11 billion. Thus, a saving of \$ US 3 billion can be realized through coordinated planning. SAPP pooling arrangements have been evolving from loose pool arrangements dominated by long-term bilateral contracts among vertically integrated utilities towards a competitive pool in which bilateral contracts are complemented by STEMs (Zimba, Oosthuysen, Chikova, and Muringai., 2018).

### **2.3.1.2 The Central African Power Pool (CAPP)**

The countries of Central Africa created the Central African Power Pool (CAPP) in April 2003. The CAPP is a body of the Economic Community of Central African States (ECCAS) and is headquartered in Brazzaville, Republic of Congo.

The vision of the CAPP was to use the enormous Central African hydroelectric potentialities, estimated at more than 650 TWh/year (52 % of all the African potential), to satisfy all the demands for electricity, in favour of households, States and industries of Central Africa through systems of interconnection of national networks, and an open market for the electric energy exchanges (Infrastructure Consortium for Africa, 2016). The main objectives of CAPP are to:

- i. Enforce energy policy at the regional level,
- ii. Promote and develop power trade and ancillary services,
- iii. Increase access to electricity to populations and reduce poverty,
- iv. Improve electricity system reliability and quality of supply in the whole region, and
- v. Create a free regional electricity market.

### **2.3.1.3 The East African Power Pool (EAPP)**

An MOU for the creation of the East African Power Pool (EAPP) was signed in Dar Es Salaam in November 2003 and was created in February 2005 with 7 member countries signing an Inter-Governmental Memorandum of understanding (IG – MOU) paving way for the conclusion of an Inter-Utility Memorandum of understanding (IU – MOU) by the respective national utilities, (Deloitte, 2015). The creation of EAPP was based on agreement not by law. The EAPP embodies a regional institution established as a specialized agency of the Common Market for Eastern and Southern African for Regional Economic Communities (COMESA REC) to enhance energy interconnection and related matters in the region. The main objectives of the EAPP are to:

- i. Optimize the usage of energy resources in the region by working out regional investment schemes in power generation, transmission and distribution areas, taking into account the environmental effects.
- ii. Increase power supply in the region in order to increase the access rate of the population to electricity in Eastern Africa.
- iii. Reduce electricity production cost in the region, using power systems interconnection and increasing power exchanges between countries.
- iv. Provide an efficient co-ordination between various initiatives taken in the fields of power production and transmission as well as exchanges in the region.
- v. Create, in the framework of New Partnership for Africa's Development (NEPAD), a conducive environment for investments, in order to facilitate integration projects financing in the fields of power generation and transmission in the region, and facilitate the development of competitive electricity market in the EAPP region.

#### **2.3.1.4 The Northwest Power Pool (NWPP)**

The Northwest Power Pool membership (NWPP) was founded in 1941 to promote efficient production of electrical energy. The NWPP is the geographic area encompassed by the electric systems of the NWPP Agreement Signatories. This area includes the states of Washington, Oregon, Idaho, Montana, Utah, and Wyoming; portions of northern California and northern Nevada; and the Canadian provinces of British Columbia and Alberta. The NWPP is a collective voice for the coordination of operating reliability issues, addressing both adequacy and transmission reliability for consumers within the area. According to, (Kershner, 2016) there have been processes and procedures that are in place and have been effective in maintaining system reliability for NWPP. The operating reliability processes include: coordinated (transmission) outage processes, seasonal evaluation of transmission constraints and System Operating Limits

(SOL), next day reliability analysis, automated contingency reserve sharing, coordinated under frequency load shedding programs, coordinated under-voltage load shedding programs, power and reactive sign conventions, energy emergency plan, interconnection clearance and hold terminology, and coordinated communication during critical operating conditions. The planning processes include: Coordinated hydro planning, drought coordination-planning, transmission expansion, area coordination, transmission adequacy, and long-range significant outage planning.

**Table 2.1: Installed Capacity per Thousand Habitants by Power Pool (Infrastructure Consortium for Africa, 2011)**

POWER POOLS RATINGS	CAPP 2009*	COMELEC 2009*	EAPP 2008*	SAPP 2010*	WAPP 2010*
Installed capacity (MW)	6073	27347	28374	49877	14091
Hydropower Share (%)	86%	8%	24%	17%	30%
Thermal Share (%)	14%	91%	73%	83%	70%
Populations (Millions)	123.9	85.6	385.6	160.5	260.6
KW/1000 Habitants	49	319	74	311	54

\*Base year: Most recent year for which data is available for all countries of the power pool

Infrastructure Consortium for Africa, 2011, presented the installed capacity per thousand habitants by power pool in Table 2.1 in which the most recent year the data availability for all countries of the power pool is indicated in terms of ‘base year’. SAPP has the highest MW installed capacity as at 2010 base year, followed by EAPP in 2008 and then COMELEC in 2009 base year. Hydropower share of 86% which was the highest was obtained in CAPP with 2009 base year. The highest in thermal power share was COMELEC and lowest was CAPP.

**Table 2.2: World rate of electrification (Igbinovia et al., 2018)**

	Population (Million)	Population with electricity (Million)	Population without electricity (Million)	Electrification rate (%)	Urban Electrification rate (%)	Rural Electrification Rate (%)
Africa	891	337	554	37.8	67.9	19.0
Developing Asia	3,418	2,488	930	72.8	86.4	85.1
Latin America	449	404	45	90.0	98.0	65.6
Middle East	186	145	41	78.1	86.7	61.8
Developing Countries	4,943	3,374	1,569	68.3	85.2	56.4
Transition Economies and OECD	1,501	1,501	8	99.5	100.0	98.1
World	6,452	4,875	1,577	75.6	90.4	61.7

(Igbinovia, Ing, and Thlusty., 2018) presented the rate of electrification in the world as shown in Table 2.2. Africa, with a population of over 891 million has urban electrification rate of 67.9% and rural electrification rate of 19.0%. This is in contrast to other developing countries with urban and rural electrification rate of 85.2% and 56.45 respectively. Generally, Africa's electrification rate stands at 37.8% compared to 68.8% of other developing countries. This is very low and needs to improve.

### **2.3.1.5 Nordic Power Pool (NPP)**

The world most developed international market for electric power is found in the Nordic countries. They moved from the old model of cooperation among the leading vertical integrated utilities in each country to recently a competitive market.

(Carlsson, 1999) explained the differences in generation mix in the establishment of interconnections in Scandinavia. Norway relies entirely on hydro, while Denmark generates all power in thermal plants, mainly from imported coal. Sweden has a mix of about half hydro and half nuclear generation, and Finland a mix of hydro (25 percent), conventional thermal (45 percent), and nuclear (30 percent) plants.

The power market is fairly large: together, the four countries consume about 360 terawatt-hours (TWh) a year, surpassing the U.K. market. The differences in generation structure have made it economically attractive to trade power, allowing the countries to optimize production.

The long tradition of cross-border bilateral energy trade and cooperation and the existence of cross-border transmission structures was one of the major achievements of the Nordic pool. Setting up the pool did not require privatizing government-owned companies. A mix of companies continues to operate in the Nordic power sectors—from large government-owned utilities to privately and municipally owned companies of varying size—running generation, regional networks, and distribution systems and supplying power to consumers.

The main problem of the Nordic Pool has been that the cost of installing hourly metering which has prevented small consumers from changing suppliers, restricting competition.

Another shortcoming in the Nordic market (as in most other power markets) is that there are not clearly defined rules prescribing when network expansions have to be built by the grid companies and how they should be financed.

## 2.4 Load and Classifications

This may be classified under customer type and nature of load. The nature of electrical loads that an individual or a group of customers presents to the distribution system or electrical network is constantly changing. This is because every time a light bulb or an electrical appliance is switched on or off, the load seen by the distribution feeder changes Shelby Power (Michael, 2014). In order to describe the changing load, the electrical loads are classified into the following terms:

### 2.4.1 Customer – based Load Classification

- i. Residential Load
- ii. Industrial Load
- iii. Governmental Load
- iv. Commercial Load
- v. Agricultural and
- vi. Others Loads

i) **Residential Load:** These are loads consumed in households or homes for various purposes such as lighting, heating, cooling, and running appliances. The consumers are typically billed for their electricity usage on a monthly basis (Energy Information Administration, 2020).

In general, residential electric loads or consumers are the largest group of electric consumers, and their usage patterns vary significantly based on factors such as house hold size geographic location and climate. Some common factors that can affect electricity usage in households include – weather, appliance usage, lighting and time of the day.

Overall, residential electric loads and consumers play a significant role in the electricity industry, and efforts to improve energy efficiency, and reduce electricity consumption often focus on this group.

ii) **Industrial Load:** The loads consumed in business areas and organizations that uses electricity for industrial purposes such as manufacturing, mining and construction (U.S. Energy Information Administration, 2021). These load consumers tend to use significantly more electricity than residential consumers and often require specialized equipment and systems to operate.

iii) **Government Load:** This includes loads consumed by public institutions such as schools, hospitals, libraries, police stations, fire stations, and other government – owned facilities that uses electricity.

iv) **Commercial Load:** These are businesses and organizations that use electricity as part of their operations. This includes a wide range of businesses such as retail stores, restaurants, banks, hotels, and office buildings. Commercial electric loads typically use a lots of electricity and may have needs and requirements when it comes to electricity service.

In many parts of the world, commercial electric consumers have the option to choose their electricity supplier. This means that they can select from a range of electricity providers and plans and may be able to find options that better meet their specific needs and budget (Electric Research Institute, 2020).

Some commercial electric consumers also take steps to reduce their electricity usage and costs, such as by upgrading to more energy – efficient appliances and lighting, implementing energy management systems, or using renewable energy sources like solar power.

Altogether, commercial load consumers play an important role in the electricity market and are key drivers of demand for electricity generation and distribution services.

v) **Agricultural Load:** They are farmers and agricultural businesses that uses electricity for various purposes, including irrigation, heating and cooling and operating equipment such as tractors and other forms of machinery. Like industrial load consumers, agricultural loads can also use significant amount of electricity.

Both industrial and agricultural electricity consumers play an important role in the electricity industry and economy as whole. Efforts to improve energy efficiency and reduce electricity consumption often target these loads as potential sources of energy savings.

vi) **Other Load:** Other electric load consumers are as seen in the transportation industry such as – Electric vehicles which are becoming more common, and they consume electricity to charge their batteries. In addition, transportation systems such as train subways also use electricity to operate (U.S. Energy information Administration, 2021).

Data centers – are facilities that house computer systems and other equipment that require electricity to function. They consume large amount of electricity to power their servers and cooling systems.

Mining and resource extraction – Extraction and processing of natural resources such as oil, gas, and minerals requires significant amounts of electricity (International Energy Agency, 2020).

Military and defense – military installations require electricity to power their operations and equipment.

Telecommunication – This includes the infrastructure needed to provide phone, internet, and other communication services.

Entertainment and leisure – Facilities such as theme parks, sports stadiums, and movie theaters require electricity to operate.

#### **2.4.2 Nature of Load – based Classification:**

Based on type and nature of loads, there are heterogeneous and homogeneous Loads.

Load classification enables customers to adjust their electricity consumption strategies more economically and optimally. It could be Fixed voltage loads, where current is drawn by load and voltage is constant such as DC appliance, like TV and Radio and ideally battery loads, their I-V

characteristics is simple or Resistive loads – as seen in incandescent lighting, cookers and heaters, their I-V characteristic is a straight line. Inductive loads – used for electric motors, the I-V characteristic is non- linear. Examples are pump motors, centrifugal ventilation fan etc. Load classification is partitioned into various load patterns of groups such that load pattern in the same group are similar to each other than to load patterns in other group based on various clustering algorithm (Kai-le Zhou, 2013).

Load classification is a process which consists of many steps – such as load data preparation; load classification implementation using clustering method as well as the understanding and applications of load classification.

#### **2.4.2 Nature of Load – based Classification:**

Based on type or nature of Loads, there are heterogeneous and homogeneous Loads

##### **(i) Heterogeneous and Homogeneous Load**

Loads are further divided into heterogeneous and homogenous loads depending on the application area. According to (Zhang *et al.*, 2013), a model of a large number of similar devices is obtained through statistical aggregation of individual component models. This aggregated dynamic model are developed for a homogeneous population of thermostatic loads using stochastic diffusion models based on solving Fokker-Planck partial differential equation (PDEs). The approach is further extended, where a closed-form solution of solving Fokker-Planck equations is derived and the need for having heterogeneous population of loads was motivated. Residential or commercial end-use loads can be divided into two principal classes, one for all non – thermostatic loads, such as lights and plugs, and one for all thermostatic loads, such as water heating and air-conditioning (ATM, counters, ie frequently switched devices). Single devices of thermostatic loads give rise to pulse sequences where the pulse width and frequency

arise from the control hysteresis and heat balance in the load, while power drawn changes between two or more relative fixed values.

**(ii) Homogeneous Loads**

Mitra and Dutta, (2016) presented a load demand response following strategy for an interconnected source and load system. The load considered in the study of Thermostatically controlled loads (TCLs) and renewable power injection was used. Bilinear aggregate model was developed for aggregate evaluation of the multiple TCL aggregators so as to regulate the regulation capacity and the regulation rate. The major problem solved in this work is the optimization of the optimal generating schedules for generating units and planned utilization for TCL aggregators. The models considered are the model for a single TCL and an aggregator, look ahead economy dispatch and distributed pinning control of multiple aggregated TCL which is proposed. From the simulation result using IEEE-9 bus system and Monte-Carlo method, the load following strategy proposed can guide the aggregate power of the load agent in an orderly manner.

Chertkov, Deka, and Dvorkin., (2018) considered optimal control of load in distribution grid with network constraint. The loads considered are flexible loads (TCLs) because they are technically feasible to participate in demand response (DR) programs. Three factors were considered in this control of the TCL loads;

- i. The aggregated TCL loads must operate in synchronism to scale DR benefits.
- ii. Uncertainty of TCLs need to be accounted for
- iii. Exercising the flexibility of TCLs need to be coordinated with distributed system operations to avoid unnecessary power losses and compliance with power flow and voltage limit

The method formulated or proposed by the authors is the open loops stochastic optimal control. Aggregated Markov process was used to ensemble the TCLs, where each Markov process state with a given power consumption or production level. This Markov process was extended to a multi-period distributed power flow optimization.

A transition probability matrix was developed for the optimization to control the TCLs ensembles and physically enabled by local active and reactive power controls at TCLs location. The optimization was solved with Spatio-Temporal Dual Decomposition (ST-2D) algorithm and the performance is shown using IEEE 33-bus distribution model. The proposed method shows that the optimal dispatch decisions on TCL ensembles are sensitive to the assumption made on their comfort (utility) function and to the network constraint. The work was limited to TCL loads and utility function.

Mathias, Basic, and Meyn., (2017) considered demand dispatch with heterogeneous intelligent load. The authors presented a distributed control architecture which is intended to make a collection of heterogeneous loads appear to the grid operator as a nearly perfect battery. In the work, a decentralized control design is utilized, to balance resources of much lower cost and greater performance, the design respects the limitation of loads which are based on dynamic constraints as well as strict bounds on the quality of service (QoS) delivered to consumers. The paper also addresses the question of which intelligence is required to implement demand dispatch. The distributed control architecture considers the grid level control using inverse filter design and a design with heterogeneous load. The parameter considered for the grid simulation are the design of virtual battery open loop tracking, closed loop performance, time varying capacity, resource availability and cost and ramp services. The parameters are used to investigate the management of the heterogeneous loads on a battery based renewable energy on a time load varying condition.

Koch, Mathieu, and Callaway., (2011) considered a novel modelling approach for aggregation of large number of TCLs such as refrigerators, water heaters, etc for short term (seconds to seconds) demand response auxiliary service, such as balancing and frequency control. Markov chain statistical approach is used to describe the evolution of probability mass in terms of temperature state space. A predictive controller is used to control the aggregate population of loads such that it tracks a signal. A simulation example is done on an approach to realistic systems, which include a comparison of control performance depending on available state information and controller parametrization. The work concentrates more on elastic loads without the consideration of general load type.

Kundu, Sinitsyn, Backhaus, and Hiskens., (2011) investigates control of TCLs. The author stated that as load increases, there will be need to control TCLs for proper management of loads, which can contribute greatly to the fluctuation in generated power. The authors derived a transfer function relating the aggregate response of a homogenous group of TCLs to disturbance that are applied uniformly to the thermostat set point of all TCLs. In the discussion of set point variation, the authors stated that control of active power can be achieve by making a uniform adjustment of all load within a large population, most especially the TCLs. Although, making reference to general load, the authors limited their study to control of TCLs alone.

Totu, Wisniewski, and Leth., (2015) modelled population of loads with switching rate actuations. The authors argued that TCLs can be used to balance out grid fluctuations. It can also be used to reduce the overall capacity of spinning reserves, and contribute towards integration. The authors developed a stochastic hybrid model for the TCL unit for unactuated TCL and switch rate actuation using focker-plank equation and successfully verify it using Monte Carlo simulation. Also, the work is limited to using TCLs to control grid renewable input.

## **2.5 Demand – Side Energy Management**

### **2.5.1 Demands-Side Energy Sources**

Demand Side Management is the term for all activities undertaken by load- Serving Entity or its customers to influence the amount or timing of electricity they use (Wikipedia, 2008). Energy management, also known as Demand-Side Management (DSM) or demand-side response (DSR) is the modification of consumer demand for energy through various methods such as financial incentives and behavioural changes through education. Usually, the aim of demand side management is not to encourage customers to use energy during peak hours, or to move the time such as night times and weekends.

Peak demand management does not necessarily decrease total energy consumption, but could be expected to reduce the need for investments in networks and or power plants for meeting peak demands. Example is the use of energy storage units to store energy during off-peak hours and discharge them during peak hours.

A new application for DSM is to aid grid operators in balancing intermittent generation from wind and solar units, particularly, when the timing and magnitude of energy demand does not coincide with renewable generation.

#### **2.5.1.1 Forms of Demand – Side Energy Sources**

As every demand continues to expand, different suggestions are proposed by researchers on how to improve the supply even if it is at a higher price, but to meet the consumers need. To this end, there were need for proper energy demand-side structure which will tend to be in a dynamic form if new suppliers are to be considered to boost the generation,(Goldman *et al.*, 2010) The technology approach will determine the nature of the behaviour of the demand response price. This approach depends on the mode of supply considered to counter the demands of consumers

at every point in time. The supply of source can be on emergency-based, normal supply of distributed generation considerations.

### **2.5.2 Normal Supply Demand-Side Response**

Normal supply from the grid to the consumers without the need of an external source input have been the normal trend in some nations and Nigeria also, which have proven to be ineffective in solving the needs of individuals. The only advantage of this form of demand response is that the cost of supply is at considerable price which is regulated by the national agency in charge of power with the market operators. The price can also be subsidized further by the agency in line within government directive.

In a low economic area of a nation, their major reliance is on this mode of source since the consumers are limited to support from the governing agency, though, since the nation cannot totally cater for the need of every day, constant supply cannot be guaranteed. Consumers have to maintain the use of power only when it is made available to them if the area has to be subjected to load shedding. To counter the problem associated with the usage of individuals, most researchers have proposed several means of moderating the consumption of individuals, thereby making more power available for usage.

Barbato and Capone, (2014) suggested the use of smart meter that introduces a threshold usage for every consumer. Consumers according to the author will be charged on a higher price when the threshold is exceeded. This will create a consciousness on the consumers' usage.

(Energy Sector Management Assistance Program, 2011) in its article in implementing energy efficiency and demand side management suggest the sensitization of consumers on the use of energy efficiency appliances to boost the supply of power in South Africa. This was as a result of the crises faced in 2008 in South Africa when there was a shortage in supply (about 10% shortage). Then, those whose reliance was purely on the grid supply or normal grid supply were

on blackout till some remedies were done. This shows that over reliance on the normal grid supply will only lead to constant denial of power at a lower generation or when there is a problem with any generation.

Most times, the market operation of this type of source consideration brings about a constant pricing per kilowatt of power. The constant pricing is decided on when all considerations have been done by the market regulators. The constant pricing is due to the fact that the source of power is from constant generation on daily basis. The price of operation, maintenance and production of power, etc, are assumed to be constant. The pricing can only change when there is deviation in the cost of, (e.g. fuel cost) which can be for a long period of time (Haney *et al.*, 2012).

### **2.5.3 Renewable Source Demand Side Management**

In recent times, the trend of researches has been in the introduction of renewable energies to assist the existing supply. In Germany, where renewable energy plays a vital role in their supply, (supplies more than 80GW of power from renewable energy), the availability of power at a very low cost have been achieved. This has countered the problem of power to the extent that excess power is available after supplying to all consumers (the introduction of renewable in Germany brought suppliers close to the consumption site). The transformation came as a result of the electricity privatization policy in 2006. This policy gives right to anybody who have the capacity to generate or distribute power can play a part in the power market. This gave rise to more than 1000 distribution companies in Germany of which some also generates alongside distributing to individuals, (Deloitte, 2014); (Brandt, 2009).

Due to the improvement in the German electricity market, most nations are tittering to the use of renewable energy to counter the problem of power supply. Most nations, like Nigeria targets the use of renewable energies to produce at least 20% of the power needed in Nigeria, (Olugbenga,

Jumah, and Phillips., 2013). The advantage of renewable energies is not only that it can be environmentally friendly but can also reduce the cost of power. This is due to the reduction in the use of fuel which attracts the major costing in the use of DGS. After the installation, cost attracted will only tend to operation and management of the renewable energies without any worry on the fuel cost, (Longe, et al, 2017).

Drovtar, Rosin, and Kilter., (2016), suggested the use of DGS for low demand areas since introducing them in the direct grid supply will result to losses which will increase the cost of power. DGS have advantage of reducing the losses incurred due to transmission since it is located at load centres. This will not only reduce the cost of transmission, but also the cost incurred during operation and management. The major problem encountered is the cost of installation. The author(s) took a case study of Estonia.

Introduction of renewable energies can be done in different ways; by consumers (personal owned), organizations, and cooperatives or by high penetration into the grid. Most individuals cannot afford the installation of renewable energies but, can rely on organizations whose supply is through DGS. In recent times, most emerging IPPS are tending to the use of DGS as it is more economical and less stressful to them. The best form of installation of DGS is when consumers come together, as in a form of cooperative, and decided to install DG(S). This will be cooperatively owned property which will reduce the cost of power to the lowest minimum. The market is decided by the cooperative members and prices. Both at peak and off-peak can be constant. The only cost incurred will be on the management and operation of the DGS which can be countered if excess of the supply can be given to non-cooperative members. Cooperatives purchasing for the property will be very stressful at the installation level, but, very economical as time goes on, (Agbo *et al.*, 2015); (Tommaso, 2015); ( Mendes, *et al.*, 2011).

## 2.6 Load Flow and Models in Power System

The steady-state analysis of the power system network is called load flow analysis, and load flow analysis determines the shared loading operating condition of the system (Bansal, 2022). The load flow method decodes a collection of concurrent non-linear algebraic power equations for the two unknown variables at each system node. (Afolabi, et al, 2015). Knowing the voltage allows one to calculate the power flow via each network bus and the impedances of the lines connecting them (Gaya, Sokunbi and Habiballa ,2020). The total power flow of all the lines linked to each bus, which serves as a network terminal, goes into and out of each bus. Finding the set of voltages, including their magnitude and angle, as well as the network impedances that result in the load flows that are known to be accurate at the system terminals is the solution to the load flow problem. At first glance, electricity system is considered as a network of buses connected by line and equipment supplying or drawing electricity from the system to each bus, assumed as nodes (Singhal, 2014).

When a power system is running under typical steady-state or static conditions, the load flow (or power flow) solution used to calculate the current, voltage, active power, and reactive volt-amperes at various locations in the system (Muzzamme ,2019).

The power system load flow is classified into three bus configurations (Afolabi et al., 2015):

- i.* **The load bus** with specified variables P-Q and unspecified variables  $|V|, \delta$ . At this type of bus, the net powers  $P_i$  and  $Q_i$  are known ( $P_{Di}$  and  $Q_{Di}$  are known from Load forecasting and  $P_{Gi}$  and  $Q_{Gi}$  are specified). The unknowns are  $|V_i|$  and  $\delta_i$ . A pure load bus (no generating facility at the bus, *i.e.*,  $P_{Gi} = Q_{Gi} = 0$ ) is a PQ bus.
- ii.* **The generator or voltage controller bus** specified variables P,  $|V|$  and unspecified variables Q,  $\delta$ . At this type of bus  $P_{Di}$ , and  $Q_{Di}$ , are known a priori and  $|V_i|$  and  $P_i$  (hence  $P_{Gi}$ ) are specified. The unknowns are  $Q_i$  (hence  $Q_{Gi}$ ) and  $\delta_i$ .

- iii. **The slack or reference or swing bus** specified variables  $-|V|$ ,  $\delta$  and unspecified variables  $P$ ,  $Q$ . The fact that actual and reactive powers at this bus are not stated sets it apart from the other two types. Instead, the voltage level and phase angle (which is often set to zero) are stated.

Where  $\delta$  is the phase angle of the voltage;  $P$  is the active power and  $Q$  is the reactive power.

One of the fundamental power system analyses performed at the power system planning, design, and operation stage of power system planning, design, and operation is the load flow analysis. This determines the system's steady-state performance under various operating scenarios and investigate the implications of changing the equipment's setup. The load flows analysis could be carried out for the DC and AC Models:

### **2.6.1 DC and AC Load Flow Models**

Only active power flows are taken into account, faultless voltage support and reactive power management are assumed, and transmission losses are ignored in DC power flow. As the non-linear AC power flow is linearized into the DC power flow, the linearization's reference point matter. For AC power networks, direct current load flow provides estimates of line power flows. Reactive power flows are ignored in direct current load flow, which solely considers active power flows. Although this approach is absolutely convergent and non-iterative, it is less precise than AC Load Flow solutions. The sequential modified Gauss and Gauss-Seidel power flow for AC-DC systems is designed using a straightforward and trustworthy method. The foundation of this strategy is the application of nodal injection theory to all buses. The current supplied to the buses where the DC system is attached treats it, and its effect is reflected at internal buses by the addition of power injection. The boundary conditions of the two systems are matched through iterations of the AC and DC power flow algorithms. In this method, each iteration step considers the interface between the AC and DC equations to be the active and reactive power as well as the

AC voltages at the converter buses. The sequential modified Gauss and Gauss-Seidel methods are used individually to solve the combined AC-DC equations (Messalti *et al*, 2012).

Rezvani and Mehraeen (2021) formulate a unified model for Ac-Dc analysis of the load flow and the power industries were compelled to adopt for their future of distribution systems in order to reap the benefits of both ac and dc grids. These grids have a lot to offer the power system in terms of stability, reliability, and resilience, they also complicate studies of power networks by increasing the need for evaluations of load flow, short circuits, dynamic behavior, and stability. The presence of ac-dc converters causes several complications. A hybrid grid requires the simultaneous or sequential solution of the ac and dc system in Figure 2.3.

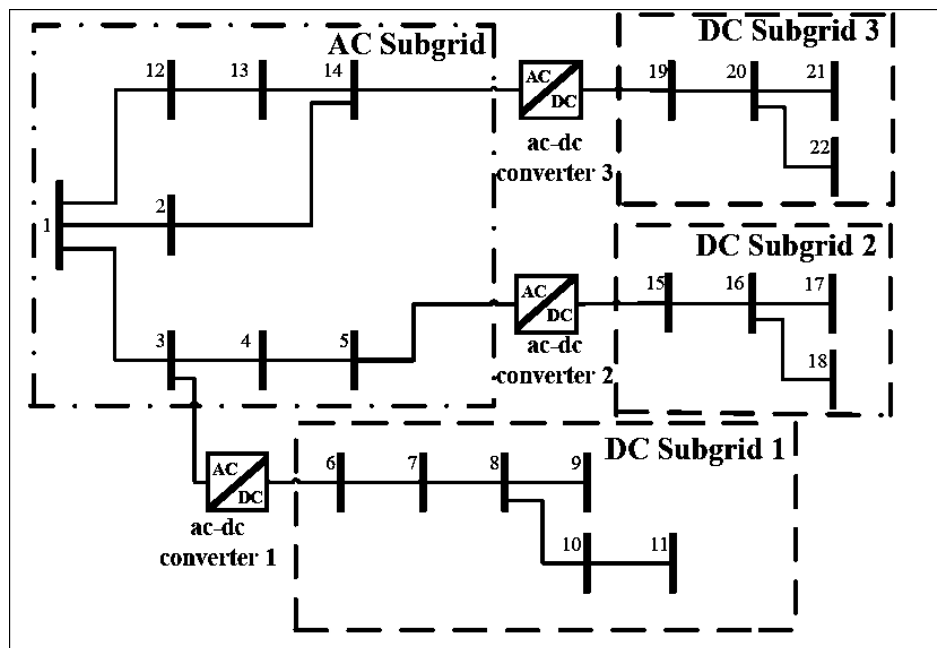


Figure 2.3: Typical Unified Ac-Dc Hybrid Grid Model

Despite the sequential technique being the focus of attention, simultaneous approaches have not been thoroughly studied because of significant technological obstacles. In order to better understand the ac equivalent circuits of dc grids, this research explores.

