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SMART MICRO-GRID DESIGN TO IMPROVE POWER SUPPLY AT FEDERAL UNIVERSITY OTUOKE USING HYBRID RENEWABLE ENERGY RESOURCES

Moses A.Ibidiran,Longson S. Yenigha

Department of Works and Services, Federal University Otuoke, Bayelsa State, Nigeria

Email: ibidiranayodelem@gmail.com

Department of Electrical Engineering, Niger Delta University, Yenagoa, Bayelsa State,Nigeria

Email: longson.suomowei@yahoo.com

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Abstract:

The present states of electricity infrastructures in Nigeria face number of challenges including increased demand amidst ageing infrastructure. In the Federal University Otuoke(FUO), the current stand-alone generation cluster running at various sites on the campus has a lot of unused potential inside the system which often raises the operational (fuel) costs of electricity generation and also contributes to environmental pollution on the campus. To alleviate this problem, especially with the choice of renewable energy sources; some of which have recorded some degree of success, but still have their limitations. This research work is focused on the educational sector and studies will be based on smart micro-grid designing that will link various renewable plants with the existing infrastructure in a university environment (hybrid), and also monitor and control the system characteristics, such as load demand, plant-side and consumer-side energy management, load schedule, the costs of generation and consumption. A workable smart micro-grid architecture was realized and algorithms and programs developed for key parameters of the micro-grid, especially geared towards plant-side and consumer-side energy management. The impact of integrating the proposed renewable facilities on the existing infrastructure was assessed using Voltage Stability Analysis toolbox of MATLAB software and it was observed that integrating the proposed hybrid plants will improve the voltage profile of the already existing network.

Keywords —Renewable energy sources (hybrid), Smart micro-grid, Load demand, consumer-side energy management, Load schedule,Voltage Stability Analysis toolbox, Voltage profile.

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I. INTRODUCTION

Studies indicate that rural areas in Nigeria need inexpensive and stable electricity not only to increase their livelihood but also to grow. In the meantime, solar, wind, micro-hydro and biomass (in several of Nigeria's northern countries) have exciting prospects because they are abundantly available for supply of electricity. The deployment of these forms of renewable energy is also exciting and environmentally friendly options for this purpose.

Decentralized rural electrification initiatives focused on the renewable electricity generation on site, the construction of stand-alone electricity systems in rural homes, and the installation of renewable energy-supplied electricity mini-grids illustrate the exciting capacities for high quality, efficient electricity for connectivity, illumination and other critical energy uses. Off-grid clean energy systems explicitly meet energy requirements in order to eliminate the need for long-distance delivery networks. Renewable electricity mostly arises from the heat. Solar energy may be used for power generation as well as for heating hot water and a number of industrial and non-commercial applications. Renewable technology installations need low-cost generator servicing. The usage of green energy resources minimizes Carbon dioxide (CO_2) and pollutant output and thus decreases environmental impacts [1].

in a particular community, the consumption costs of energy will rely on various local factors, such as load size and distribution, the availability of renewable resources, fuel prices and the transport network.

The cost of clean energy innovations has been rendered appealing by a mixture of improved technology and economical size. In comparison to traditional sources of energy, the cost of generating power from renewable energy sources has, provided the required conditions, been estimated in the past to reduce over the years. This forecast is increasingly right but is also significantly influenced by human factors such as insufficient knowledge of the value of clean energy solutions and energy efficiency during use, import regulations, fees and duties etc.

of all green energy options, solar, hydro and wind energy are, in addition to their low operating cost and inexhaustible sources, the best option as a standalone power generation source. On the other side, these self-sufficient sources have their own drawbacks, including reliance on temperature, contributing to difficulties in controlling production power to satisfy their varied load demands. Further, the usage of these standalone solar power stations to generate bulk power in amounts relative to those generated by traditional fossil fuel generators is daunting, and the end-user is thus forced to either preserve or find a replacement energy source to satisfy their requirement for load. Furthermore, renewable sources of energy remain highly cost-effective, especially when viewed as stand-alone housing facilities [2]. The generally advantageous policy structure and public support incentives of traditional energy schemes contribute to relatively low market and construction costs while at the same time significant cost of service [3]. This challenge raised by independent renewables will address it by balancing several diverse sources of renewable energy and thereby driving the needs for an effective, energy-saving transmission and distribution network built to feed demands centered on preference and availability.