The fundamental concept used converter theory on all converter buses and nodal injection theory on all converter buses to determine the injected currents in both DC terminals. Only in the buses to which they are attached can DC terminal currents enter AC equations as in figure 2.4.

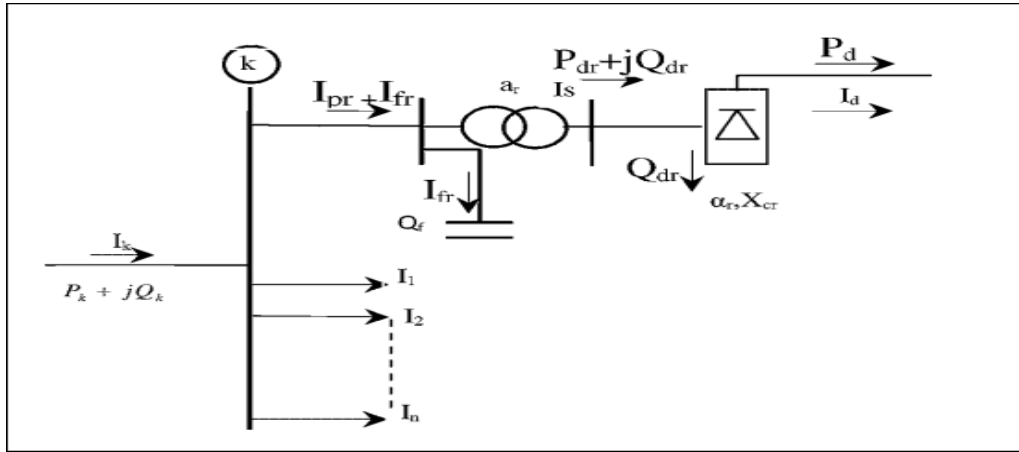


Figure 2.4: Simple AC-DC power System Nodal

These procedures create the admittance matrix for the hybrid grid system based on the Bus Bar described before the load flow model was created. This study demonstrates how, with certain adjustments, the traditional load flow analysis of ac power systems may be used for hybrid ac-dc grids.

## 2.6. 2 Methods of Load Flow Model Analysis

The Gauss-Siedel method, the Newton-Raphson method, and the Fast-Decoupled approach have all been utilized for load flow analysis. On the basis of the number of iterations attained, the three load flow strategies have been contrasted. Power travels from generating plants to load centers in a power grid (Afolabi et al,2015; Singhal, 2014).

### i. The Gauss-Siedel method

Set of nonlinear algebraic problems are solved iteratively with the use of an initial assumption for the voltage value to calculate the value of a certain variable. A determined value is used in

place of the initial guess. Once the iteration solution converges, the process then repeated itself. The starting values that are assumed have a significant impact on the convergence but this approach has weak convergence properties. Kirchhoff current law are used to assume the current injected into bus.

#### Advantages of Gauss-Siedel method

- a) Memory requirements for small computers
- b) Ease of use of the method
- c) Shorter computation times for each iteration.

#### Disadvantages of Gauss-Siedel method

- a) The number of iterations rises in direct proportion to the number of buses.
- b) There are many iterations due to the slow pace of convergence.
- c) The impact of choosing a slack bus on convergence.
- d) Because there are more iterations, the Gauss-Siedel approach requires more computer memory.

#### **ii. *The Newton-Raphson method***

This method uses Taylor's series expansion, it is an iterative method that restricts the terms to the first approximation and approximates a set of non-linear simultaneous equations to a set of linear simultaneous equations. The Newton-Raphson approach is comparatively reliable because it can resolve situations that cause divergence with other well-known processes, and it is the most iterative method used for load flow because of its convergence characteristics that are relatively more powerful than other alternative processes. The result is reached extremely rapidly if the assumed value is close to the solution, but the approach may take longer to converge if the supposed value is farer from the solution.

#### Advantages of Newton-Raphson method

- a) This Method is faster, more reliable and results are more accurate.
- b) Generally, it's suitable for large systems.

#### Disadvantages of Newton-Raphson method

- a) The coding rationale is more intricate than the Gauss-Siedel approach.

#### **iii. *The Fast-Decoupled Method***

One of the improved approaches is the Fast Decoupled Power Flow Method, which was introduced by Stott and Alsac in 1974 and is based on the Newton-Raphson method's simplification. In load flow analysis, this method—like the Newton-Raphson method—offers computation simplifications, quick convergence, and accurate outcomes. Nevertheless, because rapid decouple is an approximation method and makes some assumptions to reduce the Jacobian matrix, it may not converge effectively for some circumstances where high resistance-to-reactance (R/X) ratios or severe loading (low voltage) at particular buses are present. In these situations, numerous efforts and advancements have been made to get over the convergence barriers. Some of them focused on the convergence of high R/X ratio systems, while others focused on low voltage systems.

#### Advantages of Fast-Decoupled Method

- a) The linearization of the matrix equations makes this method simpler.
- b) Where the X/R ratio is larger, the power system is suitable.
- c) Memory use is lower than using the Newton-Raphson Method.

#### Disadvantage of Fast-Decoupled Method

- a) So much iterations than the Newton-Raphson technique is necessary.

The summary of the load flow methods could be given in terms of speed and accuracy:

- i. Gauss-Seidel method is very slow in speed and approximately accurate
- ii. Newton Raphson method is slow and accurate
- iii. Fast Decoupled method is fast and accurate

### **2.6. 3 Software for Load Flow Model Analysis**

Several software could be used in the design and implementation the system load flow analysis for power system. The following are some of the software:

- i. **Electrical Transient Analyzer Program (ETAP):** This is an electrical network modeling and simulation software program used by power systems engineers to generate an "electrical digital twin" to investigate electrical power system dynamics, transients, and protection. The ETAP Load Flow Result Analyzer is a time-saving tool that compares and analyzes several reports in one view time. It compares the outcomes of more detailed information, such as the load flow outcomes for buses, branches, loads, or sources, or more basic information about a project (Muzzammel, et al, 2019).
- ii. **MATrix LABORatory (MATLAB) software:** For IEEE 6, 9, 14, 30, and 57 bus systems, a MATLAB software was created to calculate the voltage magnitude, phase angle, active power, and reactive power at each bus. Three approaches for load flow analysis have been discussed in this thesis; the Gauss-Siedel method, the Newton-Raphson method, and the Fast-Decoupled method. On the basis of the number of iterations attained, the three load flow strategies have been contrasted. When you build and set up a three-phase AC or DC electrical power transmission system for analysis using Simscape Electrical TM, the Load-Flow Analyzer software performs a load-flow, or power-flow, study. Three tables are produced by the app. The data for the AC network nodes, which are represented by the AC busbar, load flow source, synchronous machine, induction machine, and three-phase load blocks, are found in the AC

Nodes table. All busbar data is contained in the AC & DC Busbars table. The transmission line and transformer blocks that make up the network connections are represented by data in the AC Connections table (Singhal,2014; Vijayvargia et al., 2016)

- iii. **PowerWorld Software:** The research presented in this paper examines the fundamental characteristics, mechanisms, benefits, and drawbacks of long-distance power transmission through the analysis of a number of case studies built around a straightforward simulated system made using the PowerWorld software. In particular, the variables that affect active power, reactive power, voltage magnitude and phase, among other power flow variables, were evaluated and analyzed. The outcomes will then be contrasted with those of PowerWorld's simulations. The goal of the study is to help readers understand the PowerWorld package and all of its benefits, particularly for the research of power flow dynamics. (Zuo et al. 2015)
- iv. **Power Systems Computer Aided Design (PSCAD):** PSCAD computes the internal voltage required to maintain the specified terminal state behind the Thevenin impedance. Also mentioned are the positive sequence impedance and negative sequence impedance values. The study by Ishak et al., (2010) analyzes the flow of electric power under defined power and voltage input conditions, generating complete voltage data at all system buses, and presenting the results. The parameters of current flow and voltages were determined by this investigation. If there is no need for a huge power system, computing the solution to the power flow problem is simple. Nevertheless, utilizing a calculator or an iterative calculation method is difficult when a power system has hundreds or thousands of buses involved. The Power System Computer Assisted Design (PSCAD) program was used to address the power flow issue. There are other software packages available, including PSpice, however PSCAD was selected to tackle the power flow problem. Because of PSCAD
- v. **Power Factory Software:** A number of load flow calculation techniques are available from Power Factory, including a comprehensive AC Newton-Raphson technique (balanced and

unbalanced) and a linear DC approach. Round-off errors for all buses produced by the improved non-decoupled Newton-Raphson solution technique with current or power mismatch iterations are typically less than 1 kVA. The implemented algorithms show outstanding convergence and stability. Convergence is guaranteed over a number of iterations, with the option for automatic constraint relaxation and change. The DC load flow is exceptionally quick and reliable when accounting for active power flows and voltage angles (linear system; no iterations required). The load flow analysis is supported by the DIgSILENT PowerFactory program, which offers many ways for calculating the load flow. Current or power mismatch repetitions are combined with the Newton-Raphson solution technique, and the resulting algorithms exhibit high stability and convergence. It is true that the analysis of DC power flow rectifies the flow of active power and voltage angle. Several iteration levels can adjust limitations and ensure convergence under all circumstances (Bekal, Hosamani, Salunke, Patil, and Hedge., 2021)

## **2.7 Energy Integration and Harmonization**

The recent trend in power system, more especially in Nigeria is how to counter the problem of energy supply not sufficient for the consumers. Energy can be conserved through so many means like implementing and educating the environment of need to use energy efficient devices, collate different generators together to enable them reach their optimum usage, etc.

A sustainable energy can be regarded as a cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks, (Olayinka, 2012). In Nigeria, half of the energy consumed can be saved if energy is efficiently utilized, but the issue is that the energy policy has undermined the importance and gains of energy efficiency to the environment and economic growth.

Oyedepo *et al.*, (2015), further highlighted that though Nigeria is blessed with abundant sources of energy, it will still remain where it is unless structured and managed in such a way as to ensure sustainable energy development. Every individual or firm should utilize a low level, low risk, and economical way of accessing energy if energy problem is to be solved in Nigeria according to the author.

In 2014, energy policy was introduced hoping to create a competitive market, thereby creating seriousness among the distribution company to tend to constant power supply (Van Niekerk *et al.*, 2020). The hope of achieving that was destroyed when it was reversed to sharing the power supply market regionally among the interested distribution companies. Politicians with this advantage brought the asset with the hope of making so much from it without investing anything into the energy sector. So many means in which energy could be conserved have been overlooked by the current leadership in Nigeria. Technologies could have been implemented to improve on the power supply like installation of FACTS devices, accessing renewable energy supply which is environmentally friendly and reduced losses when located close to the consumers, generators pooling for maximum usage, orientation of consumers on energy efficient appliance usage, etc

With the recent increase in electricity price, it will be advisable for owners and operators to own their individual facilities to generate power. Another reason is the daily increase in demand due to new houses and industries emerging every day with little or no supply from the grid to satisfy the demand of the consumers. Energy owned by organization or individuals could be managed efficiently to minimize the cost of usage (Adjei-twum *et al.*, 2016). With the grid supply in Nigeria which is about 7,000MW trying to supply more than 50,000MW load demand with daily increase of demand could lead to so much load shedding and unsatisfied supply which cannot be resolved by reliance on the government alone. For more accessibility to power, individuals will have to create a system to access more power on their own. Or find a way to manage the little

supply from the grid. Though, individuals might manage to survive with the little supply from the grid (especially residential users), industries might have to fold relying on grid supply. This have led to so many industrial start down, and those who could survive had to think of a way of owning their own supply, though more expensive as compare to the grid supply.

Another means to harmonize energy is the use of energy efficient materials with the trend of technologies emerging. An example is the large consumption of refrigerator in the world, which accounts for almost 30% of power usage. Energy efficient materials will aid save more than 60% of the energy consumed which can also be transmitted to other usage. Almost all electrical and electronics materials energy consumption could be shranked to reduce the usage to a very large extend. This could be achieved by sensitization of the consumers on energy usage and also showing them its benefit in the reduction of the bills

In order to reduce the cost of energy, storage systems can be used by the consumers at time when power is available. The storage systems aid to store power for use at periods when there is no supply. Not just on the consumer's end alone, distribution systems can also introduce distributed generations to reduce the cost of power, which can in turn require a storage system. Distributed generation have been proven by researchers to be the best substitute to the lack of power availability and also economical. It is also chosen due to its low power losses encountered since it can be installed close to its load centres. Minimizing losses, accounts for cost reduction of power due to loss wastage and thus, results in availability of more power to the consumers. Also, Distributed Generation System (DGS) just like other system requires a onetime cost installation, and little costing based on maintenance, unlike some other means which accounts for fuel cost. Though the initial installation is cost intensive, studies show that it is more economical when compared with cost of fuelling generators over a long period of time.

### **2.7.1 Energy Market in Nigeria**

Since reliance of energy in Nigeria have been on the national grid which is controlled by the government who have no interest in satisfaction of the consumers but on the profit, they make by inducing payments on the consumers. Some researchers argue that to revive Nigerian power system, individuals and independent power producers (IPPs) have to play a major role in the power market,(Onochie., 2015);(Economists, 2016);(Roland & Kenneth, 2013);(Olugbenga *et al.*, 2013). This will aid to introduce more generating and distribution stations that will improve the electric power need and hence, increase the power market competition, thereby improving the seriousness of the market participants. At present, Nigeria have eleven (11) distribution companies spread across the geopolitical zones, with the intent that when privatization was done, (Joseph, 2014) ;(Awosope, 2014); (Makwe, et al, 2018), it would create competition in the market, but, at the end, a monopoly market was still maintained in the market structures giving the distribution company so much power that every complain of the consumers is neglected.

Several researches have been done to improve the Nigeria electricity Market structure and the current market operation which have created more problem than solution, and bringing about customer's dissatisfaction and reliance on individual generators. Most researchers argue that for a more effective market, a competition need to be introduced into the market, which will in turn reduce the cost of power and also make power readily available to every consumer. Imagine a scenario where more than three (3) distribution companies operate in a state and the consumers can choose who to rely on for supply which is what was introduced into German electricity market to transform the electric supply. The advantage on Nigeria electricity structure is not only to reduce the cost of power but, will also create jobs and also lead to constant power supply. Some researchers suggest that for a constant power to be guaranteed, individuals have to come in and play a major role in power investment. It is clear that reliance on the government who have not seen any need to invest thoroughly in power will yield no result. The market should not be

left for only the government whose major aim is to make them richer, but to individuals, cooperatives societies, industries, ordinary persons who have the idea on how to improve the market and power supply as well as its implementation. This was the initial idea before the politicians chose to share the power market among themselves.

### **2.7.2 System Integration, Synchronization and Paralleling**

Paralleling in electrical terms is the combination of synchronization of two electrical inputs by matching the output voltage waveform of one electrical system with another electrical system voltage waveform-synchronization can be between two or more generators or a generator with the utility supply(Onsite energy, 2017). When weighing the merits of a parallel system, a system designer considers the redundancy, capacity and UL (Underwriters Laboratories) codes for proper choice. Redundancy involves paralleling an incoming set with an outgoing set before the outgoing is switch off and shut down. Capacity allows addition set to be powered on when there is load increment. The UL codes help a system designer to choose a variety of system if paralleling with utility.

The synchronization of power system must be done with much carefulness. The speed (frequency) and the voltage must be close to instantaneous power phase angle prior to closing the generator breaker to connect isolated generator to the power system (Thompson, 2012).

Erdal & Alper, (2009) developed an automatic synchronization unit for parallel generators. In their work, two synchronous generators are connected in parallel automatically with the developed control unit and in parallel with the lines. The voltage, frequency, phase sequences and synchronization time data is transferred to the microcontroller. The data are monitored and evaluated with an algorithm and the system does not require an additional measuring tool for monitoring the control process.

Amin *et al.*, (2014) suggested a load management system in Pakistan which will minimize the power consumption, thereby reducing the cost of power. This work showed the limitations of running a single generator whether it is fully loaded or 20% loaded. The author suggested that to run an economic load management system, an automatic synchronization of all the generators can be achieved in the University of Gurat, which will be controlled based on available load in the system. Synchronizing generators in parallel can reduce the cost, number of personnel required and also increase in the reliability of the system.

Gawande *et al.*, (2010) suggested the use of FACTS devices to overcome the problem associated with thermal based generator use of non-conventional sources, though they are pollutant free and economical. The authors suggested STATCOM for issues of stability and synchronization. The authors gave an analytical solution using simulation platform to show the effect of STATCOM in voltage stability during synchronization.

Shinde & Bharadwaj, (2016) reviewed generator grid synchronization, its needs, effect, parameters and various methods. According to the author(s), “Synchronization” is important in overall power sharing process that it ensures quality reliability and efficiency within the power system and it is all about matching voltage, frequency and phase angle of both generator and respective connected grid. Three synchronization methods were cited by the authors in recent times; manual synchronization method; where operators control generator’s voltage magnitude, speed and operates the relays or breaker at the exact synchronization instant, manual with permissive relay which is similar to manual synchronization method but it has an additional sync-check relay and automatic synchronization where phase matching type is automated with a breaker closing angle window and voltage magnitude approval system.

Sen *et al.*, (2014) considers the design of a low-cost quasi automatic synchronizer for alternator. The work explores an automatic synchronizing process for three phase alternators in a cost-

effective manner. The design is in such a way that the individual voltage, frequency and phase sequence are measured with respect to incoming generators. Once the three parameters match for both generators they connected electrically using a relay circuit. These enable synchronizations by just pressing some switches, which will minimize the cost of installation as well as maintenance cost.

Dabowsa, (2011) introduces a new approach of generators synchronization using Controller Area Network (CAN). The device consists of three independent controller modules connected with CAN protocols, which are the circuit control breaker responsible for closing the circuit breaker between the generators, while the other two captures the voltage, frequency and phase differences for each generator due to reference signal and control of the governor of the generators. The author tries to focus on minimizing the false synchronization decision which is corrected with the CAN protocol which shows fastness in error detection. It is also cost effective because it eliminates the cost of construction and maintenance.

Synchronization of distributed generation can most times pose a big problem due to its low power quality and requires an accurate control not to disrupt the behaviour of the system.

Khalil *et al*, (2018) discussed issues connected to power converters, connected to the mains and the related control methods. The method was validated using 200KW wind generator connected to the power grid. The method employed is zero crossing synchronizer having zero error in steady state, moderate speed response to grid frequency changes, amplitude variation and harmonics and noise immunity. The proposed synchronism was tested with extreme disturbance on the grid voltage. The result shows that the phase angle converges to the real value in less than one grid period. The work is limited low DG penetration.

Miller, (2003) suggested that it will be proper that majority of the new DG is of a more conventional types that relies on rotating synchronous generators for energy conversion. The

properties of synchronous machines are substantially different from that of inverter-based DGs and have ability to affect the system's performance positively. This will be necessary since the whole world is tilting to distributed generation due to its advantages. The author further stated that high DG penetration will help the bulk power system performance, but will include some penalties and undesirable behaviours, such as overaggressive DG tripping becomes greater.

Varnado, Laurel and Sheehan, (2009) stated that several policy makers are working to resolve related issues on electricity generation by convention means, including ageing infrastructure, grid congestion, electric rate increases, natural price volatility, climate changes, diminished air quality and related public health concerns, reliability issues, energy security and energy efficiency which in turn affects grid synchronization, most especially DG impact on the synchronous systems. The author(s) also noted that interconnected standards should be set based on the type of generators to be considered and conditions stated above on the problems associated to interconnection.

The necessity for synchronizing parallel generators is due to the rated generated capacity of an existing system might not be enough for the new load demand, enhanced reliability, operating efficiency of the generator set, need for proper management during off-peak period to be managed by lower distributed systems like DGs, proper utilization of the power produced for economy purposes, to reduce losses due to single generator usage. In the case of incoming generators, it must be synchronized properly to ensure minimal disturbances to the bus, minimal shock to the generator (mechanical and electrical) and rapid loading of the oncoming generator per-take in the supply (Basler Electric Company, 2016).

Kumar et al., (2016) accounts for the use of fuzzy logic to control the grid fault in synchronizing DGs to grid supply. The author(s) stated that to achieve satisfaction with DG grid synchronization, it is necessary to count accurate and fast grid voltage synchronization algorithms, which are able to work under unbalanced and distorted conditions. The analysis was

done under three advanced synchronization systems, the decoupled double synchronous reference frame phase-locked loop (PLL), the dual second order generalized integrator PLL, and the three-phase enhanced PLL. The analysis done showed that using fuzzy logic gave rise to a better system which reduced the possibility of polluted network due to their greater band pass or low pass filtering capabilities.

### **2.7.3 Recent Energy Integration Model**

The new paradigms and latest developments in the Electrical Grid are based on the introduction of distributed intelligence at several stages of its physical layer, giving birth to concepts such as Smart Grids, Virtual Power Plants, microgrids, Smart Buildings and Smart Environments. Hernandez et al., (2014) applied Short-Term Load Forecasting (STLF) in microgrid environments with curves and similar behaviours by comparing two different data set. Based on the comparison the first one packing electricity consumption information during four years and six months in a microgrid along with calendar data, while the second data set was just for four months of the previous parameters along with the solar radiation from the site. The model that took into account the solar radiation, since the photovoltaic installations of the microgrid will cause the power demand to fluctuate depending on the solar radiation. Marquez et al., (2013) came out with a model that described a new hybrid method that combines information from processed satellite images with Artificial Neural Networks (ANNs) for predicting global horizontal irradiance (GHI) at temporal horizons of 30, 60, 90, and 120 min. The forecasting approach used information gathered from satellite image analysis including velocimetry and cloud indexing as inputs to the ANN models. The result obtained enable comparison of the hybrid approaches using standard error metrics to quantify the forecasting skill for the several time horizons considered.

Community micro-grids, as a new generation of community energy infrastructure, share similar challenges to other public infrastructure projects, such as roads and water in reducing costs and attracting finance. Generation and distribution assets in a community micro-grid require effective management of common pool resources. The electricity to be consumed is rivalrous, in that, their consumption by one consumer prevents or reduces simultaneous consumption by other consumers. The transportation of the electricity by the distribution network requires load and capacity management that can increase in complexity with increasing number of users (Brown et al., 2021). Its rivalrous nature is particularly prominent when the network is at congestion during peak demand period. In short, a community electricity facility is limited in physical capacity and its overuse leads to negative consequences, including reduced quality and reliability of electricity supply, inequality of electricity provision, and higher maintenance and replacement costs. Its non-excludability allows everyone within the micro-grid network access to the facility. Absent preventative measures, the free riding problem can present, which may lead to collective provision to be undersupplied by private companies (Wang & Song, 2006). Distributed generation units – such as solar PV, battery storage units – are often site/location specific infrastructure that can only be redeployed to other locations with significant additional costs, such as transportation and labour costs. These assets have large upfront capital costs and require periodic maintenance to retain high technical performance. Distribution assets require large capital stock which can only be installed in location- specific, discrete units. These investments are immobile and sunk once these infrastructures are established and there is generally no possibility to turn them into other physical goods or for resale (Xu et al., 2019).

The research conducted by (Jenkins et al., 2018) used mixed integer linear programming formulation to more accurately represent the distinct technical operating constraints of nuclear power stations, including impacts of xenon transients in the reactor core and changing core reactivity over the fuel irradiation cycle. In a power system with significant solar and wind

energy was said to be very flexible with a high potential. It was pointed out that flexible nuclear operation lowers power system operating costs, increases reactor owner revenues, and substantially reduces curtailment of renewables. In the same vein, flexibility is said to have valuable energy transition to low-carbon power systems with higher shares of variable renewable energy sources such as wind or solar power

Alonso-Montesinos & Batlles, (2015) developed a useful model that predicted sky conditions, demonstrating its potential as a useful application in decision-making processes at solar power plants using solar component such as beam, diffuse and global. The key to managing solar plants for correct electrical grid management is the prediction of atmospheric features. Meteorological conditions are decisive in solar plant management and electricity generation. Any increases or decreases in solar radiation mean a plant has to adapt its operation method to the climatological phenomena. An unexpected atmospheric change can provoke a range of problems related to various solar plant components affecting the electricity generation system and, in consequence, causing alterations in the electricity grid. The increasingly widespread use of CSP (concentrated solar power) plants to produce electricity has generated a constant search to improve and optimize final production. As a matter of necessity, (Alonso & Batlles, 2014) presented a short and medium-term cloudiness forecasting that predicted cloudiness using beam, diffuse and global radiations under all sky conditions, presenting the results in a general way and classifying them into cloudless, partially-cloudy and overcast conditions. The ESRA model was used to estimate the three solar radiation components under clear skies, whereas the Heliosat-2 method was utilized to model total atmospheric attenuation. Huge success was recorded as the beam and global radiation presented an nRMSE value lower than 9% and an R value close to 1 for the three hours predicted, whereas the diffuse component presented lower RMSE values, having an nMBE value lower than 4% in all cases. However, the rapid appearance of cloud transients in partially-

cloudy skies, were not seen by satellite images thus provoking a decrease in the solar radiation forecasting success rate.

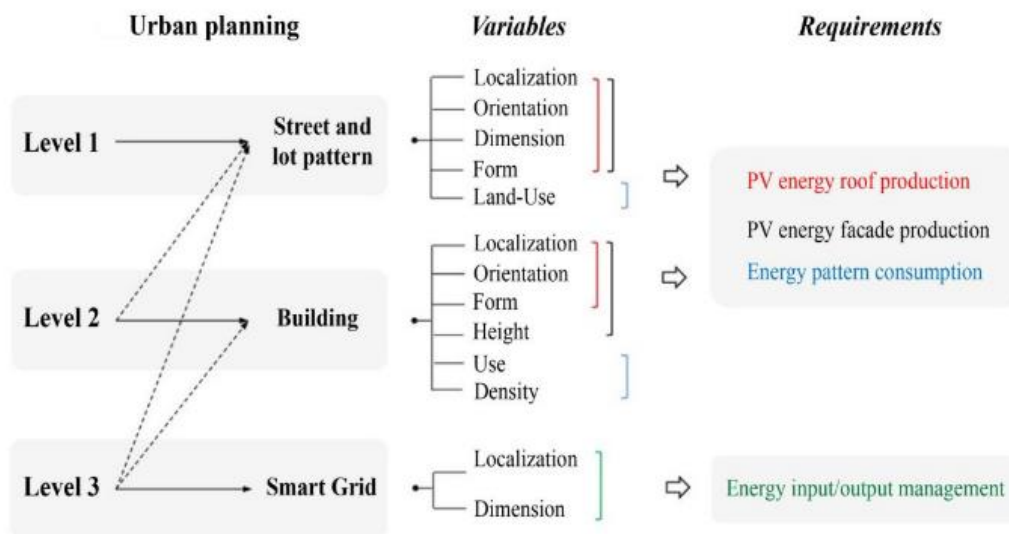
The "hard" modeling techniques promoted by scholars in the engineering and economics fields have dominated the energy sector. The contemporary trend in favour of a liberalized society shifts from centralized management to market-based available resources, resulting in the invention and usage of strategic instruments with very much "softer" criteria, in the "systems-thinking" lineage. In order to provide a foundation for integrated energy analysis, (Dyner, 2000) presented the application of system dynamics in a generalized manner. In order to make the modeling platform more usable and reusable, considerations of modularity and strategy change are crucial. Therefore, the idea of a platform—as opposed to a model—must be executed in a consistent manner if it is to continue to add value for complementing corporate strategy and government policy Dyner, (2000).

A significant paradigm shift in the planning and operation of electric power networks is presently underway, mostly due to the extensive integration of renewable energy sources. The "smart grid" integrates the relevant information technologies to make more effective use of the available resources, enabling higher adoption of them within the current grid infrastructures. It was necessary to create new automation architectures, control strategies, and relating information and communication solutions in order to take advantage of the benefits of such smart grids. This enables the efficient use of a large number of distributed generators and the utilization of their "smart" capabilities. To handle a large number of distributed generators, the scalability and openness of automation systems now employed by energy utilities must be greatly increased. Due to the lack of open and common interfaces and the sheer quantity of various protocols, this will be required to address the difficulties. These issues have been addressed by a conceptual approach for open and interoperable information interchange and the building of automation applications. The technology was distinguished by remotely controlled services, a general notion

for communication, and a formal mechanism for modeling applications for decentralized energy resource components. In addition, a fine-grained separation of access rights for used cases and actors was made possible by the development of an access management system for distributed energy resources that took into consideration various customer roles in the smart grid. Finally, was the creation of a generalized, open line of communication foundation for smart grid components, which offers a versatile and adaptable facilities and supports future smart grid requirements and roll-out. The key advantages of this strategy have been validated by proof-of-concept testing of the remote controlled service idea built on this infrastructure in suitable laboratory settings (Veichtlbauer et al., 2021).