The Federal University Otuoke (FUO) campus has been without power supply for years from the Power Holding Company of Nigeria (PHCN).The (FUO) is a public University owned by the Federal Government of Nigeria and was established in the year 2011. It is situated in the Bayelsa State, Ogbia Local Government Area, Nigeria. At 4.7923°N, Longitude 6.3203°E and 21km south of the Yenagoa State Capital of the oil rich Bayelsa State in Niger Delta Area. The Institution has relied on diesel generators as the only way to provide renewable fuels. The smooth running of University operations now relies on the power supply from remote generators at the University campus in different places. The annual fuel and repair expenses of the generator are also very expensive, which has an effect on the University's annual expenditure. The University's annual allocation for diesel (according to real current market costs **N224.37** is approx. N329.166.944 million for 1,467,072 liters of procurement. When operating charges are applied, the allocation rises to N450,625,364 million. The University consists of faculties, departments, classes, libraries, laboratories, hostels, staff quarters, coffee shops etc.

The inadequate availability of grid power mostly affects administrative and scholarly jobs for both University employees and students. These include:

i. The office working hours of the University staff is affected and reduced during the session.

ii. Affects teaching and research, which are main activities on the University campus.

iii. Lack of water in hostels, causing health hazards and hygiene risk on campus.

iv. Spontaneous protests and disruption of activities, protests increase and turn violent often time.

v. Shutting down and/or re-opening of campuses frequently, Students are made to pay for damages when properties are damaged. Some students are also given other punitive measures.

vi. Energy wastage as some office/ laboratory appliances may not be turned off before close of work resulting to inappropriate consumption, or damage of the appliance.

vii. The risk of air and noise pollution whenever the fossil fuel generators are being used to supplement energy supply.

II AIM AND OBJECTIVES

The aim of the research is to design smart micro-grid using hybrid renewable energy resources for a typical University campus. This grid will connect the renewable energy resources in a hybrid network with the existing network in order to make clean and reliable electric power available for community (FUO Campus) use. While doing this,

The specific objectives of smart micro-grid design with renewable energy resources will be;

i. Developing a load audit/inventory of the Federal University Otuoke campus.

ii. Sizing and reconciling the require generating components with the estimated daily energy consumption.

iii. Developing a load monitoring and switching system that dispatch the varying load demand to the most economic energy sources.

iv. Developing algorithms for load scheduling and energy management that will guide the minimization of energy wastage.

v. Stability and sensitivity analysis using Matrix Laboratory (MATLAB) to predict the effect of the proposal on the already existing system.

III. Review of Previous Related Studies

The first alternating power grid structure was constructed in Manhattan on 255 – 257 Pearl Street in 1886. It initially supplied electricity to 85 consumers and 400 lamps with a consolidated unidirectional power delivery, gas supply and demand based control device. This first electric grid experiment was successful.

In its work entitled "Optimal Design And Techno-economic Analysis Of A Hybrid Solar Wind Generation System,"[4]. The autonomous hybrid device was planned to service a telecommunications station along the Chinese coast. In order to detect the ideal power generating angle and the optimum values of other variables like the battery capacity and the number of wind turbines, the PV slope angle was examined. The genetic algorithm was used to verify the complementarity of the two sources of energy.

The Federal University of Otuoke Library (FUO) only has one green energy facility, but its usage has been restricted due to factors such as robbery, vandalism and energy waste. Driven PV by the FUO Library (3) Three 5 kVA inverter units (15 kVA) installed for usage in and during working hours as well as solar streetlights in the library were installed. However, these facilities do not have the means to track and manage them.