One of the most significant difficulties for the future of humanity is supplying energy responsibly, with more than half of the world's population already living in cities and almost 75% of people projected to do so by 2050. The Geographical Urban Units Delimitation (GUUD) model was used by the authors to illustrate how solar energy can be integrated into urban planning. The idea behind this is that urban areas like neighborhoods and city centers can be transformed into solar power plants that operate similarly to atoms. The GUUD model, which draws inspiration from the cellular automata (CA) concepts, assumes that the city is divided into "cellular units" in accordance with four delimitation criteria: the timeline for construction, population density, urban morphologies, and land-use patterns. To do this, the model was calibrated to collect a selection of data inputs which are the bases of a workflow that combines GIS with parametric modeling and solar dynamic analysis. Its application to a case study demonstrates how crucial it is to comprehend the current urban models in order to relate them to energy aspects at the scale of the entire city. Moreover, the results of solar dynamic analysis suggested how the energy supply from the widely available installation of photovoltaic systems in the urban context can provide a sustainable contribution to energy demands but at the same time has to be supported by smart grids for its correct management and completed by more

energy efficient buildings and other renewable resources towards the city energy balance (Amado & Poggi, 2014).



**Figure 2.5: GUUD Model (Lund et al., 2014)**

(Lund, et al, 2014) offered the results of a series of research that assessed the issues and prospects of changing the existing energy system into a full renewable energy system by employing a smart energy systems methodology. As a contrast to, for example, the smart grid idea, which places a singular focus on the power industry, smart energy systems incorporate the complete energy system in its means for identifying optimal energy system designs and operation techniques. Transmission lines, flexible power demands, and electricity storage are frequently identified as the main strategies for integrating erratic renewable energy sources into the smart grid due to the traditional smart grid's exclusive concentration on the electrical sector (Lund et al., 2014).

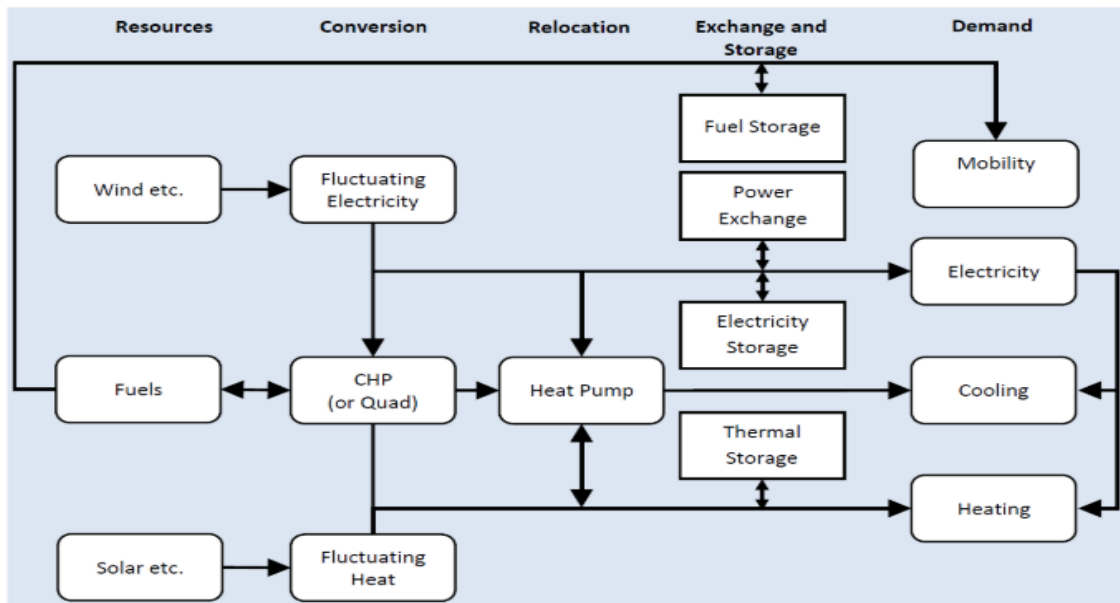


Figure 2.6: Smart Energy System Illustration (Lund et al., 2014)

The nature of wind energy as well as many other similar sources, however, has the effect of making these measures neither very effective nor very cost-efficient. When the heating, cooling, and/or transportation sectors are combined with the electricity sector, the most cost-effective and efficient solutions can be found. Additionally, the design of future renewable energy systems may benefit from the integration of gas and electrical infrastructures. The authors illustrated the incorporation of flexible combined heat and power (CHP) generation (Fig 2.6) in the electricity balancing and grid stabilization and provides an illustration of why electrical smart grids should be viewed as a component of overall smart energy systems. Furthermore, it demonstrates how to build and simulate prosperous and sustainable smart energy systems (Lund et al., 2014).

A smart grid is a network of energy devices that allow energy to be exchanged between users in a smart way (Lund et al., 2014) (Espe et al., 2018). This means that prosumers can help to keep the grid running by using their energy, producing energy, storing energy, and sharing energy with other prosumers. Researchers have been interested in this type of community because it is important for the long-term sustainability of the grid and the efficiency of energy sharing. Prosumers are new components of a smart grid that generate, consume, stored, and distribute

energy to many other grid subscribers (Espe et al., 2018). (Cabrera et al., 2018) proposed a new approach built on the idea of smart energy systems. Increased penetration of renewable energy is the goal for islands. The technique is applied to Gran Canaria (a Spanish island), taking into account the whole island's energy system. A cross-sectional approach involving the electricity, heating/cooling, desalination, transport, and gas sectors was taken to consider a number of smart renewable energy techniques. In order to make the switch from the current energy system to one that is almost entirely powered by renewable energy, a number of smart renewable energy strategies were implemented. Based on an analysis, the study draws the conclusion that the recommended approach is appropriate for boosting renewable incorporation on islands and may even be utilized to assist energy planners in choosing objectives for the sector's growth to enhance such integration. The findings suggest that, in the instance of Gran Canaria, a 75.9% renewable energy system might be achieved with currently available technology. Furthermore, it is demonstrated that Gran Canaria might reach a virtually entirely renewable energy system if some technologies mature more quickly (Cabrera et al., 2018).

The traditional one-way power flow from power generation to end consumers will be replaced by a bidirectional-way power flow with a multidirectional electricity network among central grids and distributed prosumers as a result of increased access to renewable energy resources and quick ubiquitous connection of all. Digitalization and decentralization are the main drivers for achieving a transactive Energy Internet (EI), which is prosumer-centric and enhances the integration of services that are energy-aware. The Internet of Things (IoT) and blockchain both contribute to the digitization and decentralization of transactive provided a thorough analysis of these two trends (Wu et al., 2021).

The decentralization of energy supply and demand can contribute decisively to protecting the environment and climate of the planet by consuming electricity in the proximity of the generation source and avoiding losses in transmission and distribution. Blockchain technology happened to

be another possible way to support the formation and use of energy communities. (Petri et al., 2021) proposed a model using Block chain-based energy framework as a mean to support energy exchanges in a community of prosumers. And it was further demonstrated how smart contracts could manage energy transactions and enable a more secured trading environment between consumers and producers. From the work, it was evidential that the usage of Block chain technology in energy markets attest the use of renewables and provide a reliable framework to monitor real-time information of energy production and consumption.

When operating in grid-connected and islanded modes, the microgrid central controller (Fig 2.7) plays a significant role in ensuring efficient automated operation and control of the system. Numerous elements of the central controller allow for appropriate coordination of dispersed energy resources according to their ability to provide enough power to support both critical and non-critical loads. When a severe short circuit fault occurs at the grid end or in the microgrid, it also starts the protection procedures, assuring stability and dependability. Kaur, Kaushal, and Basak.,(2016) explored and presented the development of microgrid central controller technology in a condensed manner (Fig 2.8). Based on the results of the evaluation process, it was suggested that microgrid central controllers be categorized (Kaur et al., 2016).

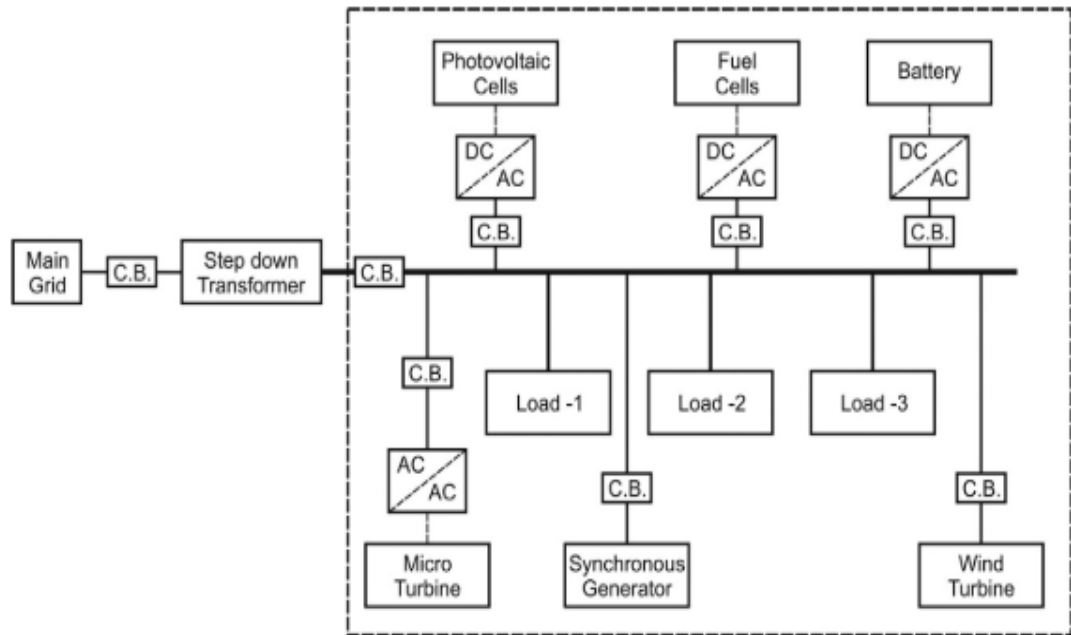


Figure 2.7: A typical Microgrid (Kaur et al., 2016)

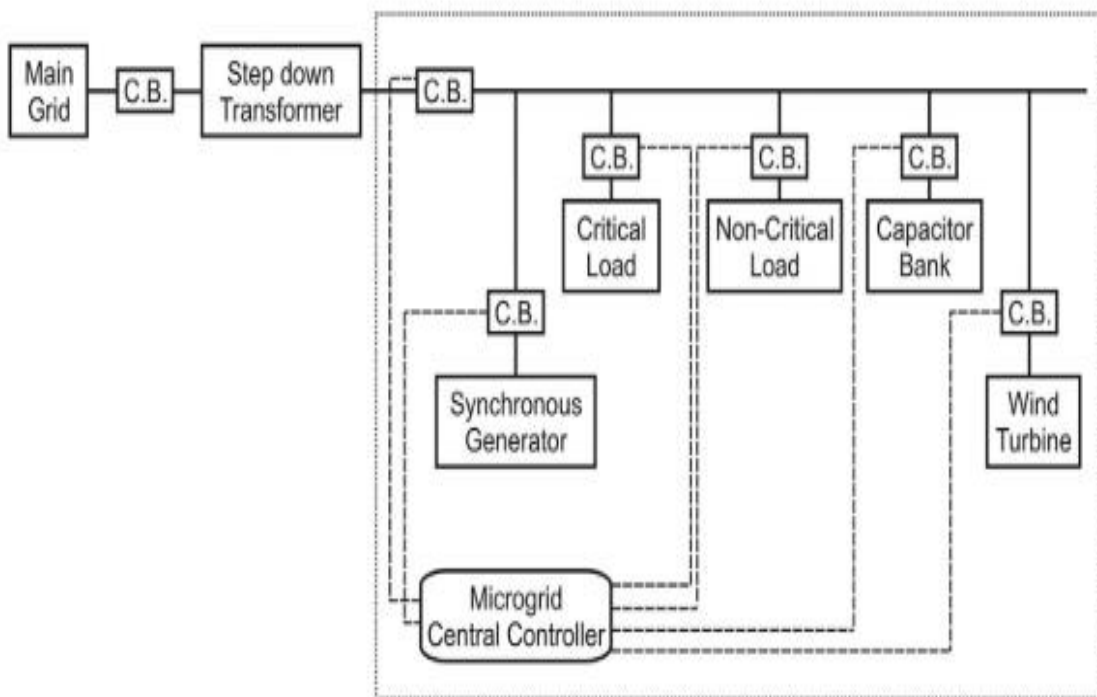


Figure 2.8: Model of a Microgrid with Controller (MGCC) (Kaur et al., 2016)

Also investigated and described is the central controller's function in the areas of microgrid stability, power quality, and protection. The viability of a central controller for microgrid running is widely established. For the preservation and protection of electricity quality, protection, and stability, the MGCC performs vital functions. If it is equipped with a human-machine interface system, an MGCC may function with high level intelligence (Kaur et al., 2016).

Energy management strategies in smart grids may be reviewed within the cloud, as opposed to between the devices of the end user, using cloud computing apps. With this design, there is more memory and storage available for evaluating computational mechanisms for cost- and energy-efficiency (Naveen et al., 2016). Currently energy crisis is being experienced because fossil fuels are quickly running out and environmental consciousness is rising. Researchers are thus making an effort to look into novel approaches to get energy from renewable sources. Distributed generators (DG) known as "Microgrids" are being integrated with renewable energy systems. By allowing dependable and cost-effective resource use, optimization techniques help to justify the expense in a microgrid. In order to integrate renewable energy into microgrids, (Fathima & Palanisamy, 2015) aimed to highlight the idea of Hybrid Renewable Energy Systems (HRES) and the most recent state-of-the-art deployment of optimization methodologies and tools. A framework of many objectives was created using a thorough literature review on HRES, for which optimization techniques have been used to strengthen the microgrid (Fathima & Palanisamy, 2015). Equation showing the loss of power supply probability, finding a practical method to coordinate all DERs and allow distributed energy automation to attain local or even regional self-sufficiency is urgently needed (Wu et al., 2021).

The authors provided an overview of hybrid renewable energy systems (HRES), as well as the software tools and optimization techniques that are used to construct the system's optimization targets. As they effectively support one another, solar and wind energy conversion devices are commonly incorporated into HRES. For a steady source of energy, HRES has found redox

batteries and sodium-sulfur batteries to be particularly promising. While lithium batteries are also able to equal flywheels in terms of affordability and accessibility, the latter may deliver deeper discharges (Fathima & Palanisamy, 2015).

Fixed feed-in tariffs (FITs) have been used by energy policy makers globally to increase the use of intermittent renewable energy sources (RESs). But FITs often lose their validity after a certain amount of time. Exclusive participation in wholesale energy markets could not be a workable business model for RES that no longer get a FIT because of the inconsistent power supply provided by RES, market distortions, and a lack of flexibility choices. Which RES business models and Results – Based Managements, (RBMs) therefore guarantee the continued operation of RES in the post-FIT period are yet unknown. The author provided a typology spanning five RBM archetypes in order to fill this research gap: the wholesale electricity market (1), physical power purchase agreements (2), nonphysical power purchase agreements (3), self-consumption (4), and on-site power-2-X (5). Three extra service levels are included in the typology that might increase the profitability of RBM archetypes by creating new income streams. These additional service layers include infrastructure services (layer 1), electricity storage services (layer 2), and ancillary services (layer 3). The emphasis was on the necessity for fresh methods for determining if RBM archetypes and service layers are viable under various legislative, technological, and commercial circumstances. The next phase of the energy transition must be shaped by policymakers, who must balance the consequences of market-based and intervention-based energy policy approaches in order to avert the impending decommissioning of current RESs (Rövekamp et al., 2021).

The incorporation of solar power, one of the most rapidly expanding renewable energy sources, creates massive issues to power networks due to its erratic and unpredictable nature. In the past ten years, there has been a growing appreciation for the utility of probabilistic predictions as a strategy for encouraging the integration of solar power in power networks. Although there is

currently little usage of probabilistic predictions in power systems, several strategies have been presented and a vast amount of study has been done to encourage their use. The authors thoroughly analyzed the ways in which the problems can be solved by using probabilistic solar predictions in power systems. The potential approaches to managing uncertainties in power systems are enumerated, including stochastic load flow models, resilient optimization, and chance limitations. State-of-the-art research were also presented, and particular areas where these techniques might be used are highlighted (Li & Zhang, 2020). Similarly, for the ECOWAS Renewable Energy Planning, International Renewable Agency, (IRENA) created the ECOWAS Renewable Policy "EREP" power sector planner for Western African nations. With the use of this tool, analysts may create a power system that satisfies different system criteria, such as dependability. In order to fulfill daily/seasonally varying demand, EREP additionally considers the system's economically efficient designs (along with investment and operation expenses) (Miketa & Merven, 2013).

Markovic et al., (2013) stated that residential load forecasting played an increasingly important role in modern smart grids. Due to the variability of residents' activities, individual residential loads are usually too volatile to forecast accurately. Kong et al., (2017) provided the basis of ensuring a non-volatile problem using Long Short – Term Memory, (LSTM) based deep learning forecasting framework with appliance consumption. And result proved that LSTM recurrent neural network-based forecasting framework performs better in establishing meaningful temporal relationships between consumptions across time intervals. Nevertheless, the accuracy of the meter-level needs to be improved under a consumption sequence of major appliances.

As a result of difficult in developing a universal forecasting model dominating over other alternative models, (Lin et al., 2015) developed a multi-model combination (MMC) approach for short-term probabilistic wind generation forecasting in order to exploit the advantages of different forecasting models. In the approach different forecasting models that provide different

kinds of probability density functions to improve the probabilistic forecast accuracy were combined. And was able to obtain three probabilistic forecasting models based on sparse Bayesian learning, kernel density estimation and beta distribution fitting.

Probabilistic load forecasting (PLF) has become necessary for power system operators to do efficient planning across power transmission and distribution systems. (Arora et al., 2021) did come out with algorithm for spatially correlated multiple loads wherein a global parameter is learned from state-space parameters of individual loads by an amalgamation of deep neural networks and state-space models. The model employed complex pattern learning capabilities of recurrent neural networks and temporal pattern extraction of innovation state-space models. However, the method was highly interpretable and can be employed in areas where limited training data is available to the areas where colossal data is available.

Advancing probabilistic solar forecasting methods is essential to supporting the integration of solar energy into the electricity grid. (Raterink et al., 2019) adopted a variety of state-of-the-art probabilistic models for forecasting solar irradiance. And also investigated the use of post-hoc calibration techniques for ensuring well-calibrated probabilistic predictions. The model was trained and evaluated with the help of public data from seven stations in the SURFRAD network, and demonstrate that the best model, NGBoost, achieves higher performance at an intra-hourly resolution than the best benchmark solar irradiance forecasting model across all stations (Rathnayaka & Potdar, 2015). It was shown that NGBoost with CRUDE post-hoc calibration achieved comparable performance to a numerical weather prediction model on hourly-resolution forecasting suggesting that NGBoost was an excellent baseline for probabilistic solar irradiance forecasting at both intra-hourly and hourly resolutions. Nevertheless, machine learning-based solar irradiance forecasting will play a major role in achieving more accurate result.

#### **2.7.4 System Interfacing and Integration**

Interfacing a PLC with SCADA and ETAP involves communication setups protocol and sometimes intermediate hardware or software (Liang et al, 2017). Interfacing PLC with SCADA is one of the most common setups in industrial automation and control systems. The following are applied;

- i. Communication Protocols; SCADA systems typically communicate with PLC using standard industrial protocol such as Modbus (RTU or TCP/IP); Ethernet/IP; Profibus/Profinet; OPC (OLE for Process Control) and DNP3 (Distributed Network Protocol)
- ii. PLC Programming: to ensure that the PLC is programmed to read and write data from sensors or other field (input/output) devices.
- iii. SCADA Configuration: Tag Mapping – creating tags in the SCADA software that correspond to the PLC's register. These tags represent physical quantities such as pressure, temperature or motor status.
- iv. Testing: This involves testing the data flow once communication is established to ensure that SCADA is properly reading from and writing to PLC.

Interfacing PLC with ETAP takes various different major steps to interface depending on area of application. ETAP is mainly used for electrical power system analysis, but it can also be used for real – time monitoring when integrated with PLC and SCADA systems (Alvarez et al, 2006), (Mohammadi, et al, 2018). The following steps are taken to interface with PLC;

- i. Data acquisition and ETAP – Real Time Integration. This needs a data acquisition system or SCADA that collects data from the PLC. ETAP's real – time module can interface with SCADA systems using OPC, Modbus or DNP3 protocols.

- ii. OPC Server for ETAP: Through an OPC Server, ETAP can be interfaced especially where the SCADA system or PLC supports OPC.
- iii. Modbus/Direct Integration: Configures ETAP to act as a Modbus master and the PLC as a Modbus slave.
- iv. RTAC or Substation Gateway: Some setups use a RTAC (Real – Time Automation Controller or Substation gate way between ETAP and PLCs. It an intermediate device that gathers data from PLCs using common protocols (Modbus, IEC 61850) and then feeds it into ETAP.
- v. Testing: after integration, the data flow from the PLC to ETAP is tested to ensure accuracy and responsiveness, especially for real – time power system monitoring.

## **2.8 Energy Scheduling for both Sources and Load Demand**

Balaji *et al.*, (2015) worked on reliability of generator scheduling using integer coded differential evolution algorithm. The author(s) developed an optimization technique for generators scheduling with generator maintenance for reliability purpose. The generator maintenance is done considering the maximization of the reliability index and subject to a set of nonlinear constraints. Using mixed integer optimization to validate the developed model, it was compared with integer coded particle swarm optimization model and the result shows the capability of the proposed model to be more reliable.

Bukhari *et al.*, (2014) reviewed on the application of genetic algorithm in generator scheduling. The authors stated that generator scheduling is a nonlinear, mixed integer, combinatorial and constrained optimization problem. According to the authors, generator scheduling involves searching for the most economical way to start up and start down a generator while satisfying the forecasted load demand and spinning reserve for every time horizon while satisfying several constraints. The objective of generator scheduling is to maximize the total production cost, the

proposed model is subjected to real power balance constraint, spinning reserve constraint, generator output unit constraint, minimum up time constraint and minimum down time constraint. The authors also stated that genetic algorithm which is the method proposed for the generator scheduling requires two things to be defined for its solution to be possible, a genetic representation of the solution and a fitness function to evaluate the solution domain. The two categories of generator scheduling unit commitment genetic algorithm solution are; traditional genetic algorithm and hybrid genetic algorithm. The authors work was limited to review of genetic algorithm solution to generator scheduling.

Zein *et al.*, (2012) proposed a power scheduling that takes account of uncertainties attached to using a distributed generation as a generator support. This uncertainty changes the behaviour of the generators for a micro grid system and must be taken into account for a reliable solution. The optimization method proposed by the authors is two mixed integers linear programming (MILP) model for ahead of the day unit commitment problem in the proposed micro grid and each model correspond one mode of operation. The authors compared the grid connected mode of operation and the isolated mode of the Distributed Generation Information System (DGIS). The micro grid (isolated) mode shows a better result as compared to the grid connected mode in the stability of the power supply with time.

Pazheri *et al.*, (2014) investigates the impact of high penetration DGIS on a hybrid power system. The author (s) emphasized the need to use DGIS as it reduces the cost of power and also environment friendly. A hybrid generation power model was developed which consist of thermal and level of renewable power. The author(s) used optional dispatch model which shows the advantage of using DGIS with energy storage facilities to help manage the penetration of the DGIS.

Fan *et al.*, (2018) proposed a generation rescheduling algorithm which adjusts generation output to avoid or mitigate the variation of branch power and relieve the overload probability. This rescheduling have to do with offloading the overloaded generations and use high penetration DGIS as alternative. The mode proposed help to reduce congestion in the generations and balance the renewable power generation. The author(s) applied a probability method to evaluate the system uncertainties considering generation scheduling operation, and the probabilistic model developed was tested on ARIZONA transmission system of which the proposed method enhances power system reliability with high penetration of renewable energy resource.

Electrical power systems across the globe are undergoing serious challenges due to the increasing number of loads demands with inadequate power supply. This challenge has led to a lot of breakdowns of several generators and consequently dissatisfaction from the consumer's side. Several researches are being done to propose ways on maximal usage of the supply without consumer's dissatisfaction and without incurring a collapse in the network. (Radhakrishnan & Selvan, 2015) proposed a load scheduling for residential buildings using smart energy management systems which involve renewable sources and demand response mechanism. The user's end of load usage will also help in proper management of the load which gives the consumer's end more priority than the supply end. The proper management of the load according to the author(s) will aid in distributing more loads to other residential buildings and reduce cost on consumer's ends which makes it profitable to both the distributors and the consumers equally. The work proposes an off-line scheduling algorithm that aims at maximizing the energy savings along with the reduction in cost of energy consumption by concentrating more on consumer's energy efficiency.

Hafeez *et al.*, (2018) also stated that 80% of energy usage due to negligence could have been conserved to supply other consumers and reduce cost of usage on the consumer's end optimally. The work proposed the use of photovoltaic cell to supply utilities, but showed that for optimal

usage, the consumers have to be sensitized on their energy usage since distributed generations comes in smaller sizes. According to the authors, the greatest problem encountered in power sector is to create a balance between the load demand and supply. Problems associated to this can lead to system collapse at higher load, power losses, voltage imbalance, etc. The proposed optimization algorithm reduced the peak to average (PAR) load usage by 49.1% which can be used for other purposes and reduce the consumer's cost.

Joy & Krishnakumar, (2016), suggested a way of balancing the load using neural networks as against the traditional method of load shedding. Load shedding involves the disconnection of unnecessary or extra load to maintain the voltage limit of the system in order to avoid system collapse or generator overloading. The proposed method overcomes the problem by scheduling the load automatically based on the requirement. Another purpose of the neural network is to economically schedule the generators to minimize cost and optimize profit, since each generator source is economically different. The total load required is the input of the network and the power generation. From each source and power losses at the time of transmission are the output of the neural network. The algorithm reduces the processing time to adjust the generators.

Rasheed *et al.*, (2015) proposed a mathematical optimization model for household energy units to optimally control the major residential energy loads while preserving the user's preference. The objective of the developed model is comfort maximization and minimization of cost of electricity. Also, to minimize the energy billing at peak period, min – max regret – based knapsack problem (k-WDO) is developed. The result from simulation shows that the proposed method gave an optimal result with the fast convergence rate as compared to existing methods.

Dunja *et al.*, (2019) proposed a day – ahead load demand for a wind power supply. The demand is done day ahead in hourly basis and allocated supply is based on the demand per individuals which is dynamic. In this way, more of the regulating power can be reserved during sudden

change in the intensity of the wind. The regulation is done in such a way that it minimizes the transmission losses (allocating the wind closer to load centres) with optional correction according to economic criteria. The validation of the proposed scheme which was tested on the Coatian network showed a considerable reduction of the necessary positive and negative regulating reserve with increased safety compared to the classic method.

Mizack, (2011) proposes a time – of – use method of load scheduling which customers are billed based on their usage with smart meter. The model determines which machine will be turned on and off during a certain amount of time. Though the integer program developed clearly shows that by letting machines run longer and staggering the start of machines, the electricity cost for a typical day can be greatly reduced.

Fattahi, (2015) suggested how a microgrid should be managed with distributed generation. The author suggested that the grid installation should be more than the load demand and it will be proper to manage the maximum load demand than to later add more load to the network which might result to a system collapse. Also, possible ways to reduce cost is to introduce demand and supply scheme, most especially at peak period. The work proposed a price – based demand response schemes with a two-part tariff based on time of use priority. Load scheduling problem was formulated as a combinatorial optimization problem constraint by the maximum limit of the microgrid. The author did not work with the price effect of the method.

## **2.9 Research Summary and Gap**

Prior to now, pooling was taken into consideration for regional energy access, which has been quite beneficial to countries in West African Regions. The advancement in technology has provided certain advantages to the regions that employ it, including increased bankability for new independent Power Producer (IPP) projects, and notably intermittent renewables. Regional power pooling systems enable IPPs to locate projects in one nation and contract power to meet

demand from public or private entities in another, reducing off-taker risk and curtailment risk, among other risks. Most national grids in Sub-Saharan markets could only support a few hundred MWs of intermittent renewable energy. As it organizes the planning of crucial infrastructure, which necessitates political cooperation, and generates economic dependencies that encourage trade and peace has boosted regional cooperation.

It has been proven that the regional pooling did not suffer from integration problem, because the energy was pooled at a large scale, but micro-designing the pool system to meet the university community scenario may be hampered by integration problem which this research intends to understudy. However, universities have not yet benefited from this energy pooling system technology, and thus, that engendered this model. Although, this model is formulated for institutional based use, load equilibrium and balancer could be another envisaged problem. Researchers in 2020 demonstrated power pooling model in a virtual market scenario, where renewable energy were integrated with considerations to risk of its uncertainty, which however, affected the energy market valuation. In the light of this, it's model can find its application in the university community, which is more or less like to be a market place with different operations (Gersema & Wozabal, 2018).

Highlight of the research gap:

- i. The pool system model (network architecture) already in existence could not be used for institutional purpose.
- ii. There has been no known energy integration model for institutional based application.
- iii. There was no energy load equilibrium schedule scheme and balancing model for university-based community utilization.
- iv. There was no load flow analytical model formulated for the university-based community demonstration.

**Table 2.3: Selected comparative Literature for the Institutional Based Power Pool Model**

	<b>Authors</b>	<b>Title</b>	<b>Strength</b>	<b>Weakness</b>	<b>Research Gap</b>
1	Gersemaa, & Wozabal, (2020)	Risk-Optimized Pooling of Intermittent Renewable Energy Sources	Extent which energy pooling could be deployed optimally considering renewable energy uncertain nature.	The model was demonstrated with a virtual power plant:	Development of risk model using German Market for demonstration, which can be adopted for institutional based energy pooling
2	Laufer, (2019)	Distributed energy infrastructure paradigm: Community microgrids in a new institutional economics context	This theoretical analysis provides guidelines for interested parties in establishing effective institutions to maximize benefits for both community and private actors.	The study only emphasizes on the benefits derived by the involved parties.	Establishment detailed information of energy usage and possible implications.
3	Bunker, et al., (2015)	Investment Model for Renewable Electricity Systems (IMRES): an Electricity Generation Capacity Expansion Formulation with Unit Commitment Constraints	The model was formulated to have the capacity to integrate renewable energy system in electricity generation, lower total cost of generation and less emission.	The study did not look into possible factors that lessen the renewable energy productivity.	To consider various factors that hinder renewable energy efficiency.
4	Saroha, and Verma (2013)	A community-Based Energy Market Using Decentralized Decision Making under Uncertainty	An algorithm that enables decentralized market clearing process was introduced in order to minimize	The system needs to optimize the algorithm in setting price for energy market.	Upgraded system to create full analysis of the power pool market model.

			concerns regarding data privacy and communication burden,		
5	Mujeeb, et al., (2019)	Consumer payment minimization in power pool auctions	The study presented a new methodology for generation scheduling and market clearing price determination in power pool auctions.	The study was unable to establish the significant of adopting marginal unit average cost over marginal cost approach	Cost management techniques.
6	Markovic, et al., (2013)	Assessment of renewable energy integration for a village using the energy hub concept	This study provides an energy hub model that reduces the level of CO <sub>2</sub> emission by shifting electricity production much to the renewable source rather than fossil fuels.	The study did not consider the less efficient period of renewable energy. Such as weather factor for wind and Pv.	To develop an effective model which consider variability of renewable energy source and introduce suitable option to meet the gap.
7	Minghui, et al., (2016)	Assessment of the Energy Distribution in Urban Areas by Using the Framework of Complex Network Theory.	This work programmed a mathematical too to expand energy exchange between the customers that possess energy distribution system.	The model unable to cover large distance for energy distribution. It is less sensitive to distance parameter.	To build a model with optimized level of sensitivity variables to generation and distribution.
8	Flores-espino, et al., (2020)	Assessing the Influence of Power Pools on Emission Constrained Economic Dispatch	This study developed an economic formula to quantify the approximate gain that benefited from	The framework could not estimate the cost at an uncertain change of parameters. And the cost of increasing	To improve the model integrated with the probabilistic tool, to sense a change in cost estimate

			improving the electricity utilities. By reducing production costs and emission rates.	coordination	parameters.
9	Zhang, (2013)	The energy challenge in sub-Saharan Africa: A guide for advocates and policymakers	This research provides an optimal analysis for electricity access expansion, reliability and the importance of decentralized energy resources.	The report did not provide an optimization tool for renewable energy resources.	A developed model with effective software to optimize system performance in both technological and cost.
10	Wu, et al., (2015)	Optimization in microgrids with hybrid energy systems – A review	The study provided an optimization tool for hybrid renewable energy systems and battery storage improvement.	The study did not include a reliability study of the hybrid system.	Improvement of a model to analyze renewable source data.

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1 Materials

The software materials are required for the research work. The following software as listed below were used to develop an institutional-based community power pooling model for seamless renewable energy integration:

- i. Programmable Logic Controller (PLC): Mitsubishi
- ii. Supervisory Control and Data Acquisition (SCADA): Wonderware Intouch
- iii. Proteus
- iv. Hybrid Optimization of Multiple Energy Resources (HOMER)
- v. Electrical Transient Analyzer Program (ETAP)

#### 3.2 Methods

The methods adopted to achieve the design of an institutional based power pool system are presented in this section

##### 3.2.1 Design of the Institutional Distribution Network System

The FUTO network architecture is designed to manage the energy available for the university community. The network consists of 14 different buses with respective loads attached.

- i. The supply from EEDC goes to Bakasi Bus (1) as Slack bus, with the loads from FUTO Consult, Gender Center, Health Center, Okiro Building and Hall of Mercy.
- ii. Bus 2 is the Church bus, with the loads from St. Thomas Church, Anglican Church and All Saints Church.

- iii. Bus 3 is the Hostel bus, with the loads from hostel A, B, C and D, and special student hostel.
- iv. Bus 4 is the staff school, with its loads from Primary School, Child Development Center, Secondary School, Stadium and Guest House.
- v. Bus 5 fed the SEET Complex, with loads from SEET complex, Mechanical, Chemical and Petrochemical Engineering building, ICT building and lecture office complex.
- vi. Bus 6 fed the Old SEET Complex, with loads from Old SEET, and New Biological building.
- vii. Bus 7 fed the Old Registry, with loads from old registry, Estate and Works departments, Lecture Hall, and business centers.
- viii. Bus 8 fed the Workshop, with loads from Workshop II & III, Micro Community Bank, PG lecture hall, FUTO Cooperative building.
- ix. Bus 9 fed the RGS & FUTO Library, with loads from P.H.S building, FUT HB, and Fast-food centers.
- x. Bus 10 feeds the SAAT, with loads from old SAAT, new SAAT, center for nuclear energy, and SAAT auditorium.
- xi. Bus 11 feeds the SOPS, with loads from SOPS building, SLTP building, Physics department building, and Computer Science building.
- xii. Bus 12 feeds the School of Health Building (SOHS), with its loads from school of health, old SMAT, SOES building and SOGS.
- xiii. Bus 13 feeds the SMAT, with its loads from SMAT building, SICT, Entrepreneurship center.
- xiv. Bus 14 feeds the Senate building, with its loads from senate building, research center, FUTO water, and Convocation arena.

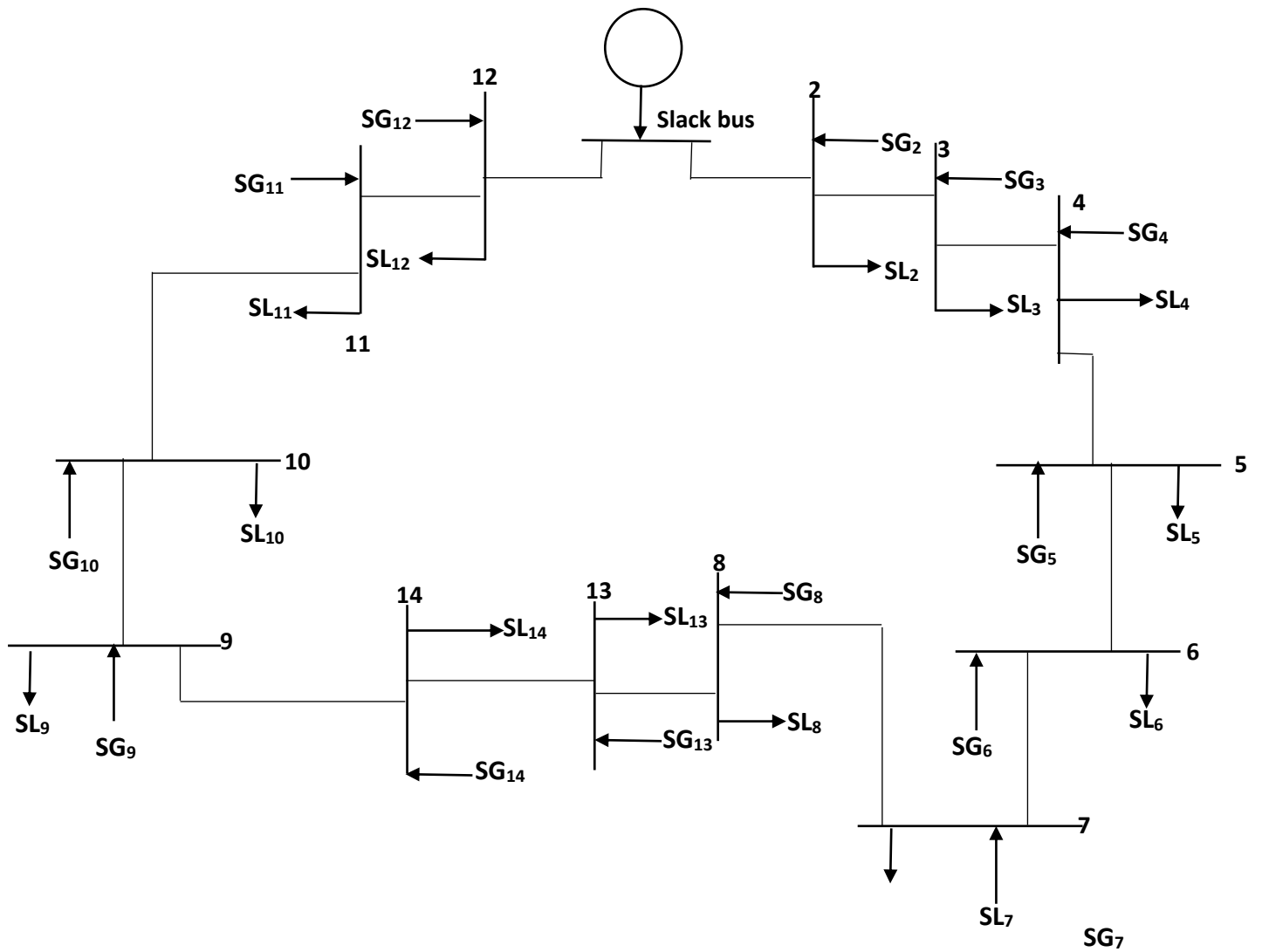


Fig. 3.1: One-line diagram of the 14-bus FUTO distribution network

The Load Estimation for the FUTO network is forecasted to be 3189.2 kW peak Load demand. This is distributed to daily energy demanded from various buildings in the school community, thus giving a total average load of 42550 kWh/day; average of 3320 kW Load, with a factor of 0.56 as shown in Table 3.1.

**Table 3.1: Load Profile of FUTO Distribution Network Model**

<b>S/N</b>	<b>Bus</b>	<b>Load Demand (KW)</b>	<b>Load Consumption (KWh/day)</b>
1	Bakasi (Slack)	200	2563.25
2	Church	150	1922.44
3	Hostel	750	9612.20
4	Staff School	300	3844.88
5	SEET Complex	180	2306.93
6	Old SEET	200	2563.25
7	Old Registry	180	2306.93
8	Workshop	200	2563.25
9	RGS & FUTO Library Bus	180	2306.93
10	SAAT	200	2563.25
11	SOPS	200	2563.25
12	School of Health (SOHS)	200	2563.25
13	SMAT	180	2306.93
14	Senate Building	200	2563.25
<b>Total</b>		<b>3320</b>	<b>42,550</b>

With these, the proposed system configuration for the Estimated Load Profile is show in the Fig 3.2

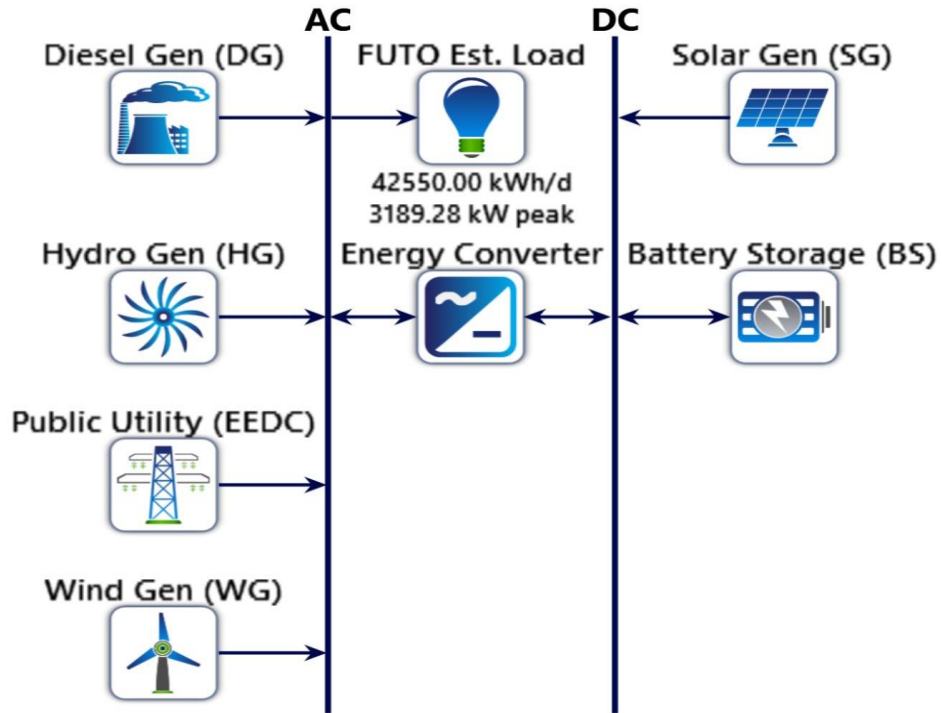


Figure 3.2: Proposed System Architecture

From the designed system architecture in Fig. 3.2, and load profile in Table 3.1, the university community pooling model proposed in this research allots the energy demand to various energy sources, integrating both renewable energy and non-renewable sources alongside the public utility supply, giving an optimized model for the system illustrated in Table 3.2.

**Table 3.2: Percentage Power allocations for Energy Resources**

Energy Sources	Percentage Allotment	Power Rating (kW)
Grid (EEDC)	50	1660
Solar Gen	19	631
Diesel Gen	15	498
Wind Gen	13	432
Hydro Gen	3	100
	100	3320

**SIZING PARAMETERS FOR THE DESIGN:**

Table 3.3 shows the sizing and units of the system parameters for the Generator, PV modules, Battery storage, Hydro Generator, wind Generators and Public Utility supply.

**Table 3.3: General Sizing Parameters for Designed System Model**

Component	Name	Size	Unit
Generator	Diesel Gen (500 kW)	500	kW
PV	Solar Gen (PV modules)	9,991	kW
Storage	Battery Storage (2100Ah)	207	Strings
Wind turbine	Wind Gen (WG)	271	ea.
System converter	System Converter	2,983	kW
Grid	Public Utility (EEDC)	1,700	kW
Hydroelectric	Hydro 100Kw	98.1	kW

Table 3.4 to 3.9 give the electrical summary of the various energy sources available in the university pool system.

**Table 3.4: Diesel Gen (500 kW) Electrical Summary**

Quantity	Value	Units
Electrical Production	26,119	kWh/yr
Mean Electrical Output	264	kW
Minimum Electrical Output	125	kW
Maximum Electrical Output	500	kW

**Table 3.5: Solar Gen (PV modules) Electrical Summary**

Quantity	Value	Units
Rated Capacity	9,991	kW
PV Penetration	83.4	%
Hours of Operation	4,451	hrs/yr
Levelized Cost	6.56	₤/kWh

**Table 3.6: Battery Storage (2100Ah) Properties**

Quantity	Value	Units
Batteries	207	qty.
String Size	1.00	Batteries
Strings in Parallel	207	Strings
Bus Voltage	48.0	V

**Table 3.7: Wind Gen (WG) Electrical Summary**

Quantity	Value	Units
Total Rated Capacity	6,775	kW
Wind Penetration	65.4	%
Hours of Operation	5,434	hrs/yr
Levelized Cost	4.56	₱/kWh

**Table 3.8: System Converter Electrical Summary**

Quantity	Value	Units
Capacity	2,983	kW
Mean Output	870	kW
Minimum Output	0	kW
Maximum Output	2,983	kW
Capacity Factor	29.2	%

**Table 3.9: Hydro 100kW Summary**

Quantity	Value	Units
Nominal Capacity	98.1	kW
Mean output	108	kW
Capacity factor	110	%
Total Production	949,588	kWh/yr

### 3.2.2 Design of an Integrating Model for the Renewable System

Mitsubishi PLC software is used for the model design to integrate the renewable energy with other available energy sources. The energy sources within the university communities for integrations are diesel generator, Enugu electricity distribution company (EEDC), solar energy, wind energy, and hydro energy supply.

For the synchronization of these energy sources into the developed university distribution network, ladder program of the PLC is adopted. The ladder program has its input codes denoted by X020 and so on; its output code denoted by Y020 and so on; its memory code denoted by M020 and so on; and its timer code denoted by T, and the constant K.

The ladder diagram makes use of electromechanical contact: normally open and normally closed contact, such that whenever a normally close contact is energized, it closes, and when a normally close contacts is energized, it opens.

In Figure 3.3, rung 0 shows the initializations of the integration model, which provides the latching configuration for the system initial settings formulation. The latching is made possible with the X020 (input code that is normally open – NO), X021 (input code that is normally close – NC), and M20 (memory code). T1 (diesel generator), T2 (EEDC), T3 (solar power), T4 (wind power), and T5 (hydro power) represents the five-energy supply to the university.

The T0 gave initial timing of 5 seconds to inject or convey the energy resources

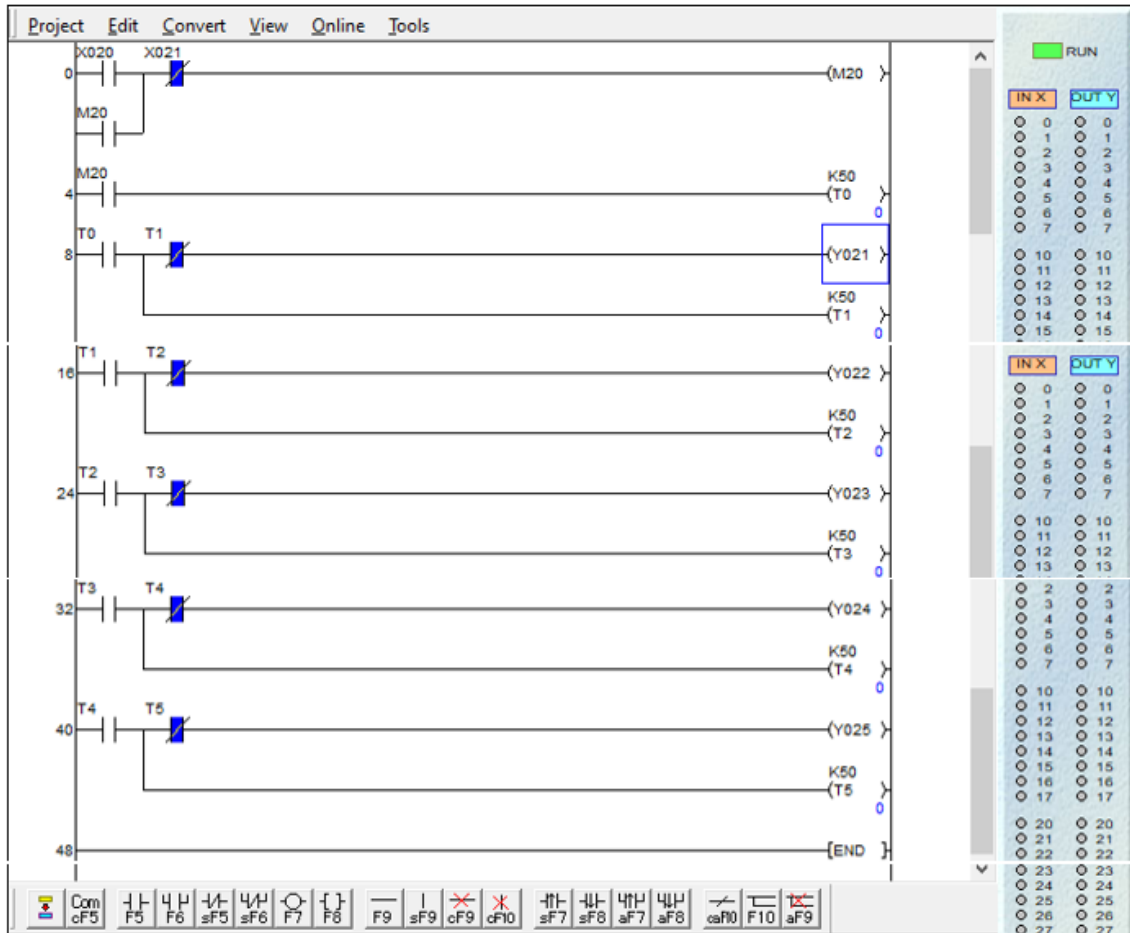


Figure 3.3: PLC Integrating Model for FUT Network System

After the design configuration, the codes are converted to a ladder instruction and written into the Programmable Logic Controller (PLC) to allow for energy integration. The integration of PLC with ETAP typically, needs the data acquisition system – SCADA that collects data from PLC. The ETAP’s real – time module can now interface with SCADA system using protocols such as OPC, Modbus or DNP3 imbedded in the Wonderware software. The PLC collects data from the field (e.g Sensors, Relays); the SCADA system reads the data from the PLC and provides a user interface for operator to monitor and control processes; the ETAP system, connected to SCADA or directly to PLC performs real – time power system analysis and simulation using the data collected. The solar power generates DC and was converted to AC before the synchronization process.

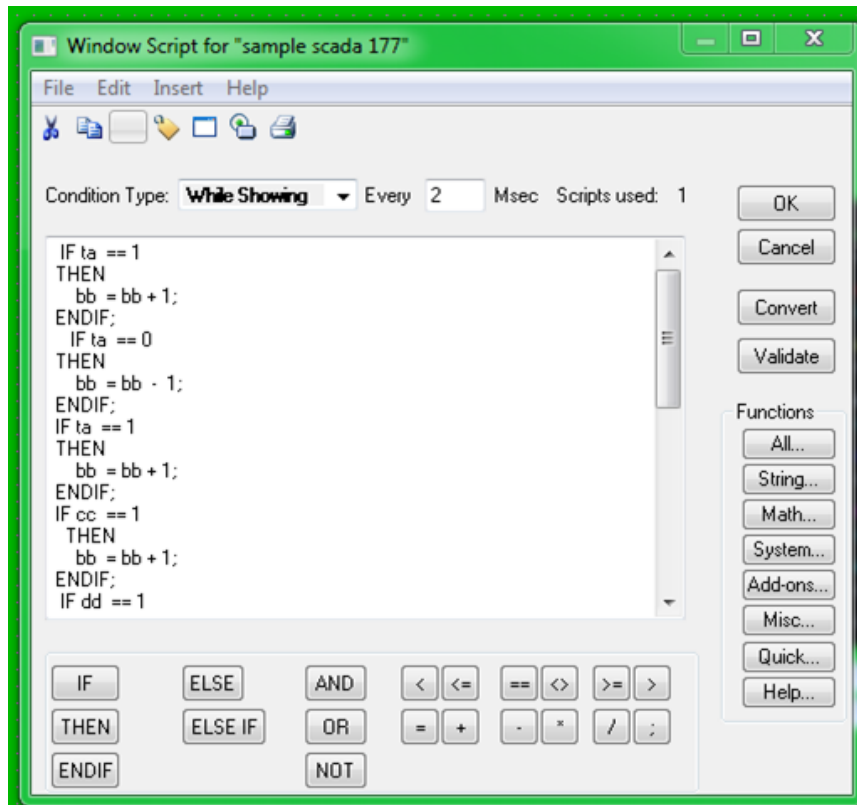


Figure 3.4: SCADA design for FUT Network System

Figure 3.4 shows the Supervisory Control and Data Acquisition (SCADA) System program written with Wonderware software and it was deployed for the institutional community power pool system. The interaction between SCADA and PLC gives the visual interface for user assessment on the synchronization and the integration process.

### 3.2.3 Design of the system equilibrium model for sources and load balancer

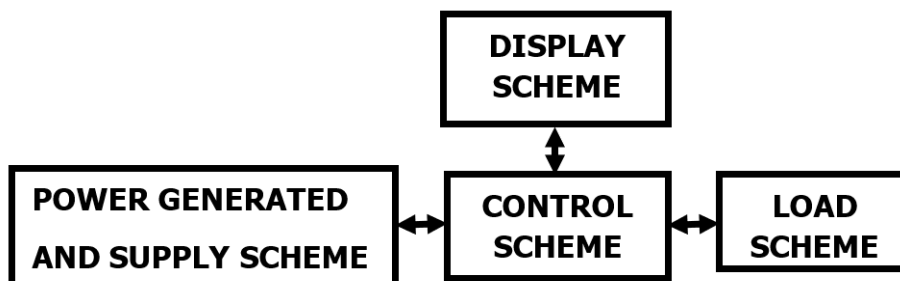


Figure 3.5: Block diagram for Electrical Load Equilibrium Monitoring and Balancing Model

This model consists of the Power generating and supply scheme, which are made of the sources from EEDC, Solar, Wind, Mini-Hydro, and Generator set. The control scheme primarily consisting of the controller, display consisting of the liquid crystal display and load for the 14 divisions of the university.

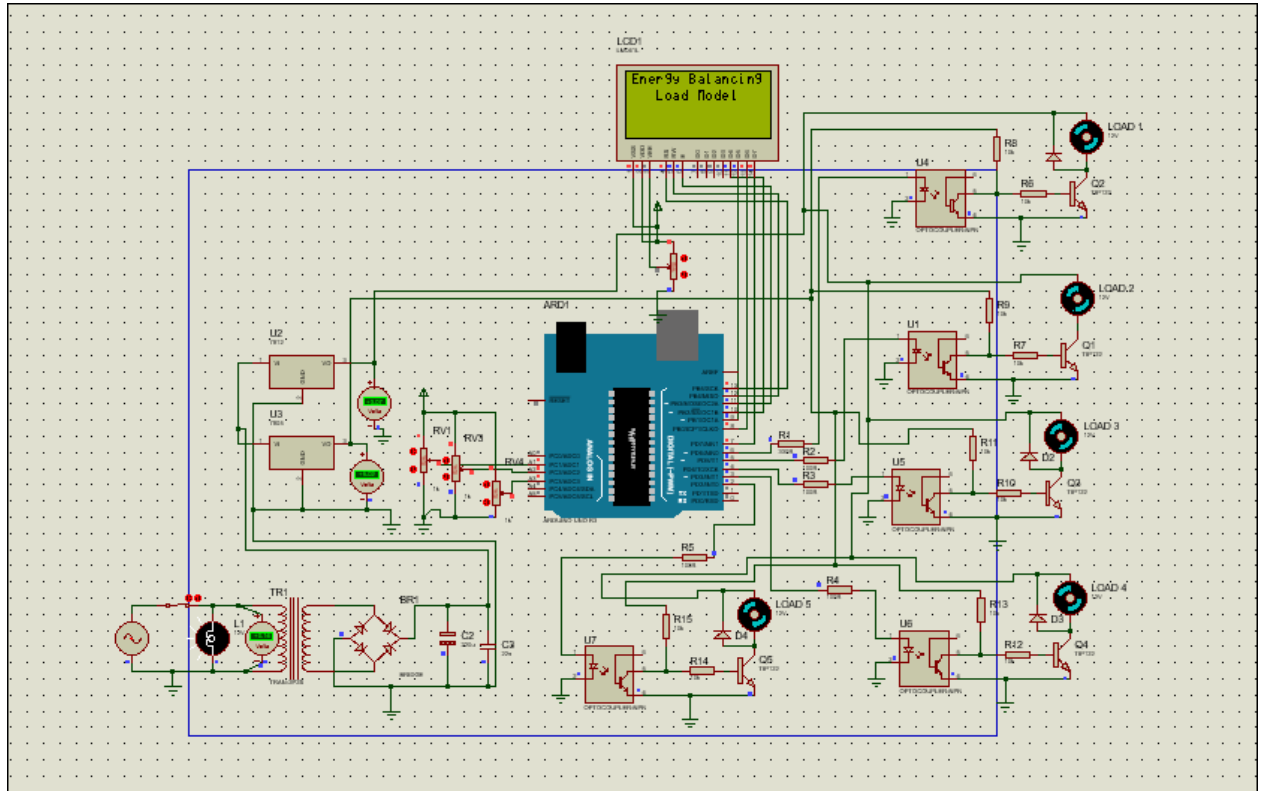


Figure 3.6: Schematic Circuit diagram for Electrical Load Equilibrium Monitoring and Balancing Model

Priority in the scheduling shows that at least one lightning points each in each of the five departments would be allocated certain watts first, while the system automatically checks the remaining energy, and select another suitable prioritized load like 13amps sockets to service personal computers, and printers. This scheduling and balancing are done in a Proteus environment with the use of microcontroller with its code written in Arduino IDE. Though ETAP has a strong connection with the Electrical load equilibrium monitoring and Balancing model particularly in industrial and grid power systems while Proteus is suited for circuit simulations and smaller systems such as PCB design hence it was used for experimental purpose.

Figure 3.6 demonstrates the equilibrium model and load balancing for the institutional-based power pool system integration with renewable energy. The loads are represented by Motors designated load 1 to load 5. This shows that within one division in the university that has five units/departments, the energy from the integrated network could be shared within the five departments following the sequence allotment. This experiment considers 20,000W (20kW) for equal distribution, using this load balance model. This department allots 10W each for the five departments to cater for their lightning point, making a total of 50W consumption. And the system records a balance of 19,950W, and allots five 13 amps socket for document printing and photocopy, with a total of 1,165W. The system again scans to know the available wattage, after which power is allocated to television, ceiling fan, and decoder amounting to 350W.

## Design of the system sequence of operations for the model

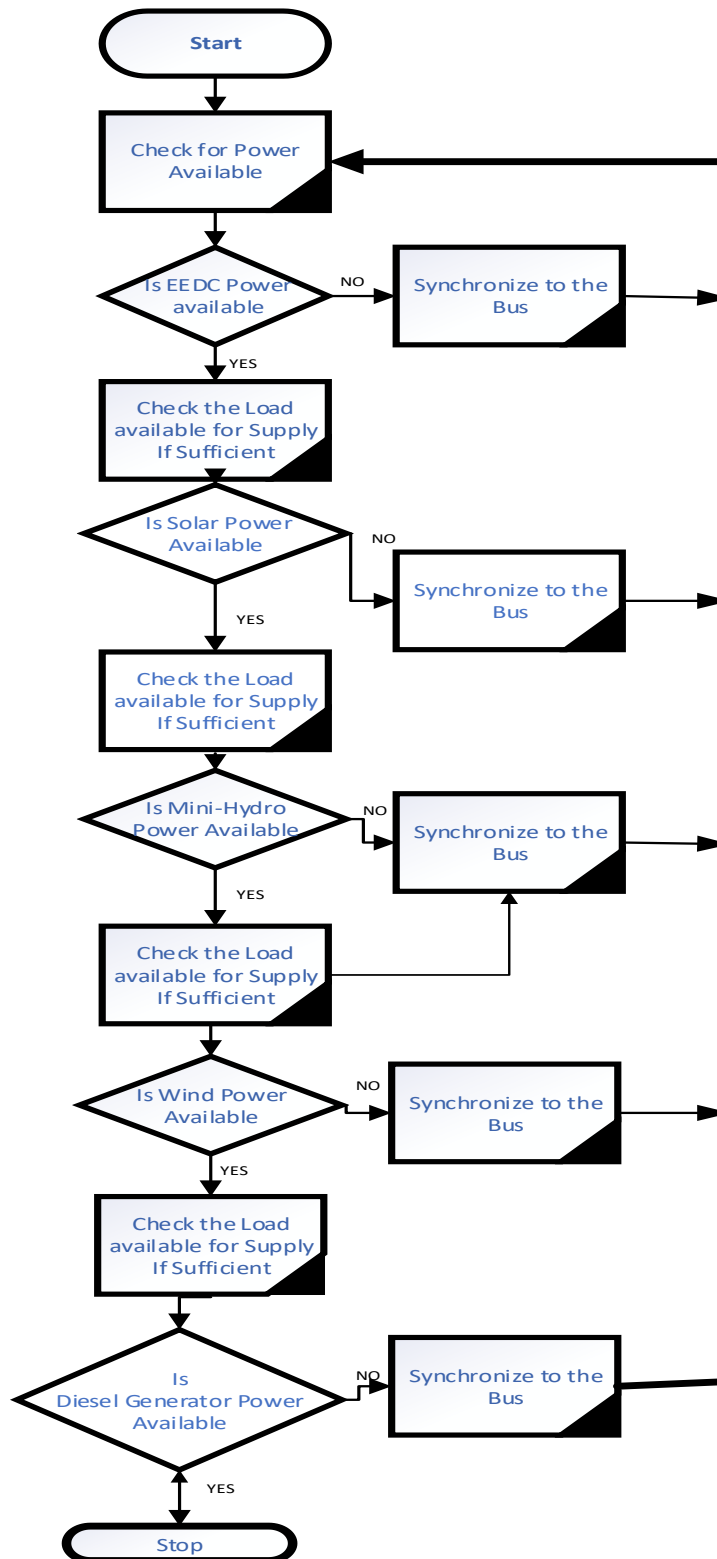


Figure 3.7: System sequence of operations flow model

### 3.2.4 Design of the system Load Flow Model for Institutional Distribution Network

Whenever the power system is running under typical steady-state or static conditions, the load flow (or power flow) solution are deployed to calculate the current, voltage, active power, and reactive power at various locations in the system. The power system load flow are classified into load, generator or voltage controller and slack or reference or swing bus.

i. The load bus with specified variables P-Q and unspecified variables  $|V|, \delta$ .

At this type of bus, the net powers  $P_i$  and  $Q_i$  are known ( $P_{Di}$  and  $Q_{Di}$  are known from Load forecasting and  $P_{Gi}$  and  $Q_{Gi}$  are specified).

The unknowns are  $|V_i|$  and  $\delta_i$ . A pure load bus (no generating facility at the bus, i.e.,  $P_{Gi} = Q_{Gi} = 0$ ) is a PQ bus.

ii. The generator or voltage controller bus specified variables P,  $|V|$  and unspecified variables Q,  $\delta$ . At this type of bus  $P_{Di}$ , and  $Q_{Di}$ , are known a priori and  $|V_i|$  and  $P_i$  (hence  $P_{Gi}$ ) are specified. The unknowns are  $Q_i$  (hence  $Q_{Gi}$ ) and  $\delta_i$ .

iii. The slack or reference or swing bus specified variables  $-|V|, \delta$  and unspecified variables P, Q . The fact that actual and reactive powers at this bus are not stated sets it apart from the other two types. Instead, the voltage level and phase angle (which is often set to zero) are stated. Where  $\delta$  is the phase angle of the voltage; P is the active power; Q is the reactive volt-ampere.

Considering the generalized load flow model in Fig.3.8, comprising the generator as the source, the bus voltage for the real and imaginary, phase angle of the bus voltage, the line length distance ABCD and the load bus.

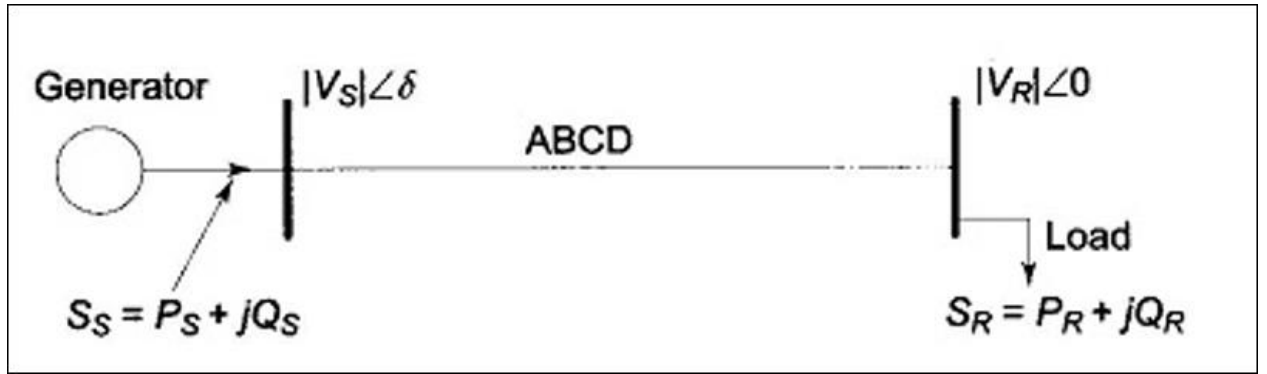


Figure 3.8: Generalized load flow model

The transmission line and transformer input data are required to form the  $Y - bus$  admittance and nodal equation for the power network  $Y$ -bus admittance becomes,

$$I = Y_{bus} \times V \quad (3.1)$$

The general nodal equation for an  $n$ -bus system is then written as

$$I_i = \sum_{j=1}^n Y_{ij} V_j \text{ for } i = 1, 2, \dots, n \quad (3.2)$$

The equation for the complex power delivered to the bus  $i$  is

$$P_i + jQ_i = V_i I_i^* \quad (3.3)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad (3.4)$$

Substituting for  $I_i$  in terms of  $P_i$  and  $Q_i$  gives

$$\frac{P_i - jQ_i}{V_i^*} = V_j \sum_{j=1}^n Y_{ij} - \sum_{j=1}^n Y_{ij} V_j \quad j \neq i \quad (3.5)$$

The equation 3.5 provides the iterative techniques to design the load flow model for the proposed FUTO network. However, Gauss-Seidel, Newton Raphson and Fast decoupled methods can adopt the general forms to solve various load flow problem.

The Gauss-Seidel Method is used in this design because it converts data more quickly and uses an initial guess for the voltage value to calculate the weight of a given variable. The initial guess value is replaced with a calculated value. Once the iteration solution converges, the process is then repeated. The starting values that are assumed have a significant impact on the convergence. This is an iterative method which is used to solve Equation (3.6) for the value of  $V_i$ , and the iterative sequence becomes,

$$V_i^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^*} + \sum y_{ij}V_j^{(k)}}{\sum y_{ij}} \quad j \neq i \quad (3.6)$$

If the current injected into bus  $i$  is positive, as determined by Kirchhoff's current law, then the real and reactive powers supplied to the buses, including generator buses,  $P_i^{sch}$ , and  $Q_i^{sch}$ , must also be positive. With regard to load buses  $P_i^{sch}$  and  $Q_i^{sch}$ , the real and reactive powers flowing away from the buses have negative values. Equation (3.6) is used to solve  $P_i$  and  $Q_i$ , giving

$$P_i^{(k+1)} = Real \left[ V_i^{*(k)} \left\{ \sum_{i=0}^n y_{ij} - \sum_{ji}^n V_i^{(k)} \right\} \right] \quad j \neq i \quad (3.7)$$

$$Q_i^{(k+1)} = Imaginary \left[ V_i^{*(k)} \left\{ \sum_{i=0}^n y_{ij} - \sum_{ji}^n V_i^{(k)} \right\} \right] \quad j \neq i \quad (3.8)$$

When the bus admittance matrix and the diagonal and non-diagonal elements of the matrix are used to describe the power flow equation, the result is Equation (3.6), which reads as follows:

$$V_i^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^*} - \sum y_{ij}V_j^{(k)}}{Y_{ij}} \quad j \neq i \quad (3.9)$$

and

$$P_i^{(k+1)} = Real \left[ V_i^{*(k)} \left\{ V_i^{*(k)} Y_{ii} + \sum_{ji}^n y_{ij} V_i^{(k)} \right\} \right] \quad j \neq i \quad (3.10)$$

$$Q_i^{(k+1)} = \text{Imaginary} \left[ V_i^{*(k)} \left\{ V_i^{*(k)} Y_{ii} + \sum_{ji}^n y_{ij} V_j^{(k)} \right\} \right] \quad j \neq i \quad (3.11)$$

The matrix's diagonal element includes the admittance to the ground of line charging susceptance and other fixed admittance to the ground thus, the model is developed.

### **Gauss–Seidel Load Flow Implementation Algorithm**

The voltage of both terminals is considered by integrating direct current injection  $I_d$  during each iteration of the load flow calculation.  $V_{dr}$ ,  $P_{dr}$  or  $V_{di}$ ,  $P_{di}$ , which are often supplied as data, are used to determine this current. As a result, all of the equations are solved at once. The  $a_i$ ,  $ar$ ,  $a$ , and  $b$  control variables must be changed (the control equations are incorporated until convergence by using the latest updated value of  $V_{busr}$  and  $V_{busi}$  to find  $a_i$ ,  $ar$ ,  $a$ ,  $b$ ).

The injected power at the terminal bus-bar due to the AC system variables is represented by  $P_i(\text{AC})$  and  $Q_i(\text{AC})$ .  $P_i$  and  $Q_i$  are the typical AC system load at the bus-bar;  $P_i$  and  $Q_i$  are the injected power at the terminal as a function of the DC system.

**The sequential Gauss-Seidel power flow for AC–DC the following steps describe DC systems:**

*Step 1: Read the AC and DC system data, and an initial value for both AC and DC systems.*

*Step 2: Form  $[Y_{bus}]$  for the AC/DC/ system.*

*Step 3: Calculate  $Q_i$  and control the voltage from the generator buses.*

*Step 4: Calculate  $I_d$  if  $V_{dr}$  and  $P_{dr}$  are defined, or if  $V_{di}$  and  $P_{di}$  are defined, then calculate  $I_{pr}$  and  $I_{pi}$ .*

**Step 5:** Calculate  $V_{di}$  (or  $V_{dr}$ ).

**Step 6:** Compute  $V_{bus}$  using Gauss–Seidel process (except for slack bus) for DC and AC buses.

**Step 7:** Repeat steps 3–6 until all the mismatches of bus voltage are less than a prespecified tolerance ( $\Delta V > \varepsilon$ )

**Step 8:** Calculate real  $a_r$  and imaginary  $a_i$  values using the last value in the real  $V_{busr}$  and imaginary  $V_{busi}$ , if ( $a_r$ ,  $a_i$ ,  $a$  and  $b$  are satisfied), go to step 9, (else adjust  $a_r$  and  $a_i$  using the margin of transformer tap ratio and calculate, then, adjust  $a$  and  $b$  and go to step 3).

**Step 9:** Compute the voltages

**Step 10:** Compute Power

**Step 11:** Calculate real and reactive power at DC buses

**Step 12:** Calculate the power at AC–DC buses

**Step 13:** Calculate power at AC buses

**Step 14:** Result for AC–DC power flow.

The system design algorithm for AC–DC Load flow model follows the steps presented in the flow chat in Fig.3.9.

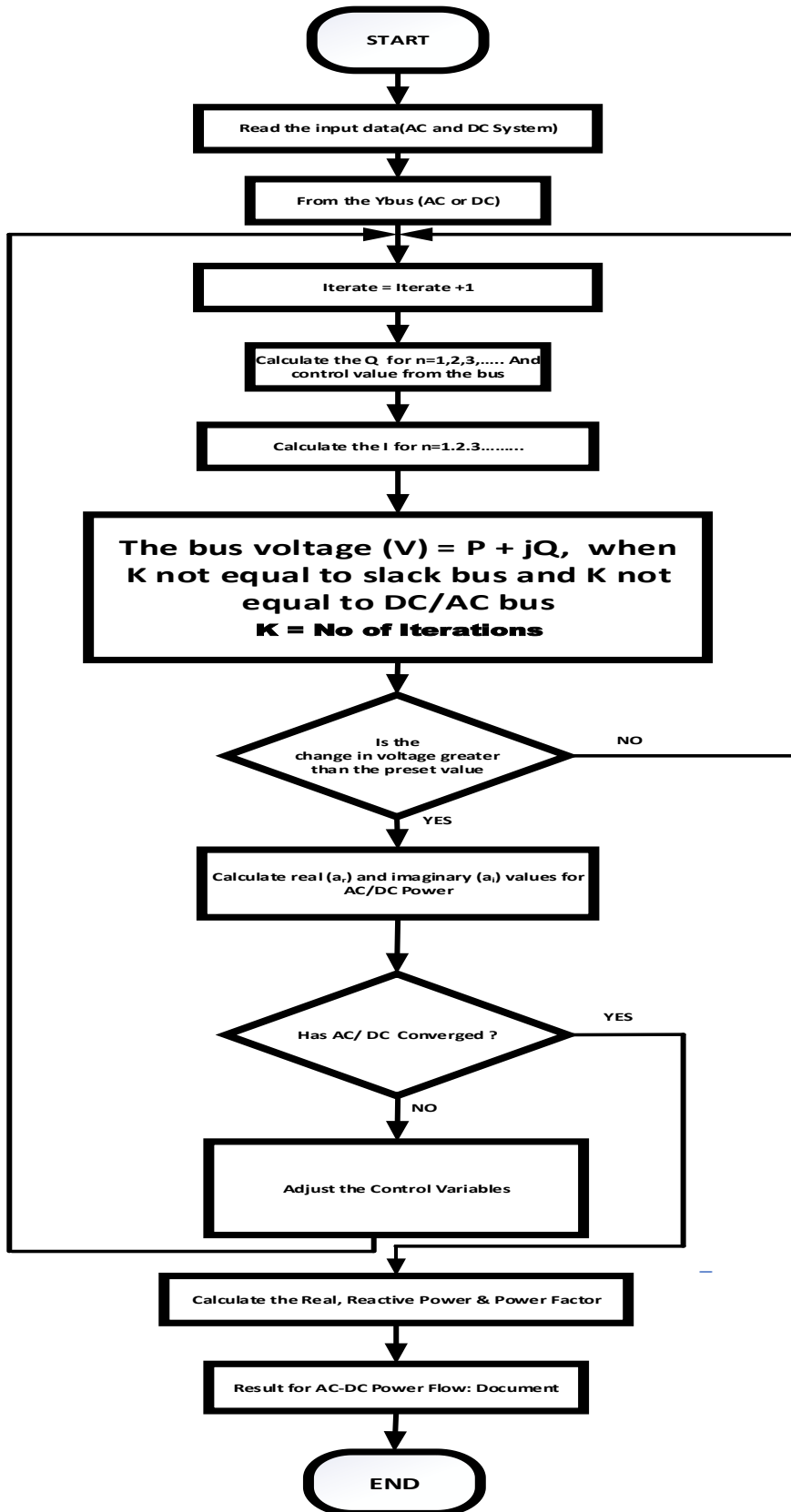


Figure 3.9: Gauss–Seidel Design Algorithm for AC–DC Load flow model

#### **3.2.4.1 Design of the system AC Load Flow Model for Institutional Distribution Network**

The topology of power systems provides the interconnections among power system components for the generators, power transformers, bus-bars, transmission lines, and loads. Fig. 3.10 shows the design of the interconnected infrastructure that forms the FUT0 power system network, whereas Fig.3.11 shows the design of the interconnected infrastructure with load flow parameters.

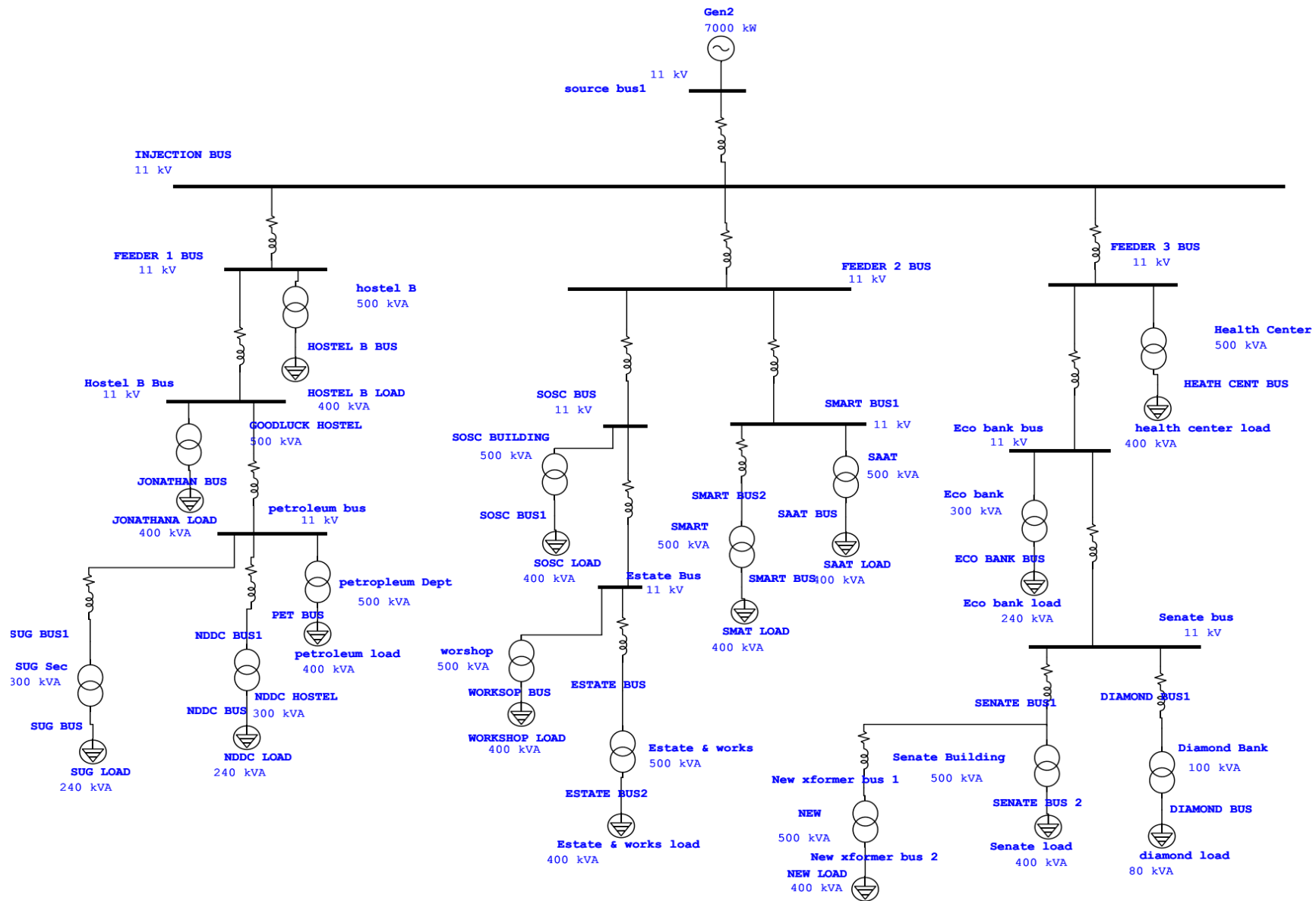


Figure 3.10: FUTO Network Topology for Power Systems

With the help of this power flow design, the flow behaviour in this coupled system was numerically examined. The fundamental elements of this design are the per unit system and single line diagram. In this design, the variables include voltage (V), voltage angles ( $\delta$ ), active power (P), and reactive power (Q). At the supply side, the reactive power and voltage angles are calculated using a numerical power flow analysis, while the active power and voltage are known. Consumer-side, knowledge of active and reactive power as well as evaluation of voltage and voltage angles through power flow analysis are done.

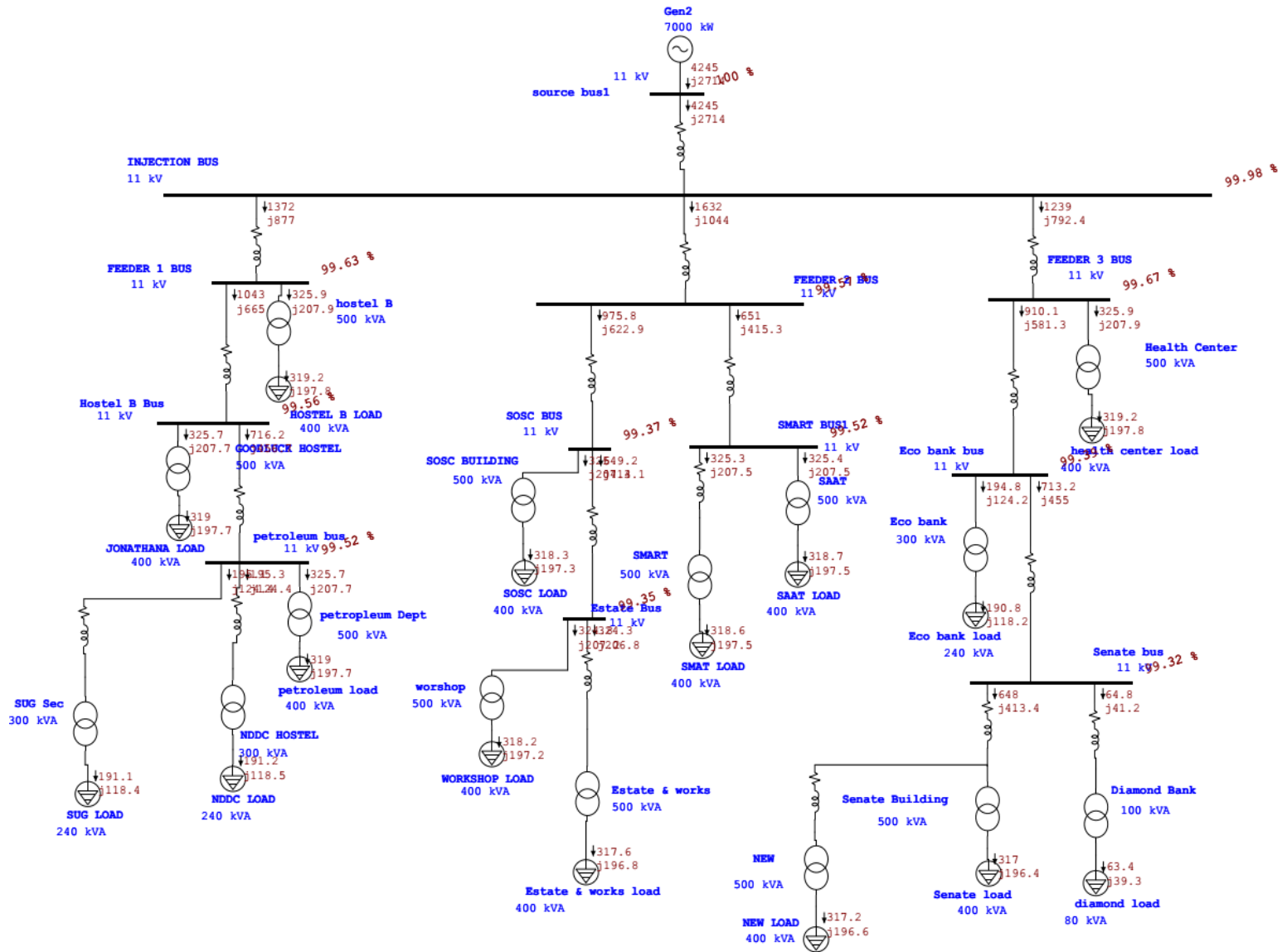


Figure 3.11: FUTO Network Topology with power flow indicated on the lines

## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 Results and discussion for the Institutional-based Energy Distribution Architecture

The results from the institutional distribution architecture as designed in Figure 3.2 is presented in this section. The electrical statistics, capacity, consumption and costs for the network are as follows:

The estimated daily load demand, hourly consumption and Load demand per building are illustrated in the Table 4.1, Fig. 4.1 and Fig. 4.2. The estimated daily load demand of the buildings is shown in Table 4.1 which indicated the power demand in Kilowatt and time of the day while Fig 4.1 and 4.2 showed the hourly load consumption Profile plot and Energy requirement per building respectively. It was found from consumption profile, load demand increases from the 10<sup>th</sup> hour to the peak at 15<sup>th</sup> and 16<sup>th</sup> hour (3,000kW). Again, it was observed that the energy requirement and load consumption is at peak in Hostel area which stood at 12,000kW load demand and about 700kWh consumption respectively.

**Table 4.1: Hourly Energy Demand**

<b>Power Demand (KW)</b>	<b>Time of day (Hrs)</b>	<b>Power Demand (KW)</b>	<b>Time of Day (Hrs)</b>
1,000.00	0	2,750.00	12
1,000.00	1	2,750.00	13
1,000.00	2	3,000.00	14
1,000.00	3	3,000.00	15
1,000.00	4	2,750.00	16
1,250.00	5	2,500.00	17
1,500.00	6	2,000.00	18
1,500.00	7	1,500.00	19
1,500.00	8	1,500.00	20
2,000.00	9	1,250.00	21
2,300.00	10	1,000.00	22
2,500.00	11	1,000.00	23

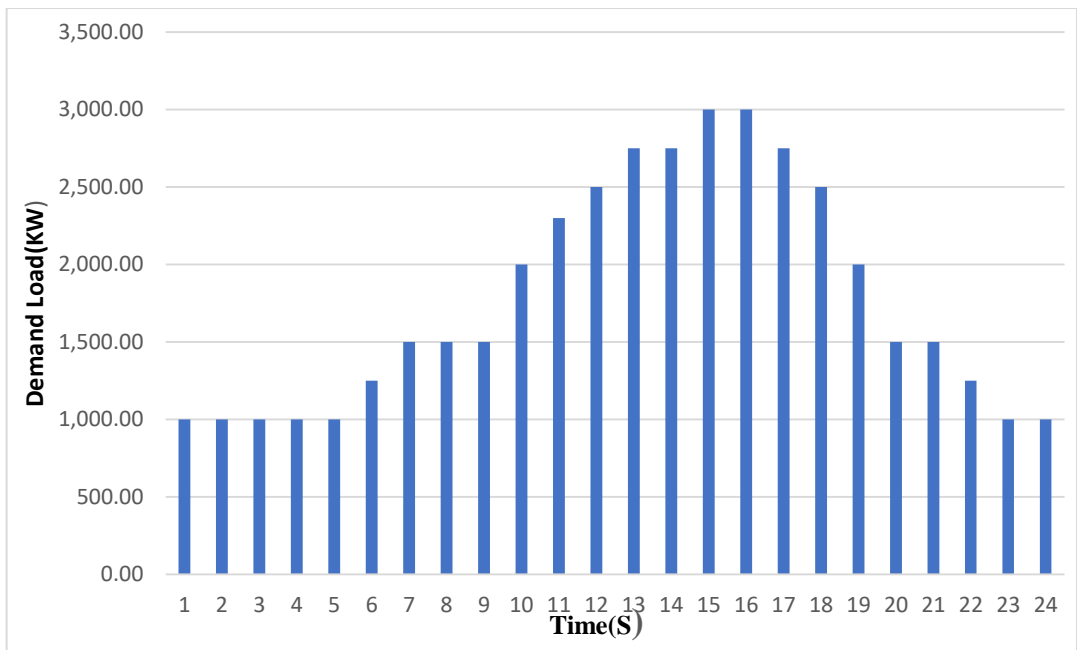


Figure 4.1: Hourly Load Consumption Profile.

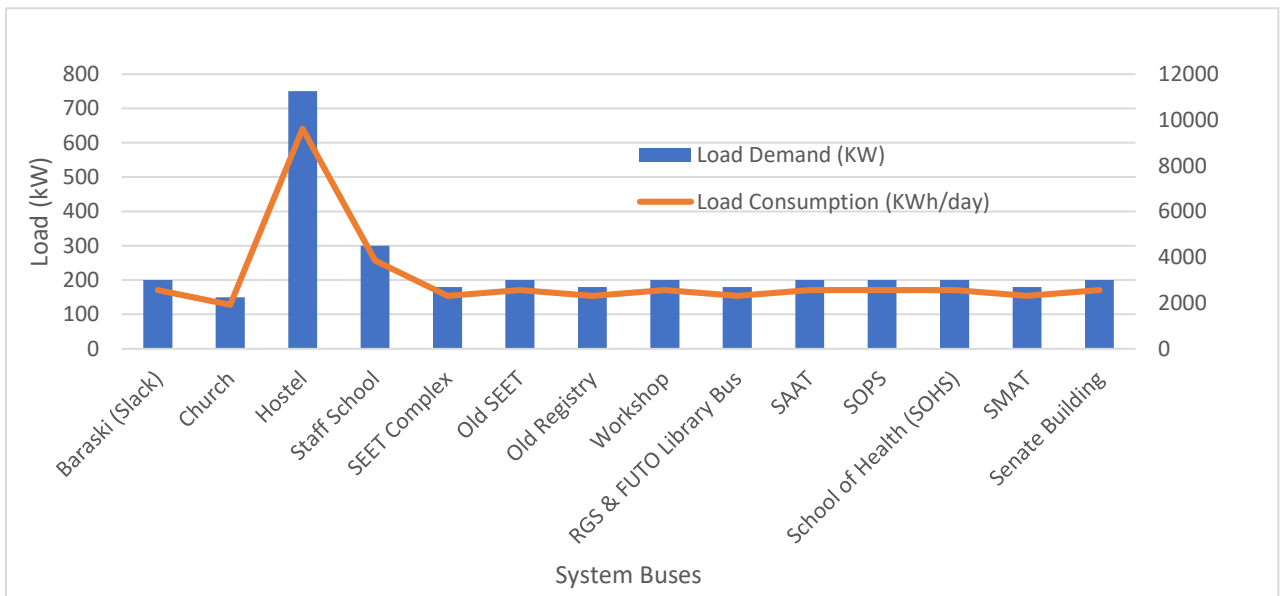


Figure 4.2: Energy Requirement and daily load Consumption per Building.

**Table 4.2: Diesel Consumption Statistics**

Quantity	Value	Units
Total fuel consumed	7,066	L (litres)
Avg fuel per day	19.4	L/day
Avg fuel per hour	0.807	L/hour

For the Diesel Generators, the diesel consumption statistics is shown Table 4.2 above. The quantity consumed per day and pay hour are shown.

Table 4.3 provided the PV and Wind Generator Renewable Energy summary, showing the capacity – based; Energy - based metrics and Peak values.

**Table 4.3: Renewable Energy Summary for PV and Wind Generator**

Capacity-based metrics	Value	Unit
Nominal renewable capacity divided by total nominal capacity	97.1	%
Usable renewable capacity divided by total capacity	94.2	%
Energy-based metrics	Value	Unit
Total renewable production divided by load	155	%
Total renewable production divided by generation	97.2	%
One minus total non-renewable production divided by load	99.8	%
Peak values	Value	Unit
Renewable output divided by load (HOMER standard)	796	%
Renewable output divided by total generation	100	%
One minus non-renewable output divided by total load	100	%

From Tables 4.4, 4.5 and 4.6, the total energy produced completely suffices the energy requirements of the FUTO network, with excesses available for commercialization. Judging from this simulation analysis, the excess can be pooled, thus giving institutions a leeway into internally generated revenue.

**Table 4.4: Electrical Excess, Unmet load and unmet with capacity shortage**

Quantity	Value	Units
Excess Electricity	8,603,334	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

**Table 4.5: Energy Production Results**

Component	Production (kWh/yr)	Percent
Solar Gen (PV modules)	12,959,298	52.4
Diesel Gen (500 KW)	26,119	0.106
Wind Gen (WG)	10,157,079	41.0
Hydro	949,588	3.84
Grid Purchases	661,293	2.67
Total	24,753,377	100

**Table 4.6: Energy Consumption Analysis**

Component	Consumption (kWh/yr)	Percent
AC Primary Load	15,527,764	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	15,527,764	100

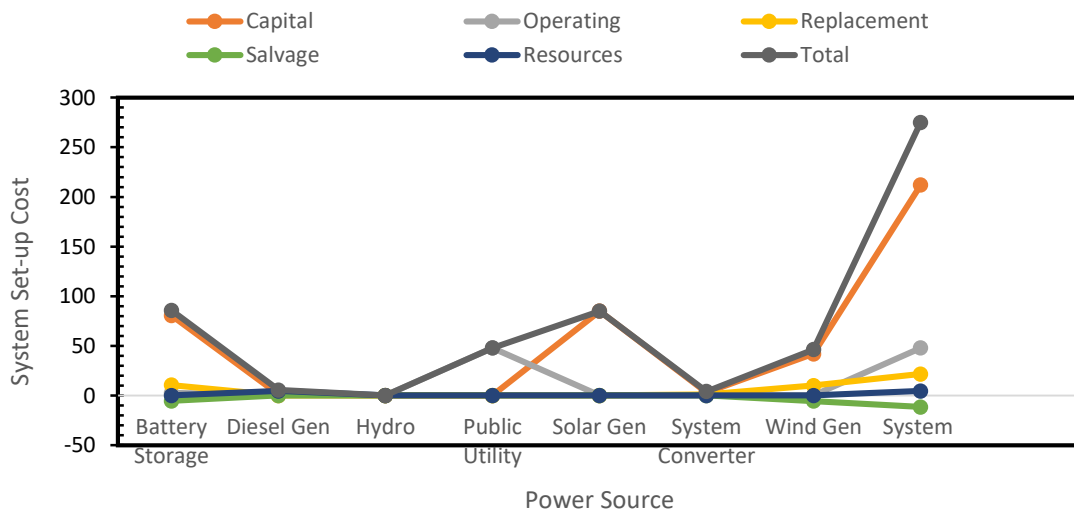
Table 4.7 gives the net present cost for setting up the system model for the Institutional based energy network. Though the initial capital for the system model is high, an annualized capital cost is proposed clearly in Table 4.8 and Figure 4.21. It is observed that negative sign found in the salvage values of Tables 4.7 and 4.8 refers to a cost rather than benefit at the end of the system's life.

**Table 4.7: Net Present Costs for the Model**

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Battery Storage (2100Ah)	₦1.04B	₦33.04	₦137M	-₦70.5M	₦0.00	₦1.11B
Diesel Gen (500 KW)	₦13.0M	₦511,930	₦0.00	-₦2.00M	₦59.4M	₦70.9M
Hydro 100kW	₦459,845	₦178,335	₦0.00	₦0.00	₦0.00	₦638,180
Public Utility (EEDC)	₦0.00	₦619M	₦0.00	₦0.00	₦0.00	₦619M
Solar Gen (PV modules)	₦1.10B	₦0.00	₦0.00	- ₦255,310	₦0.00	₦1.10B
System Converter	₦40.5M	₦0.00	₦13.9M	-₦2.62M	₦0.00	₦51.8M
Wind Gen (WG)	₦542M	₦0.00	₦130M	-₦73.0M	₦0.00	₦599M
System	₦2.74B	₦620M	₦280M	-₦148M	₦59.4M	₦3.55B

**Table 4.8: Annualized System Set-up Costs**

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Battery Storage (2100Ah)	₦80.7M	₦2.56	₦10.6M	-₦5.45M	₦0.00	₦85.8M
Diesel Gen (500 KW)	₦1.01M	₦39,600	₦0.00	-₦154,733	₦4.59M	₦5.48M
Hydro 100kW	₦35,571	₦13,795	₦0.00	₦0.00	₦0.00	₦49,366
Public Utility (EEDC)	₦0.00	₦47.9M	₦0.00	₦0.00	₦0.00	₦47.9M
Solar Gen (PV modules)	₦85.0M	₦0.00	₦0.00	-₦19,749	₦0.00	₦85.0M
System Converter	₦3.13M	₦0.00	₦1.08M	-₦202,653	₦0.00	₦4.01M
Wind Gen (WG)	₦41.9M	₦0.00	₦10.0M	-₦5.65M	₦0.00	₦46.3M
System	₦212M	₦47.9M	₦21.7M	-₦11.5M	₦4.59M	₦275M



**Figure 4.2.1: Graph of Annualized system set-up Cost**

In Nigeria, the cost of diesel fuel and maintenance of diesel generators are relatively high, thus this system gives an optimized annual operational time of 99 hours per year, which brings down the operational costs of the diesel Generator drastically. This is shown in Table 4.9, Fig 4.3 and Fig 4.4.

**Table 4.9: Diesel Gen (500 KW) Fuel Requirements Results**

Quantity	Value	Units
Fuel Consumption	7,066	L
Specific Fuel Consumption	0.271	L/kWh
Fuel Energy Input	69,529	kWh/yr
Mean Electrical Efficiency	37.6	%
Hours of Operation	99.0	hrs/yr
Number of Starts	36.0	starts/yr
Operational Life	152	Yr
Capacity Factor	0.596	%
Fixed Generation Cost	5,617	₦/hr
Marginal Generation Cost	159	₦/kWh

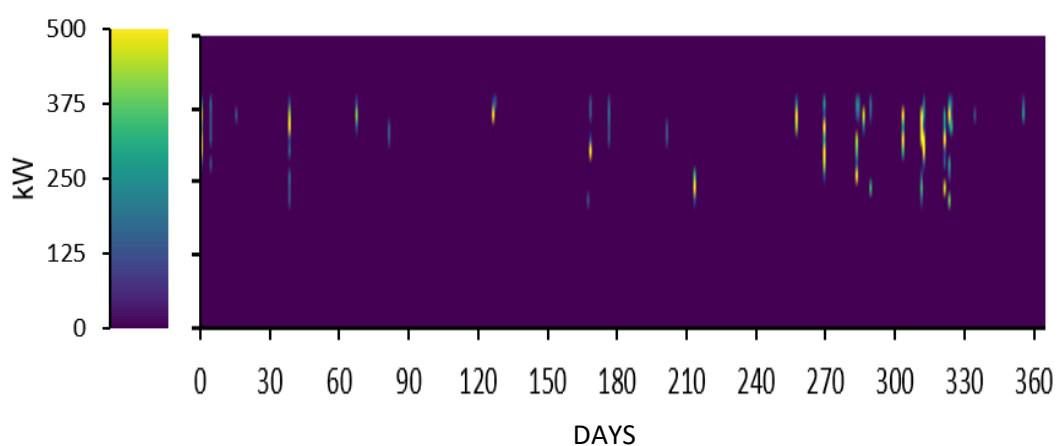
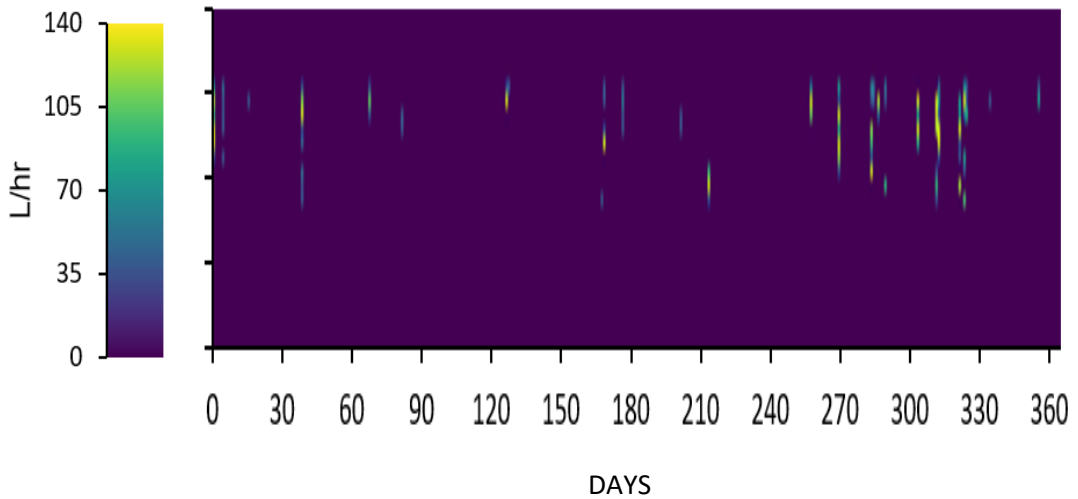


Figure 4.3: Diesel Gen (500 kW) Output (kW)



**Figure 4.4: Diesel Consumption (L/hr)**

Table 4.10 corresponding to Fig 4.5 shows that the designed PV energy generator outputs 12,959,298 KWh/yr. This is about 52% of the total energy production per year as shown in table 4.5. The designed battery storage system has the capacity of supplying energy with an autonomy of 9.42 hours as shown in table 4.11. Fig 4.6 shows the battery state of charge yearly which is commensurably sufficient for the designed model.

**Table 4.10: Solar Gen (PV modules) Results**

Quantity	Value	Units
Maximum Output	9,440	kW
Mean Output	1,479	kW
Mean Output	35,505	kWh/d
Capacity Factor	14.8	%
Total Production	12,959,298	kWh/yr

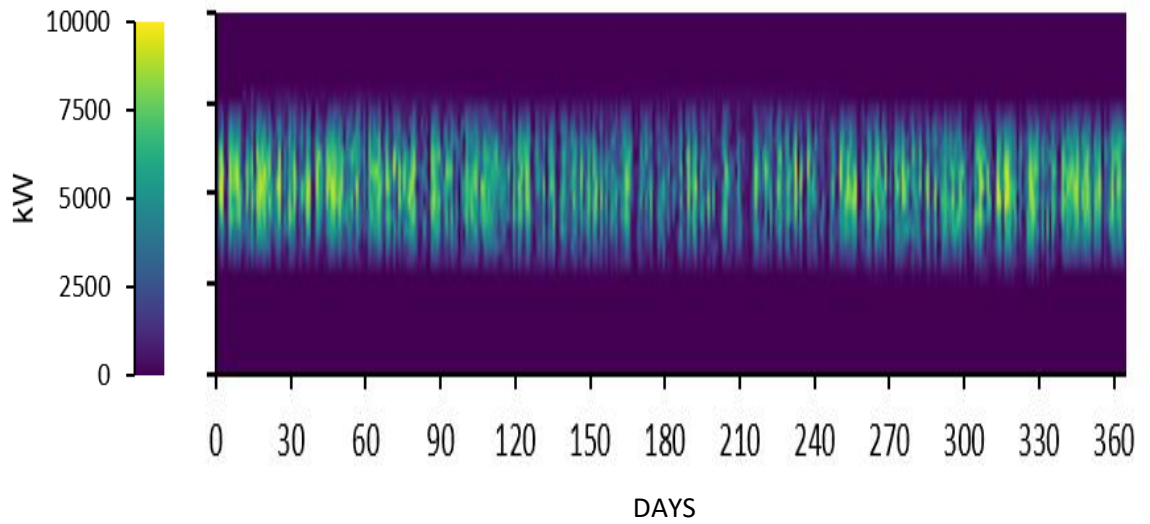


Figure 4.5: Solar Gen (PV modules) Output (kW)

**Table 4.11: Battery Storage (2100Ah) Result Data**

Quantity	Value	Units
Average Energy Cost	0	₹/kWh
Energy In	3,750,570	kWh/yr
Energy Out	3,572,711	kWh/yr
Storage Depletion	9,921	kWh/yr
Losses	187,780	kWh/yr
Annual Throughput	3,665,525	kWh/yr
Operating Hours	6,156	Hours
Autonomy	9.42	Hr
Nominal Capacity	20,866	kWh
Usable Nominal Capacity	16,692	kWh

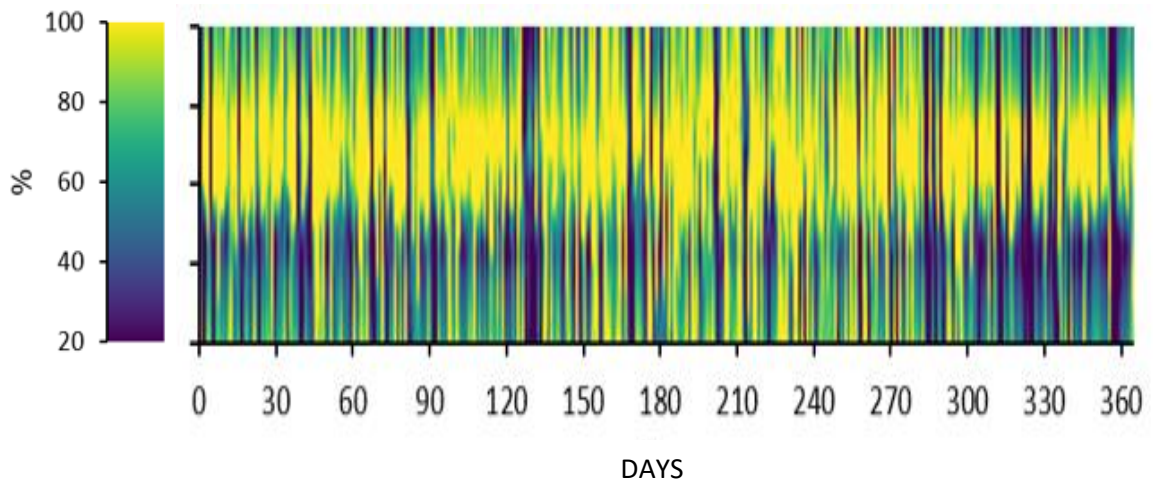


Figure 4.6: Battery Storage (2100Ah) State of Charge (%)

Table 4.12 corresponding to Fig 4.7 shows that the designed wind generator outputs 10,157,079 KWh/yr. This is about 41% of the total energy production per year as shown in table 4.5.

**Table 4.12: Wind Gen (WG) Results**

Quantity	Value	Units
Maximum Output	7,994	kW
Mean Output	1,159	kW
Capacity Factor	17.1	%
Total Production	10,157,079	kWh/yr

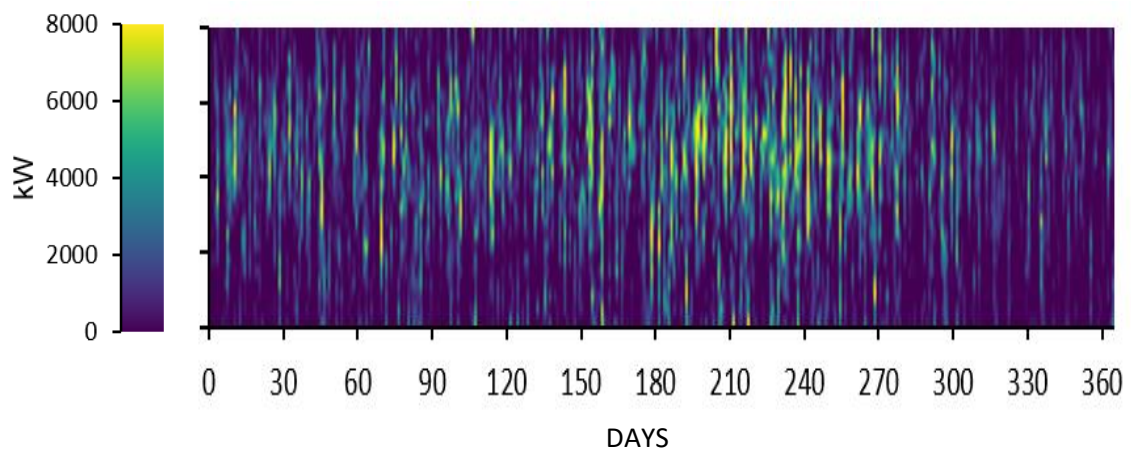


Figure 4.7: Wind Gen (WG) Output (kW)

Table 4.13 shows that the designed system converter with 6241 hrs/yr of operation gives out 7,621,159 kWh/yr with respect to an input of about 8,022,272 kWh/yr, with negligible loss of 402224 kWh/yr representing 5%. Notwithstanding its rectifying output power of 822832 kWh/yr with a loss of 5% as illustrated in Table 4.13 and the heatmap in Fig. 4.9.

**Table 4.13: System Converter Results**

Quantity	Value (Inverter)	Rectifier	Units
Hours of Operation	6,241	881	hrs/yr
Energy Out	7,621,159	822,832	kWh/yr
Energy In	8,022,272	866,139	kWh/yr
Losses	401,114	43,307	kWh/yr

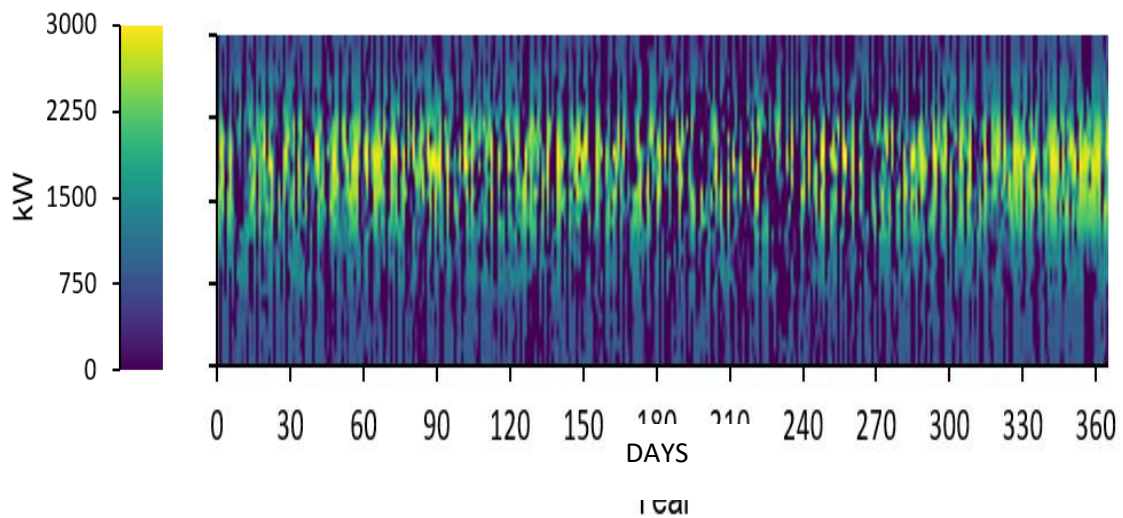
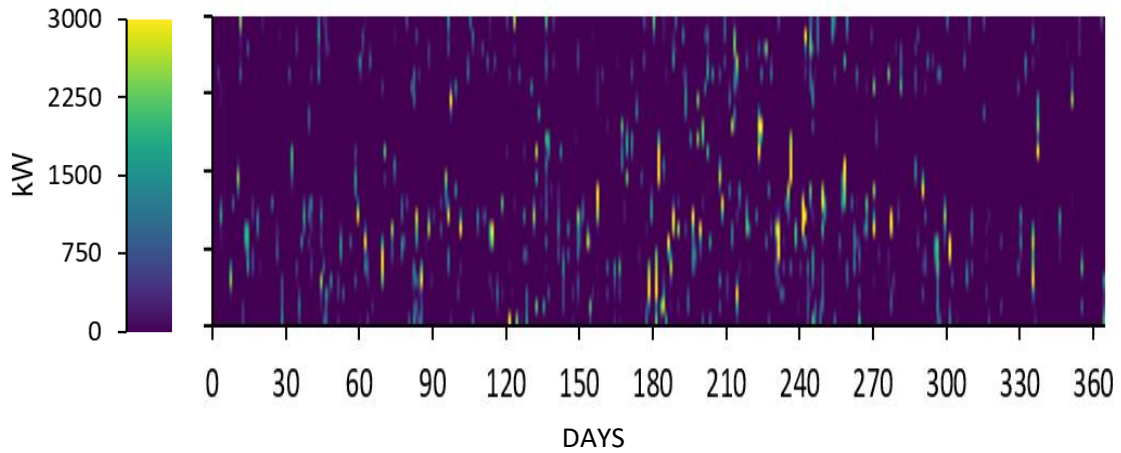


Figure 4.8: System Converter Inverter Output (kW)



**Figure 4.9: System Converter Rectifier Output (kW)**

The monthly energy purchased from the Grid is shown in Table 4.14. It is observed that the energy purchased is low during April, July and August. This results from the relatively dry weather as shown in Figure 4.9.1 during which Solar Generation is profitable.

**Table 4.14: Public Utility (EEDC) Energy Consumption Results**

Month	Energy Purchased (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge
January	62,109	62,109	1,700	₦4.50M
February	33,082	33,082	1,700	₦2.40M
March	43,992	43,992	1,700	₦3.19M
April	21,802	21,802	1,387	₦1.58M
May	54,035	54,035	1,700	₦3.91M
June	41,783	41,783	1,700	₦3.03M
July	20,248	20,248	1,611	₦1.47M
August	33,070	33,070	1,700	₦2.39M
September	55,899	55,899	1,700	₦4.05M
October	90,222	90,222	1,700	₦6.53M
November	129,442	129,442	1,700	₦9.37M
December	75,609	75,609	1,700	₦5.47M

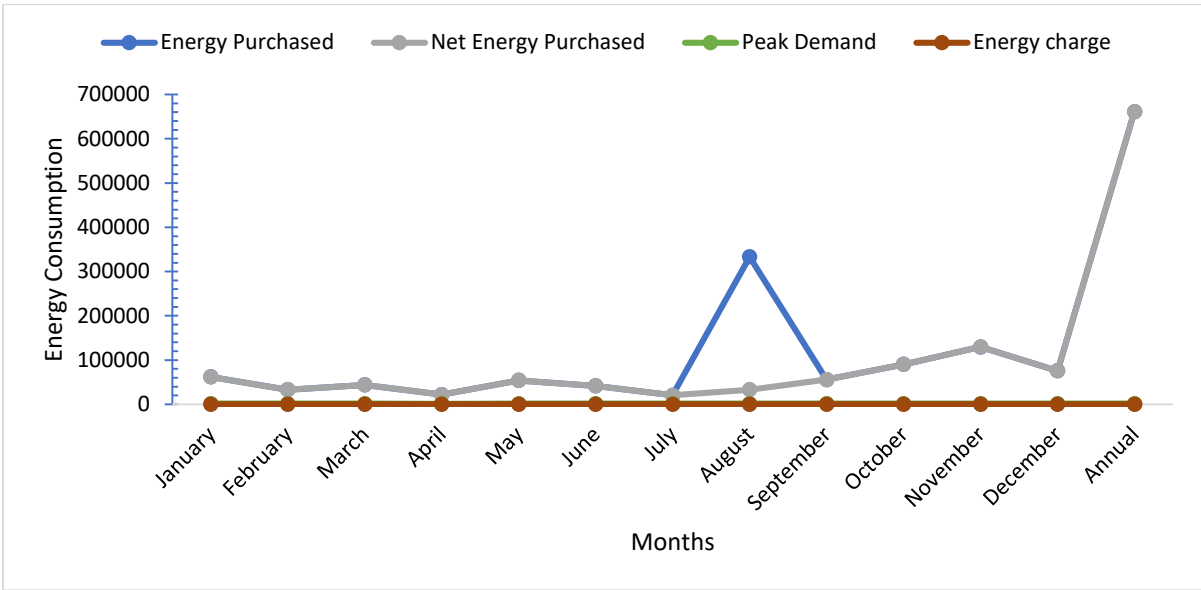


Figure 4.9.1: Public Utility Energy Consumption Graph

**Table 4.15 Hydro 100kW results**

Quantity	Value	Units
Hydro penetration	6.11	%
Hours of operation	8,760	hrs/yr
Levelized Cost	0.0520	\$/kWh

Figures 4.10, 4.11 and 4.12 show the renewable penetration and renewable fraction of the total energy produced. The optimized model gives a renewable fraction of 95.6% with 94.2% usable renewable capacity of the total generated.

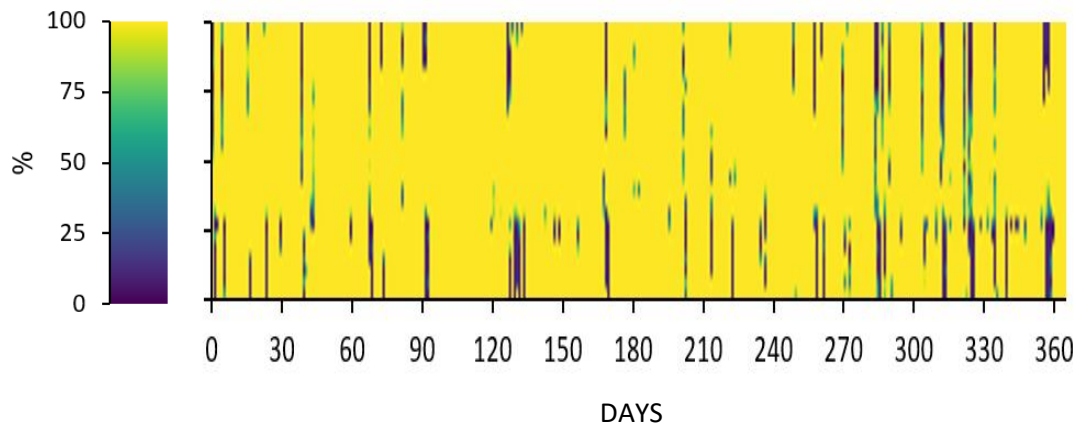


Figure 4.10: Instantaneous Renewable Output Percentage of Total Generation

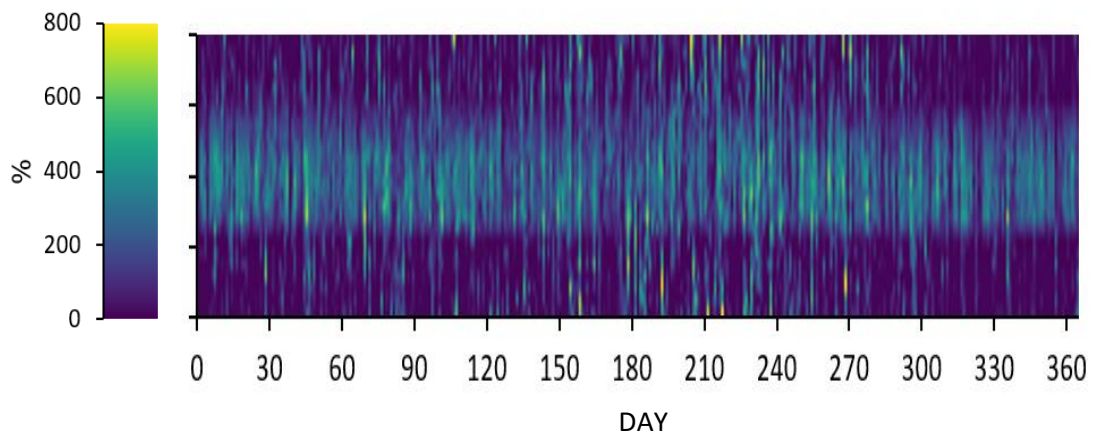


Figure 4.11: Instantaneous Renewable Output Percentage of Total Load

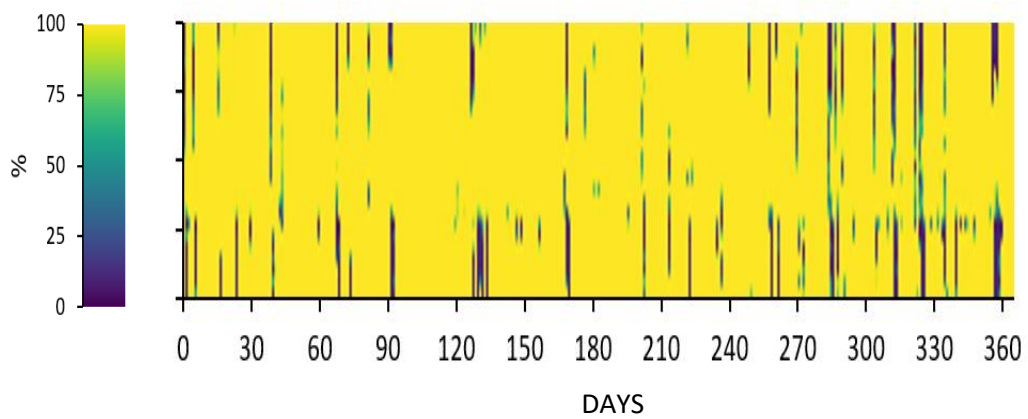


Figure 4.12: 100% Minus Instantaneous Non-renewable Output as Percentage of Total Load

## 4.2 Result and discussion for energy integration model for the institutional based power pool system

In Fig 3.3, the T0 gave initial timing of 5 seconds from the memory M20 before integrating the EEDC (T1) supply into the FUTO network bus. The common synchronized bus for the FUTO network is designated by Y021, Y022, Y023, Y024 and Y025 respectively for simulation purposes. But the purpose of this work, Y0 would be used to explain the bus voltage. After 5 seconds the generator was synchronized to the bus as in rung 16, and after 5 seconds, solar power was synchronized to the bus as in rung 24. Similarly, after 5 seconds, wind power was synchronized to the bus as in rung 32 and after 5 second, hydro power was synchronized to the bus as in rung 40.

Fig. 3.4 shows the SCADA program code of the five-energy supply utilized in the inter-institutional community power pool system to give the user interface in Fig.4.13

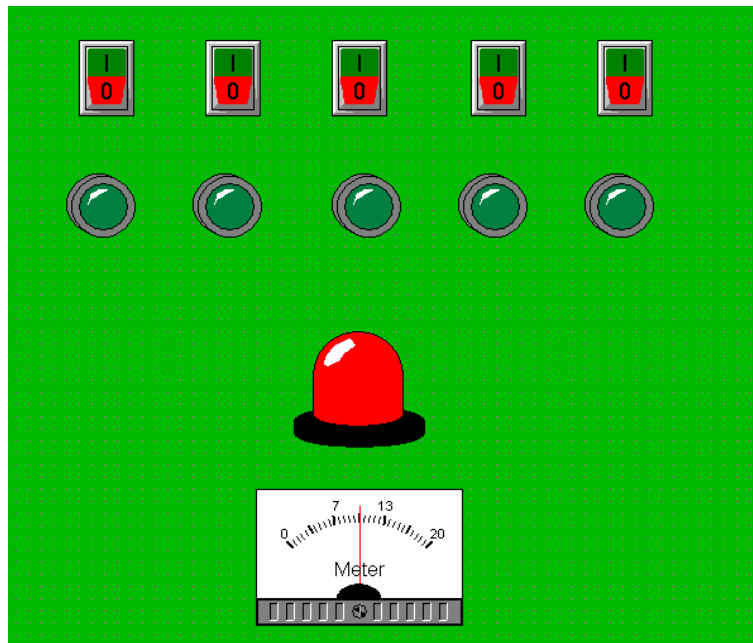


Figure 4.13: SCADA Results for the integrated system

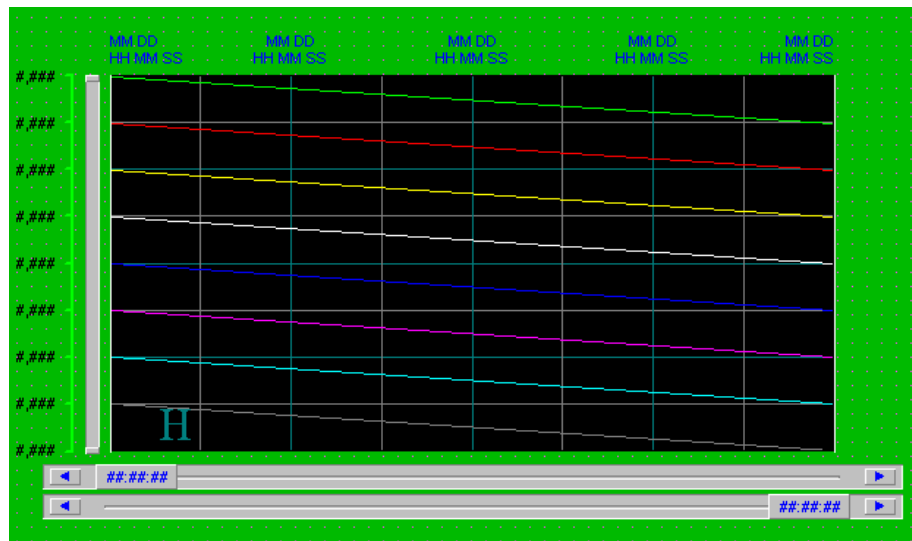


Figure 4.14: Operation Trend for the integrated system

This shows the simulation history of the SCADA and a PLC program for the institutional based power pool system.

### 4.3 Result and discussion for System equilibrium model for sources and load balancer

#### System with Sequence of Operations for the Model

##### 4.3.1 System equilibrium model for sources and load balancer System

With this model, the sources available are shared at a balance ratio to the 14 divisions in the university. The load allotment for these divisions is selected using the equilibrium model design in this work, Fig.3.5, to ensure the availability of power to all the divisions in the university. Although, power is being supplied to all the 14 respective divisions, the sections and departments under each division do not completely have their respective loads utilized at the same time. Priority is given to at least 3 essential loads in each section and departments. This would be single lighting point with 12watts, 13Amps socket, and ceiling fan, instead of complete outage within the institutional-based community, considering the need for energy for their daily operations.

### 4.3.2: Sequence of Operations for the Model

From Figure 3.6, the sequence of operation for the institutional based power pool model integrates Mini-hydro, solar, wind, into EEDC and diesel generator power to the FUTO distribution network for optimal energy utilization. This sequence follows the pseudo code presented thus:

#### Pseudo Code

*Start the System*

*Check for power available*

*If EEDC power is available,*

*Then, synchronize the power to the Bus*

*Else, check the load available for power supply, and if it would be sufficient*

*If Solar power is available,*

*Then, synchronize the power to the Bus*

*Else, check the load available for power supply, and if it would be sufficient*

*If Mini-Hydro power is available,*

*Then, synchronize the power to the Bus*

*Else, check the load available for power supply, and if it would be sufficient*

*If Wind power is available,*

*Then, synchronize the power to the Bus*

*Else, check the load available for power supply, and if it would be sufficient*

*If Diesel Generator power is available,*

*Then, synchronize the power to the Bus*

*Else, check the load available for power supply, and if it would be sufficient*

*Stop the System*

### 4.4 Results and discussion for the system Load Flow Model for institutional distribution Network

From Fig 3.11, the load flow results from the ETAP simulation for the institutional based power pool model for the FUTO distribution network follows the pseudo code presented thus:

*Start*

*Create Y-bus*

*Make initial assumptions as the old values*

*Substitute the old values into power equations for the next iteration*

*Obtain the new value*

*New value – Old value*

*If (New value – Old value) < specified tolerance*

*then end; otherwise go to step 4*

Single line diagram of the proposed university distribution network was developed using the ETAP software as specified. Load flow analysis were carried out on the SLD presented in Figure 3.11. The ETAP simulation result is presented in Table 4.16 to Table 4.20 while the real and reactive power flow within the network was analyzed. The input data used for the simulation are:

Line rated voltage	=	11kV
Total number of transformers	=	15 (11×500kVA, 3×300kVA and 1×100kVA)
Total number of loads	=	15 @ 80% loading
Total number Buses	=	34
Total number of branches	=	33
Generation capacity	=	7MW
Total number of lines	=	18
Total network line length	=	4900metres
Conductor type and size	=	ACSR@120mm <sup>2</sup>

The power generation information is presented in Table 4.16 while other detailed results are documented in appendix A. The proposed solar power generation capacity is 7MW @ 11kV. The plant generates 4.245MW real power and 2.714 MVar reactive power @ 84.25pf which represent 60.6% of plant installed capacity and the total current is 264.4Amp.

**Table 4.16: Power Generation Information**

ID	Rating/ Limit	Rated kV	MW	MVar	Amp	% PF	% Generation
Gen2	7 MW	11	4.245	2.714	264.4	84.25	60.6

Table 4.17 presents real and reactive power flow through the transformers connected in the distribution network and further explained in the graph show Figure 4.15. The real and reactive power flow through each 500kVA transformer was 325.9kW and 207.9kVar while the current flow is 20.36Amps. The percentage average loading on each transformer was 77.3%. The real and reactive power flow through each 300kVA transformer was 195.1kW and 124.4kVar while the current flow was 12.2Amps. The percentage loading on each transformer was 77.1%. The real and reactive power flow through each 100kVA transformer was 64.77kW and 41.31kVar while the current flow is 4.06Amps. The percentage loading on each transformer was 76.8%. Other detailed results are documented in Appendix A.

**Table 4.17: Transformers Load Flow Report**

s/n	ID	Type	kW Flow	kVar Flow	Amp Flow	% Loading
1	Diamond Bank	Transf. 2W	64.77	41.31	4.06	76.8
2	Eco bank	Transf. 2W	194.8	124.2	12.2	77
3	Estate & works	Transf. 2W	324.2	206.8	20.32	76.9
4	Goodluck Hostel	Transf. 2W	325.7	207.7	20.36	77.3
5	Health Center	Transf. 2W	325.9	207.9	20.36	77.3
6	Hostel B	Transf. 2W	325.9	207.9	20.36	77.3
7	NDDC Hostel	Transf. 2W	195.2	124.5	12.22	77.2
8	New Hostel	Transf. 2W	323.9	206.6	20.33	76.8
9	Petroleum Dept	Transf. 2W	325.7	207.7	20.37	77.3
10	SAAT	Transf. 2W	325.4	207.5	20.36	77.2
11	Senate Building	Transf. 2W	323.6	206.4	20.3	76.8
12	SMART	Transf. 2W	325.3	207.5	20.35	77.2
13	SOSC Building	Transf. 2W	325	207.3	20.36	77.1
14	SUG Sec	Transf. 2W	195.1	124.4	12.2	77.1
15	Workshop	Transf. 2W	324.8	207.2	20.35	77.1

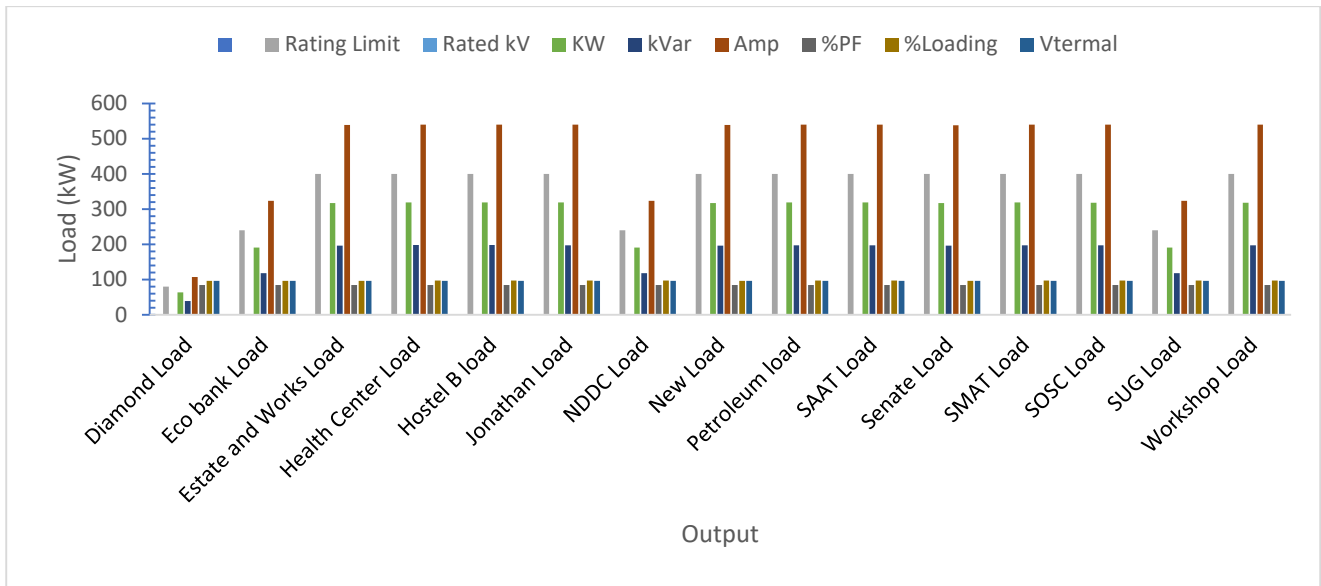


Figure 4.15: Transformer Load Flow Report Graph.

Table 4.18 presented the percentage loading on each transformer. The maximum loading input is 77.3% with 0.386MVA load while the maximum loading output is 75.1% with 0.375MVA load. The graph of percentage loading of transformers is presented in Figure 4.16. Other detailed results are documented in Appendix A.

**Table 4.18: Branch Load Summary Report**

s/n	ID	Type	Capability MVA	Transformer Loading input		Transformer Loading output	
				MVA	%	MVA	%
1	Diamond Bank	Transformer	0.100	0.077	76.8	0.075	74.6
2	Eco bank	Transformer	0.300	0.231	77.0	0.224	74.8
3	Estate & Works		0.500	0.385	76.9	0.374	74.7
4	Goodluck Hostel		0.500	0.386	77.3	0.375	75.1
5	Health Center		0.500	0.387	77.3	0.376	75.1
6	Hostel B		0.500	0.387	77.3	0.376	75.1
7	NDDC Hostel		0.300	0.232	77.2	0.225	75.0
8	NEW		0.500	0.384	76.8	0.373	74.6
9	Petroleum Dept		0.500	0.386	77.3	0.375	75.1
10	SAAT		0.500	0.386	77.2	0.375	75.0
11	Senate Building		0.500	0.384	76.8	0.373	74.6
12	SMART		0.500	0.386	77.2	0.375	75.0
13	SOSC Building		0.500	0.385	77.1	0.374	74.9
14	SUG Sec		0.300	0.231	77.1	0.225	74.9
15	Workshop		0.500	0.385	77.1	0.374	74.9

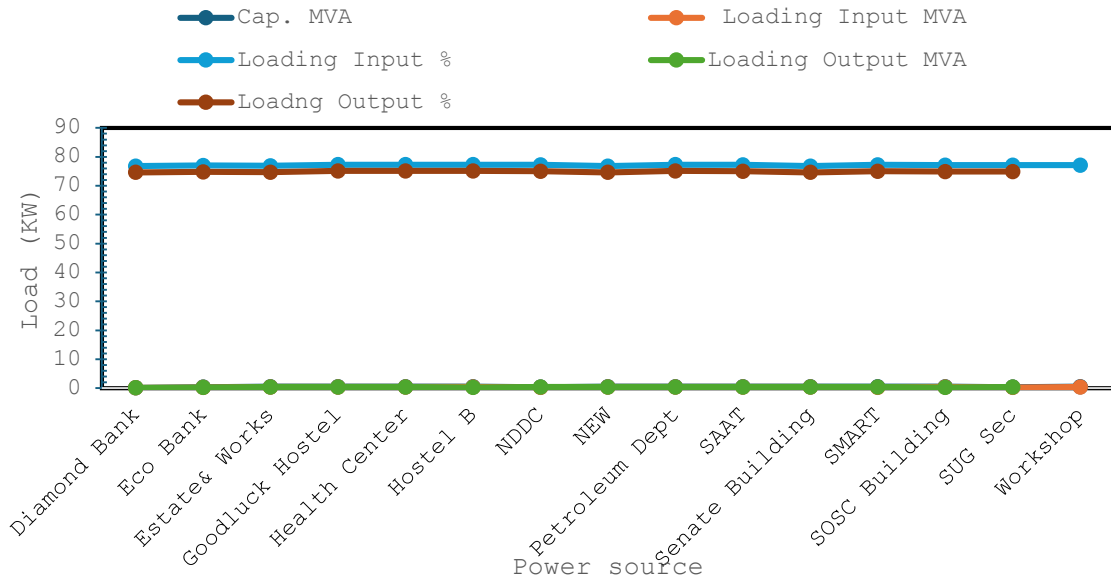
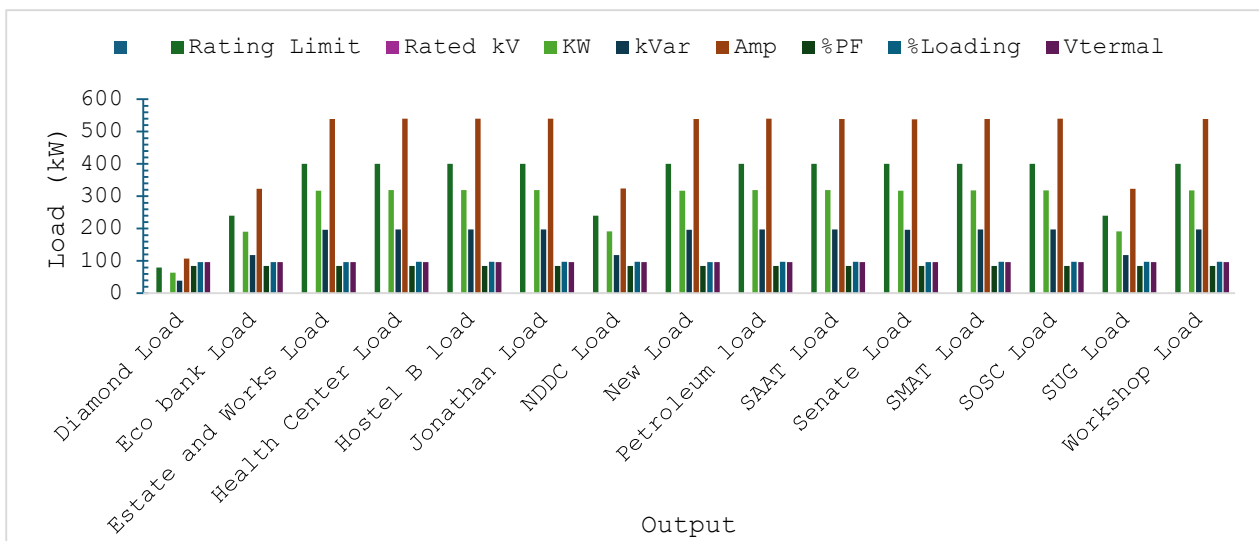


Figure 4.16: Graph of Branch Load Summary Report

From Fig.3.10, Fig. 3.111 and Table 4.19 present the real and reactive power flow on each lump load connected to the transformer. 500kVA transformer at 400kVA load generate real and reactive power flow of 317.6MW and 196.8Mvar respectively, 538.6Amps, 85pf at 96.8% loading. 300kVA transformer at 240kVA load generate real and reactive power flow of 190.8MW and 118.2 Mvar, 323.3Amps ,85pf at 96.8% loading. 100kVA transformer at 80kVA load generate real and reactive power flow of 63.44MW and 39.32 Mvar, 107.6Amps ,85pf at 96.7% loading. Figure 4.17 further explained the load connected to transformers showing the real and reactive power flow on each lump of load.

**Table 4.19: Load Connected to Transformers**

S/N	ID	Rating/ Limit	Rated kV	kW	kVar	Amp	% PF	% Loading	Vterminal
1	Diamond Load	80 kVA	0.415	63.44	39.32	107.6	85	96.7	96.48
2	Eco bank Load	240 kVA	0.415	190.8	118.2	323.3	85	96.8	96.56
3	Estate & Works Load	400 kVA	0.415	317.6	196.8	538.6	85	96.8	96.5
4	Health Center Load	400 kVA	0.415	319.2	197.8	539.6	85	97	96.83
5	Hostel B Load	400 kVA	0.415	319.2	197.8	539.8	85	97	96.8
6	Jonathan Load	400 kVA	0.415	319	197.7	539.7	85	97	96.73
7	NDDC Load	240 kVA	0.415	191.2	118.5	323.8	85	97	96.64
8	New Load	400 kVA	0.415	317.2	196.6	538.7	85	96.8	96.37
9	Petroleum Load	400 kVA	0.415	319	197.7	539.9	85	97	96.69
10	SAAT Load	400 kVA	0.415	318.7	197.5	539.5	85	97	96.69
11	Senate Load	400 kVA	0.415	317	196.4	538.1	85	96.7	96.41
12	SMAT Load	400 kVA	0.415	318.6	197.5	539.5	85	96.9	96.67
13	SOSC Load	400 kVA	0.415	318.3	197.3	539.6	85	97	96.54
14	SUG Load	240 kVA	0.415	191.1	118.4	323.5	85	96.9	96.68
15	Workshop Load	400 kVA	0.415	318.2	197.2	539.5	85	96.9	96.52



**Figure 4.17: Load Connected to Transformers Graph.**

From Fig.3.11 and Table 4.20 presents different real and reactive power flow through different lines. The length of line, resistance and reactance determines the value of power flow through the lines. The IEEE Bus voltage statutory limits stipulate ( $0.95 \leq V_{bus} \leq 1.05$ ) voltage at different buses. Marginal report presents % bus operating voltage which was calculated to be within ( $0.99 \leq V_{operating} \leq 1.0$ ) and when compared with the standard value satisfy the specification. Other detailed results are documented in Appendix A.

The branch loss summary report in Table 4.20 presents the total network real and reactive power losses with Figure 4.18 showing the summary in a graphical plot, which is equal to 106.4kW and 149.4kvar respectively. The voltage drop lies within 3% voltage IEEE standard allowable value. The distribution network did not violate the loading capacity of generation plant. The result presented is within different specified acceptable standard limits. Other detailed results are documented in Appendix A.

The initial ETAP analysis was based on optimal loading of transformers at the average of 80% to have a total load of 4.245MW real power and 2.764 Mvar reactive power at 84.25pf. From the energy demand measurement, the peak load of FUTO was 3.366MW during the day and 2.861MW at night. This translates to 63.43% average loading of the transformers at the university.

**Table 4.20: Summary of the Total Generator, Loading and Demand for the AC load Analysis**

	MW	Mvar	MVA	%PF
Source (Swing Buses)	4.245	2.714	5.038	84.25 lagging
Source (Non-Swing Buses)	0.000	0.000	0.000	
Total Demand	4.245	2.714	5.038	84.25 lagging
Total Motor Load	0.190	0.118	0.223	85.00 lagging
Total Static Load	3.949	2.447	4.646	85.00 lagging
Total Constant I Load	0.000	0.000	0.000	
Total Generic Load	0.000	0.000	0.000	
Apparent losses	0.106	0.149		
System Mismatch	0.000	0.000		

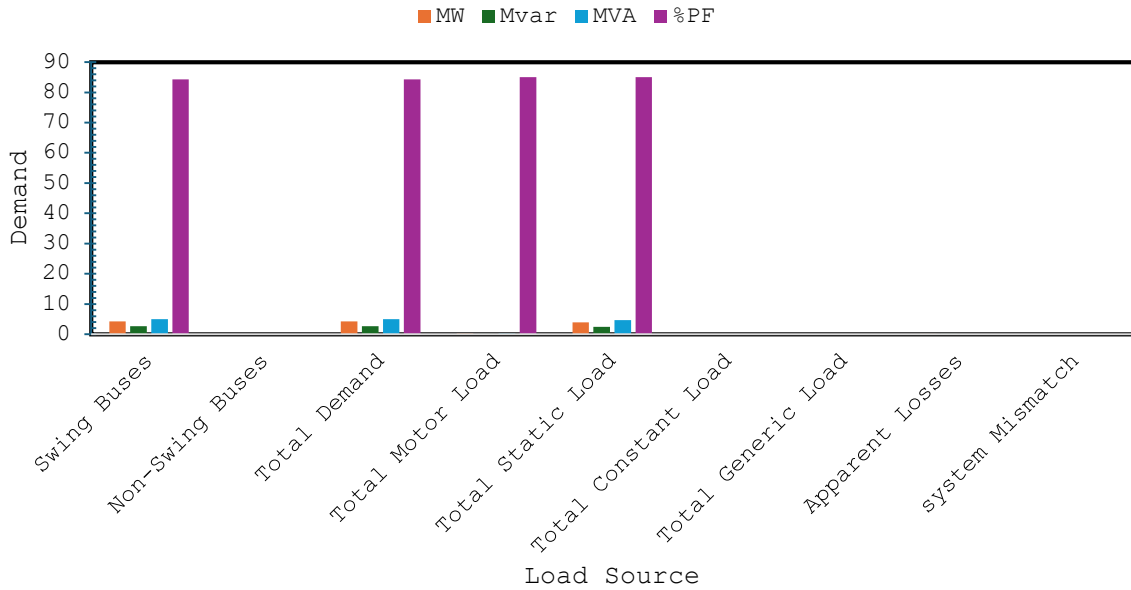


Figure 4.18: Graph of Summary of the Total Generator, Loading and Demand for the AC Load Analysis.

This implies that the university has installed capacity of transformers lower than their load demand. The solar power plant can still accommodate more load based on the present university load. It is recommended from load flow analysis that the in-depth analysis of the FUTO network should be done to include, the proposed generation plant capacity with the existing load and the distribution network.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

Educational institutions and allies with multiple energy sources within its operational vicinity from generators, public utility, and potential renewable resources such as solar, wind, hydro etc, with much energy demand to cater for their needs could adopt this model for its daily operation and energy attainment. Creation of new departments, divisions and units could continuously emerge proportionally to the quest for knowledge without stressing the educational institutions in terms energy demand and consumption with the advent of this robust enabling energy integration technology. All the objectives in this work were achieved to validate the results of designing the institutional Network/Architecture into a fourteen (14) bus network; developed the integration model for seamless renewable energy resources; developed the system sequence of operation for seamless integration, sources and load balancing using PLC, SCADA and ETAP and load flow analysis and implementation using ETAP load flow criteria for the institutional – based community distribution Network. With the aforementioned institutional-based community power pooling model with seamless renewable energy integration, university can fully utilize the energy generated within it community optimally because of energy scheduling, equilibrium of the source and the load on a balance mode. The model simulations reveal that the system is capable of synchronizing the renewable energy resources within the university in a single network bus, with wind and solar generation contributing 10,157,079kWh/yr and 12,959,298kWh/yr respectively. Alongside with public power supply and diesel generators, given a total power generation capacity of 7MW at 11kV. From the load flow analysis, the plant generates 4.245MW real power and 2.714Mvar reactive power @ 84.25 pf which represents 60.6% of plant capacity and total current of 264.4Amp. This could guarantee efficient and optimal utilization of the energy

potentials within the university community with excess energy available for sales to the neighbouring energy users with the formulated model. This model could be utilized in other universities across the nation with the view of tailoring its architecture to suit its peculiar scenario. They should consider sending the excess and unused energy to its immediate community as pool concept entails. On the proposed institutional-based power distribution network, load flow analysis was carried-out to determine the shared loading operating condition of the system and the simulation provided a virtual platform to track voltages, active and reactive power flows, and bus-bars in the power system.

## **5.2 Recommendations**

Following the realization of an institutional-based community power pooling model with seamless renewable energy integration through simulation, it is therefore recommended that:

- i. The university should adopt the developed distribution network system model for their operation period.
- ii. In furtherance to the institutional-based community energy model development, renewable system integration should be encouraged as that the synchronization offers seamless integration processes with the use of PLC.
- iii. Business outfit like shopping plaza, market and religious worship centres should attempt using this developed institutional-based model for their energy scheduling, equilibrium sources attainment and load balancing.
- iv. Institutional-based community that adopt this model should carry out its own load flow analysis to help track voltages, active and reactive power flows, and bus-bars in their power system network.

### **5.3 Contribution to knowledge**

An institutional-based community power pooling model for seamless renewable energy integration is the major contribution in this research work. In an attempt to achieve the prime objective in this work, the following specific contributions to knowledge were outlined:

- i. An institution distribution network/ architecture was designed.
- ii. An integrating model for the seamless integration of renewable energy resources was developed.
- iii. Energy system scheduling equilibrium model for sources and load balancing was developed.
- iv. The system sequence of operations for seamless integration, source and load balancing were formulated.
- v. The university-based power pool system model was validated and implemented by simulation.
- vi. The formulation and implementation of the load flow criteria for the institutional-based community distribution Network with seamless energy integration was achieved.

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## **APPENDICES**

Appendix A: Load Flow Results for the AC Power system

Appendix B: Load Flow Results for the DC Power system

# Appendix A: Load Flow Results for the AC Power system

Project: **ETAP** Page: 1  
Location: **16.0.0C** Date: 21-02-2023  
Contract: SN: 4359168  
Engineer: Study Case: LF Revision: Base  
Filename: futo drawing Config.: Normal

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## Electrical Transient Analyzer Program

### Load Flow Analysis

Loading Category (1): Design  
Generation Category (1): Design  
Load Diversity Factor: None

	<u>Swing</u>	<u>V-Control</u>	<u>Load</u>	<u>Total</u>
Number of Buses:	1	0	33	34

	<u>XFMR2</u>	<u>XFMR3</u>	<u>Reactor</u>	<u>Line/Cable</u>	<u>Impedance</u>	<u>Tie PD</u>	<u>Total</u>
Number of Branches:	15	0	0	18	0	0	33

Method of Solution: Adaptive Newton-Raphson Method  
Maximum No. of Iteration: 99  
Precision of Solution: 0.0001000  
  
System Frequency: 50.00 Hz  
Unit System: Metric  
Project Filename: futo drawing  
Output Filename: C:\ETAP 1600\futo drawing\Untitled.lfr

Project: **ETAP**  
Location: 16.0.0C  
Contract:  
Engineer:  
Filename: futo drawing

Study Case: LF

Page: 2  
Date: 21-02-2023  
SN: 4359168  
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**Adjustments**

<u>Tolerance</u>	<u>Apply Adjustments</u>	<u>Individual /Global</u>	<u>Percent</u>
Transformer Impedance:	Yes	Individual	
Reactor Impedance:	Yes	Individual	
Overload Heater Resistance:	No		
Transmission Line Length:	No		
Cable Length:	No		

<u>Temperature Correction</u>	<u>Apply Adjustments</u>	<u>Individual /Global</u>	<u>Degree C</u>
Transmission Line Resistance:	Yes	Individual	
Cable Resistance:	Yes	Individual	



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Bus			Initial Voltage		Load							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
WORKSOP BUS	0.415	1	100.0	0.0	0.020	0.013	0.320	0.198				
Total Number of Buses: 34					0.190	0.118	4.230	2.622	0.000	0.000	0.000	0.000

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min
source bus1	11.000	Swing	1	100.0	0.0					
						0.000	0.000			

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**Line/Cable Input Data**

ohms or siemens/1000 m per Conductor (Cable) or per Phase (Line)

<u>Line/Cable</u>									
ID	Library	Size	Length		#/Phase	T (°C)	R	X	Y
			Adj. (m)	% Tol.					
DIAMOND BANK 1		120	320.0	0.0	1	75	0.361371	0.388777	0.0000031
ESTATE & WORKS 1		120	150.0	0.0	1	75	0.361371	0.388777	0.0000031
feeder line1B		120	500.0	0.0	1	75	0.361371	0.388777	0.0000031
feeder2B		120	500.0	0.0	1	75	0.361371	0.388777	0.0000031
feeder 3		120	500.0	0.0	1	75	0.361371	0.388777	0.0000031
GOODLUCK LINE1B		120	140.0	0.0	1	75	0.361371	0.388777	0.0000031
Line4		120	10.0	0.0	1	75	0.361371	0.388777	0.0000031
NDDC LINE B		120	550.0	0.0	1	75	0.361371	0.388777	0.0000031
NEW ADDED		120	200.0	0.0	1	75	0.361371	0.388777	0.0000031
PETROLEUM LINE B		120	100.0	0.0	1	75	0.361371	0.388777	0.0000031
SAAT LINE1B		120	150.0	0.0	1	75	0.361371	0.388777	0.0000031
SENATE LINE 1b		120	600.0	0.0	1	75	0.361371	0.388777	0.0000031
SENATE LINE 1c		120	200.0	0.0	1	75	0.361371	0.388777	0.0000031
SENATE LINE C		120	270.0	0.0	1	75	0.361371	0.388777	0.0000031
SMAT LINE1B		120	100.0	0.0	1	75	0.361371	0.388777	0.0000031
SOSC LINE 1B		120	390.0	0.0	1	75	0.361371	0.388777	0.0000031
SUG LINE B		120	160.0	0.0	1	75	0.361371	0.388777	0.0000031
WORKSHOP 1		120	60.0	0.0	1	75	0.361371	0.388777	0.0000031

Line / Cable resistances are listed at the specified temperatures.

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**2-Winding Transformer Input Data**

Transformer		Rating					Z Variation			% Tap Setting		Adjusted	Phase Shift	
ID	Phase	MVA	Prim. kV	Sec. kV	% Z1	X1/R1	+ 5%	- 5%	% Tol.	Prim.	Sec.	% Z	Type	Angle
Diamond Bank	3-Phase	0.100	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
Eco bank	3-Phase	0.300	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
Estate & works	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
GOODLUCK HOSTEL	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
Health Center	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
hostel B	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
NDDC HOSTEL	3-Phase	0.300	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
NEW	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
petroleum Dept	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
SAAT	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
Senate Building	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
SMART	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
SOSC BUILDING	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
SUG Sec	3-Phase	0.300	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
worshop	3-Phase	0.500	11.000	0.415	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000

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**Branch Connections**

CKT/Branch		Connected Bus ID		% Impedance, Pos. Seq., 100 MVA Base			
ID	Type	From Bus	To Bus	R	X	Z	Y
Diamond Bank	2W XFMR	DIAMOND BUS1	DIAMOND BUS	2218.80	3328.20	4000.00	
Eco bank	2W XFMR	Eco bank bus	ECO BANK BUS	739.60	1109.40	1333.33	
Estate & works	2W XFMR	ESTATE BUS	ESTATE BUS2	443.76	665.64	800.00	
GOODLUCK HOSTEL	2W XFMR	Hostel B Bus	JONATHAN BUS	443.76	665.64	800.00	
Health Center	2W XFMR	FEEDER 3 BUS	HEATH CENT BUS	443.76	665.64	800.00	
hostel B	2W XFMR	FEEDER 1 BUS	HOSTEL B BUS	443.76	665.64	800.00	
NDDC HOSTEL	2W XFMR	NDDC BUS1	NDDC BUS	739.60	1109.40	1333.33	
NEW	2W XFMR	New xformer bus 1	New xformer bus 2	443.76	665.64	800.00	
petroleum Dept	2W XFMR	petroleum bus	PET BUS	443.76	665.64	800.00	
SAAT	2W XFMR	SMART BUS1	SAAT BUS	443.76	665.64	800.00	
Senate Building	2W XFMR	SENATE BUS1	SENATE BUS 2	443.76	665.64	800.00	
SMART	2W XFMR	SMART BUS2	SMART BUS	443.76	665.64	800.00	
SOSC BUILDING	2W XFMR	SOSC BUS	SOSC BUS1	443.76	665.64	800.00	
SUG Sec	2W XFMR	SUG BUS1	SUG BUS	739.60	1109.40	1333.33	
worshop	2W XFMR	Estate Bus	WORKSOP BUS	443.76	665.64	800.00	
DIAMOND BANK 1	Line	Senate bus	DIAMOND BUS1	9.56	10.28	14.04	0.0001189
ESTATE & WORKS 1	Line	Estate Bus	ESTATE BUS	4.48	4.82	6.58	0.0000557
feeder line1B	Line	INJECTION BUS	FEEDER 1 BUS	14.93	16.07	21.93	0.0001857
feeder2B	Line	INJECTION BUS	FEEDER 2 BUS	14.93	16.07	21.93	0.0001857
feeder 3	Line	INJECTION BUS	FEEDER 3 BUS	14.93	16.07	21.93	0.0001857
GOODLUCK LINE1B	Line	FEEDER 1 BUS	Hostel B Bus	4.18	4.50	6.14	0.0000520
Line4	Line	source bus1	INJECTION BUS	0.30	0.32	0.44	0.0000037
NDDC LINE B	Line	petroleum bus	NDDC BUS1	16.43	17.67	24.13	0.0002043
NEW ADDED	Line	SENATE BUS1	New xformer bus 1	5.97	6.43	8.77	0.0000743
PETROLEUM LINE B	Line	Hostel B Bus	petroleum bus	2.99	3.21	4.39	0.0000371
SAAT LINE1B	Line	FEEDER 2 BUS	SMART BUS1	4.48	4.82	6.58	0.0000557
SENATE LINE 1b	Line	FEEDER 3 BUS	Eco bank bus	17.92	19.28	26.32	0.0002229
SENATE LINE 1c	Line	Eco bank bus	Senate bus	5.97	6.43	8.77	0.0000743
SENATE LINE C	Line	Senate bus	SENATE BUS1	8.06	8.68	11.84	0.0001003
SMAT LINE1B	Line	SMART BUS1	SMART BUS2	2.99	3.21	4.39	0.0000371
SOSC LINE 1B	Line	FEEDER 2 BUS	SOSC BUS	11.65	12.53	17.11	0.0001449
SUG LINE B	Line	petroleum bus	SUG BUS1	4.78	5.14	7.02	0.0000594
WORKSHOP 1	Line	SOSC BUS	Estate Bus	1.79	1.93	2.63	0.0000223

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**LOAD FLOW REPORT**

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
DIAMOND BUS	0.415	96.484	-0.8	0	0	0.063	0.039	DIAMOND BUS1	-0.063	-0.039	107.6	85.0	
DIAMOND BUS1	11.000	99.307	-0.1	0	0	0	0	Senate bus	-0.065	-0.041	4.1	84.3	
								DIAMOND BUS	0.065	0.041	4.1	84.3	
Eco bank bus	11.000	99.390	-0.1	0	0	0	0	FEEDER 3 BUS	-0.908	-0.579	56.9	84.3	
								Senate bus	0.713	0.455	44.7	84.3	
								ECO BANK BUS	0.195	0.124	12.2	84.3	
ECO BANK BUS	0.415	96.562	-0.8	0	0	0.191	0.118	Eco bank bus	-0.191	-0.118	323.3	85.0	
Estate Bus	11.000	99.355	-0.1	0	0	0	0	ESTATE BUS	0.324	0.207	20.3	84.3	
								SOSC BUS	-0.649	-0.414	40.7	84.3	
								WORKSOP BUS	0.325	0.207	20.4	84.3	
ESTATE BUS	11.000	99.330	-0.1	0	0	0	0	Estate Bus	-0.324	-0.207	20.3	84.3	
								ESTATE BUS2	0.324	0.207	20.3	84.3	
ESTATE BUS2	0.415	96.504	-0.8	0	0	0.318	0.197	ESTATE BUS	-0.318	-0.197	538.6	85.0	
FEEDER 1 BUS	11.000	99.633	-0.1	0	0	0	0	INJECTION BUS	-1.368	-0.873	85.5	84.3	
								Hostel B Bus	1.043	0.665	65.1	84.3	
								HOSTEL B BUS	0.326	0.208	20.4	84.3	
FEEDER 2 BUS	11.000	99.567	-0.1	0	0	0	0	INJECTION BUS	-1.627	-1.038	101.7	84.3	
								SMART BUS1	0.651	0.415	40.7	84.3	
								SOSC BUS	0.976	0.623	61.0	84.3	
FEEDER 3 BUS	11.000	99.666	0.0	0	0	0	0	INJECTION BUS	-1.236	-0.789	77.2	84.3	
								Eco bank bus	0.910	0.581	56.9	84.3	
								HEATH CENT BUS	0.326	0.208	20.4	84.3	
HEATH CENT BUS	0.415	96.835	-0.8	0	0	0.319	0.198	FEEDER 3 BUS	-0.319	-0.198	539.6	85.0	
Hostel B Bus	11.000	99.559	-0.1	0	0	0	0	FEEDER 1 BUS	-1.042	-0.664	65.1	84.3	
								petroleum bus	0.716	0.457	44.8	84.3	
								JONATHAN BUS	0.326	0.208	20.4	84.3	
HOSTEL B BUS	0.415	96.800	-0.8	0	0	0.319	0.198	FEEDER 1 BUS	-0.319	-0.198	539.8	85.0	
INJECTION BUS	11.000	99.979	0.0	0	0	0	0	FEEDER 1 BUS	1.372	0.877	85.5	84.3	
								FEEDER 2 BUS	1.632	1.044	101.7	84.2	
								FEEDER 3 BUS	1.239	0.792	77.2	84.2	
								source bus1	-4.244	-2.713	264.4	84.3	
JONATHAN BUS	0.415	96.727	-0.8	0	0	0.319	0.198	Hostel B Bus	-0.319	-0.198	539.7	85.0	
NDDC BUS	0.415	96.637	-0.8	0	0	0.191	0.118	NDDC BUS1	-0.191	-0.118	323.8	85.0	
NDDC BUS1	11.000	99.468	-0.1	0	0	0	0	petroleum bus	-0.195	-0.124	12.2	84.3	
								NDDC BUS	0.195	0.124	12.2	84.3	
New xformer bus 1	11.000	99.196	-0.1	0	0	0	0	SENATE BUS1	-0.324	-0.207	20.3	84.3	

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Bus		Voltage		Generation		Load		Load Flow				XFMR	
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
								New xformer bus 2	0.324	0.207	20.3	84.3	
New xformer bus 2	0.415	96.369	-0.9	0	0	0.317	0.197	New xformer bus 1	-0.317	-0.197	538.7	85.0	
PET BUS	0.415	96.690	-0.8	0	0	0.319	0.198	petroleum bus	-0.319	-0.198	539.9	85.0	
petroleum bus	11.000	99.523	-0.1	0	0	0	0	NDDC BUS1	0.195	0.124	12.2	84.3	
								Hostel B Bus	-0.716	-0.456	44.8	84.3	
								SUG BUS1	0.195	0.124	12.2	84.3	
								PET BUS	0.326	0.208	20.4	84.3	
SAAT BUS	0.415	96.687	-0.8	0	0	0.319	0.198	SMART BUS1	-0.319	-0.198	539.5	85.0	
Senate bus	11.000	99.318	-0.1	0	0	0	0	DIAMOND BUS1	0.065	0.041	4.1	84.4	
								Eco bank bus	-0.713	-0.455	44.7	84.3	
								SENATE BUS1	0.648	0.413	40.6	84.3	
SENATE BUS1	11.000	99.229	-0.1	0	0	0	0	New xformer bus 1	0.324	0.207	20.3	84.3	
								Senate bus	-0.648	-0.413	40.6	84.3	
								SENATE BUS 2	0.324	0.206	20.3	84.3	
SENATE BUS 2	0.415	96.406	-0.9	0	0	0.317	0.196	SENATE BUS1	-0.317	-0.196	538.1	85.0	
SMART BUS	0.415	96.671	-0.8	0	0	0.319	0.197	SMART BUS2	-0.319	-0.197	539.5	85.0	
SMART BUS1	11.000	99.518	-0.1	0	0	0	0	FEEDER 2 BUS	-0.651	-0.415	40.7	84.3	
								SMART BUS2	0.325	0.207	20.4	84.3	
								SAAT BUS	0.325	0.208	20.4	84.3	
SMART BUS2	11.000	99.501	-0.1	0	0	0	0	SMART BUS1	-0.325	-0.207	20.4	84.3	
								SMART BUS	0.325	0.207	20.4	84.3	
SOSC BUS	11.000	99.375	-0.1	0	0	0	0	FEEDER 2 BUS	-0.974	-0.621	61.0	84.3	
								Estate Bus	0.649	0.414	40.7	84.3	
								SOSC BUS1	0.325	0.207	20.4	84.3	
SOSC BUS1	0.415	96.543	-0.8	0	0	0.318	0.197	SOSC BUS	-0.318	-0.197	539.6	85.0	
* source bus1	11.000	100.000	0.0	4.245	2.714	0	0	INJECTION BUS	4.245	2.714	264.4	84.2	
SUG BUS	0.415	96.678	-0.8	0	0	0.191	0.118	SUG BUS1	-0.191	-0.118	323.5	85.0	
SUG BUS1	11.000	99.507	-0.1	0	0	0	0	petroleum bus	-0.195	-0.124	12.2	84.3	
								SUG BUS	0.195	0.124	12.2	84.3	
WORKSOP BUS	0.415	96.524	-0.8	0	0	0.318	0.197	Estate Bus	-0.318	-0.197	539.5	85.0	

\* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

# Indicates a bus with a load mismatch of more than 0.1 MVA

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**Bus Loading Summary Report**

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic		MVA	% PF	Amp	Percent Loading
ID	kV	Rated Amp	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar				
DIAMOND BUS	0.415		0.002	0.001	0.061	0.038					0.075	85.0	107.6	
DIAMOND BUS1	11.000										0.077	84.3	4.1	
Eco bank bus	11.000										1.077	84.3	56.9	
Estate Bus	11.000										0.770	84.3	40.7	
ESTATE BUS2	0.415		0.014	0.008	0.304	0.188					0.374	85.0	538.6	
FEEDER 1 BUS	11.000										1.623	84.3	85.5	
FEEDER 2 BUS	11.000										1.930	84.3	101.7	
FEEDER 3 BUS	11.000										1.466	84.3	77.2	
HEATH CENT BUS	0.415		0.007	0.004	0.312	0.194					0.376	85.0	539.6	
Hostel B Bus	11.000										1.236	84.3	65.1	
INJECTION BUS	11.000										5.037	84.3	264.4	
JONATHAN BUS	0.415		0.014	0.008	0.305	0.189					0.375	85.0	539.7	
NDDC BUS	0.415		0.010	0.006	0.181	0.112					0.225	85.0	323.8	
NDDC BUS1	11.000										0.232	84.3	12.2	
New xformer bus 1	11.000										0.384	84.3	20.3	
New xformer bus 2	0.415		0.020	0.013	0.297	0.184					0.373	85.0	538.7	
PET BUS	0.415		0.017	0.011	0.302	0.187					0.375	85.0	539.9	
petroleum bus	11.000										0.849	84.3	44.8	
SAAT BUS	0.415		0.014	0.008	0.305	0.189					0.375	85.0	539.5	
Senate bus	11.000										0.845	84.3	44.7	
SENATE BUS1	11.000										0.768	84.3	40.6	
SENATE BUS 2	0.415		0.014	0.008	0.303	0.188					0.373	85.0	538.1	
SMART BUS	0.415		0.014	0.008	0.305	0.189					0.375	85.0	539.5	
SMART BUS1	11.000										0.772	84.3	40.7	
SMART BUS2	11.000										0.386	84.3	20.4	
SOSC BUS	11.000										1.155	84.3	61.0	
SOSC BUS1	0.415		0.020	0.013	0.298	0.185					0.374	85.0	539.6	
source bus1	11.000										5.038	84.2	264.4	
SUG BUS	0.415		0.006	0.004	0.185	0.115					0.225	85.0	323.5	
SUG BUS1	11.000										0.231	84.3	12.2	
WORKSOP BUS	0.415		0.020	0.013	0.298	0.185					0.374	85.0	539.5	

\* Indicates operating load of a bus exceeds the bus critical limit ( 100.0% of the Continuous Ampere rating).

# Indicates operating load of a bus exceeds the bus marginal limit ( 95.0% of the Continuous Ampere rating).

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**Branch Loading Summary Report**

CKT / Branch		Cable & Reactor			Transformer				
ID	Type	Ampacity (Amp)	Loading Amp	%	Capability (MVA)	Loading (input)		Loading (output)	
						MVA	%	MVA	%
Diamond Bank	Transformer				0.100	0.077	76.8	0.075	74.6
Eco bank	Transformer				0.300	0.231	77.0	0.224	74.8
Estate & works	Transformer				0.500	0.385	76.9	0.374	74.7
GOODLUCK HOSTEL	Transformer				0.500	0.386	77.3	0.375	75.1
Health Center	Transformer				0.500	0.387	77.3	0.376	75.1
hostel B	Transformer				0.500	0.387	77.3	0.376	75.1
NDDC HOSTEL	Transformer				0.300	0.232	77.2	0.225	75.0
NEW	Transformer				0.500	0.384	76.8	0.373	74.6
petroleum Dept	Transformer				0.500	0.386	77.3	0.375	75.1
SAAT	Transformer				0.500	0.386	77.2	0.375	75.0
Senate Building	Transformer				0.500	0.384	76.8	0.373	74.6
SMART	Transformer				0.500	0.386	77.2	0.375	75.0
SOSC BUILDING	Transformer				0.500	0.385	77.1	0.374	74.9
SUG Sec	Transformer				0.300	0.231	77.1	0.225	74.9
worshop	Transformer				0.500	0.385	77.1	0.374	74.9

\* Indicates a branch with operating load exceeding the branch capability.

Project:  
 Location:  
 Contract:  
 Engineer:  
 Filename: futo drawing

**ETAP**  
 16.0.0C

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**Branch Losses Summary Report**

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag
	MW	Mvar	MW	Mvar	kW	kvar	From	To	
Diamond Bank	-0.063	-0.039	0.065	0.041	1.3	2.0	96.5	99.3	2.82
DIAMOND BANK 1	-0.065	-0.041	0.065	0.041	0.0	-0.1	99.3	99.3	0.01
SENATE LINE 1b	-0.908	-0.579	0.910	0.581	2.1	2.0	99.4	99.7	0.28
SENATE LINE 1c	0.713	0.455	-0.713	-0.455	0.4	0.4	99.4	99.3	0.07
Eco bank	0.195	0.124	-0.191	-0.118	4.0	6.0	99.4	96.6	2.83
ESTATE & WORKS 1	0.324	0.207	-0.324	-0.207	0.1	0.0	99.4	99.3	0.02
WORKSHOP 1	-0.649	-0.414	0.649	0.414	0.1	0.1	99.4	99.4	0.02
worshop	0.325	0.207	-0.318	-0.197	6.7	10.0	99.4	96.5	2.83
Estate & works	0.324	0.207	-0.318	-0.197	6.7	10.0	99.3	96.5	2.83
feeder line1B	-1.368	-0.873	1.372	0.877	4.0	4.1	99.6	100.0	0.35
GOODLUCK LINE1B	1.043	0.665	-1.042	-0.664	0.6	0.6	99.6	99.6	0.07
hostel B	0.326	0.208	-0.319	-0.198	6.7	10.0	99.6	96.8	2.83
feeder2B	-1.627	-1.038	1.632	1.044	5.6	5.9	99.6	100.0	0.41
SAAT LINE1B	0.651	0.415	-0.651	-0.415	0.3	0.2	99.6	99.5	0.05
SOSC LINE 1B	0.976	0.623	-0.974	-0.621	1.6	1.6	99.6	99.4	0.19
feeder 3	-1.236	-0.789	1.239	0.792	3.2	3.3	99.7	100.0	0.31
Health Center	0.326	0.208	-0.319	-0.198	6.7	10.0	99.7	96.8	2.83
PETROLEUM LINE B	0.716	0.457	-0.716	-0.456	0.2	0.2	99.6	99.5	0.04
GOODLUCK HOSTEL	0.326	0.208	-0.319	-0.198	6.7	10.0	99.6	96.7	2.83
Line4	-4.244	-2.713	4.245	2.714	0.8	0.8	100.0	100.0	0.02
NDDC HOSTEL	-0.191	-0.118	0.195	0.124	4.0	6.0	96.6	99.5	2.83
NDDC LINE B	-0.195	-0.124	0.195	0.124	0.1	-0.1	99.5	99.5	0.05
NEW ADDED	-0.324	-0.207	0.324	0.207	0.1	0.0	99.2	99.2	0.03
NEW	0.324	0.207	-0.317	-0.197	6.7	10.0	99.2	96.4	2.83
petroleum Dept	-0.319	-0.198	0.326	0.208	6.7	10.0	96.7	99.5	2.83
SUG LINE B	0.195	0.124	-0.195	-0.124	0.0	0.0	99.5	99.5	0.02
SAAT	-0.319	-0.198	0.325	0.208	6.7	10.0	96.7	99.5	2.83
SENATE LINE C	0.648	0.413	-0.648	-0.413	0.5	0.4	99.3	99.2	0.09
Senate Building	0.324	0.206	-0.317	-0.196	6.6	10.0	99.2	96.4	2.82
SMART	-0.319	-0.197	0.325	0.207	6.7	10.0	96.7	99.5	2.83
SMAT LINE1B	0.325	0.207	-0.325	-0.207	0.0	0.0	99.5	99.5	0.02
SOSC BUILDING	0.325	0.207	-0.318	-0.197	6.7	10.0	99.4	96.5	2.83
SUG Sec	-0.191	-0.118	0.195	0.124	4.0	6.0	96.7	99.5	2.83
					106.4	149.4			

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**Alert Summary Report**

**% Alert Settings**

	<b><u>Critical</u></b>	<b><u>Marginal</u></b>
<b><u>Loading</u></b>		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
<b><u>Bus Voltage</u></b>		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
<b><u>Generator Excitation</u></b>		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

**Marginal Report**

<b>Device ID</b>	<b>Type</b>	<b>Condition</b>	<b>Rating/Limit</b>	<b>Unit</b>	<b>Operating</b>	<b>% Operating</b>	<b>Phase Type</b>
DIAMOND BUS	Bus	Under Voltage	0.415	kV	0.400	96.5	3-Phase
ECO BANK BUS	Bus	Under Voltage	0.415	kV	0.40	96.6	3-Phase
ESTATE BUS2	Bus	Under Voltage	0.415	kV	0.40	96.5	3-Phase
HEATH CENT BUS	Bus	Under Voltage	0.415	kV	0.40	96.8	3-Phase
HOSTEL B BUS	Bus	Under Voltage	0.415	kV	0.40	96.8	3-Phase
JONATHAN BUS	Bus	Under Voltage	0.415	kV	0.40	96.7	3-Phase
NDDC BUS	Bus	Under Voltage	0.415	kV	0.40	96.6	3-Phase
New xformer bus 2	Bus	Under Voltage	0.415	kV	0.40	96.4	3-Phase
PET BUS	Bus	Under Voltage	0.415	kV	0.40	96.7	3-Phase
SAAT BUS	Bus	Under Voltage	0.415	kV	0.40	96.7	3-Phase
SENATE BUS 2	Bus	Under Voltage	0.415	kV	0.40	96.4	3-Phase
SMART BUS	Bus	Under Voltage	0.415	kV	0.40	96.7	3-Phase
SOSC BUS1	Bus	Under Voltage	0.415	kV	0.40	96.5	3-Phase
SUG BUS	Bus	Under Voltage	0.415	kV	0.40	96.7	3-Phase
WORKSOP BUS	Bus	Under Voltage	0.415	kV	0.40	96.5	3-Phase

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**SUMMARY OF TOTAL GENERATION, LOADING & DEMAND**

	<b>MW</b>	<b>Mvar</b>	<b>MVA</b>	<b>% PF</b>
Source (Swing Buses):	4.245	2.714	5.038	84.25 Lagging
Source (Non-Swing Buses):	0.000	0.000	0.000	
Total Demand:	4.245	2.714	5.038	84.25 Lagging
Total Motor Load:	0.190	0.118	0.223	85.00 Lagging
Total Static Load:	3.949	2.447	4.646	85.00 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.106	0.149		
System Mismatch:	0.000	0.000		

Number of Iterations: 3