The US Trade and Development Agency awarded a grant in April 2017 for the deployment, in Nigeria, of 25 solar photovoltaic micro grids to CESEL (Community Social Enterprises Limited) Nigeria, with an aim of generating over 5MW power for use in rural and peri-urban areas that typically lack stable power access. [5]

[6] Carried out a feasibility review of installation, using HOMER tools, of a hybrid hydrid (solar + micro-hydro + biomass) green power station for use in an ICT building of Nigeria. He also developed the

proposed hybrid device workable.

IV. METHODOLOGY

Materials used in this study are:

i. Two HP/Compaq laptops
ii. Microsoft Office Visio Design software
iii. PV and battery sizing calculator
iv. SSO2 sensor
v. TECHNO Pouvouir smartphone
vi. MATLAB Software/ Power Systems analysis toolbox
vii. Digital Multimeter
viii. Codeblocks C++ compiler and program editor

In this study, survey and inventory of the existing load-profiles and electrical facilities of the University was firstly done. Next, it will model and design and energy management system for the micro-grid to investigate the daily load implications of utilizing this hybrid power network. More importantly, a decision-making strategy would be adopted to govern the design objectives of the micro-grid. The modeling, cost, sensitivity and stability analysis will be done using Matrix Laboratory (MATLAB) and simulated to analyze the system behavior and Alternative Energy (altE) off-grid calculator to validate the component sizes. Also, an estimating policy will be developed to determine an expected period of returns in investment, and also guide the energy users on the most economic periods of the day to consume energy.

The following tasks are necessary to serve as a guide towards the smart micro-grid design, since this research work basically borders on design.

i. Adopting a micro-grid architecture and modify it according to our network parameters.
ii. Incorporating sensing, computing and recording devices at strategic points in the adopted network.
iii. Using Modal analysis method to determine the optimal location of the proposed renewable sources
iv. Conducting a sensitivity analysis to determine the impact of the proposed system on the already existing one.
v. Load scheduling while developing an energy management system to help minimize energy wastage.
vi. Develop a pricing policy to guide the consumer-side energy management and aid the determining of the return on investment.
vii. Developing a cost-generation relationship for the currently installed diesel generators.
viii. Make provision for future expansion.

A. The Existing Load Profile of the University

The load distribution of the various offices, lecture halls, workshops, cafes and other buildings in the University based on a priority criterion was determined through an investigation carried out. Also put into consideration were some of the proposed buildings. The total load requirements for each of the buildings in the University is **2283.05 K** **w**as estimated. The ratings of the various transformers in the University and actual installed load are shown in Table I.

Table I
Ratings of Installed Transformer and actual installed load

TRANSFORMER	RATED (KVA)	INSTALLED LOAD (KVA)
1	1000	715.70
2	300	159.40
3	750	681.25
4	500	223.13
5	500	223.13
6	500	266.38

The various loads were classified according to priority, into;

i. Critical loads: Include the base loads and every other load that must be supplied at any of the energy management modes, especially when total energy demand exceeds the available energy.
ii. Adjustable loads: These include loads that need to be partially supplied in cases where the available energy is less than system demands.
iii. Sheddable loads: these are loads that can be shed off completely for some hours in the network especially when the power

demanded exceeds supply.

Loads that fall under these classifications might differ depending on the time of the day. For instance, an office or classroom load may be critical on a weekday for the Day Mode of the energy management algorithm but may fall into adjustable load during the night Mode on weekdays or even sheddable on the Day and Night modes on weekends. The load requirement for the various modes largely depends on the summation of the various individual corresponding loads of the University.

The block diagram shown in Fig 1 below describe the load classification of the University load.

For this study, four kinds of building classifications can be deduced in terms of functionality. These include:

i. Administrative buildings (consists of all offices, conference rooms)

ii. Lecture buildings (consists of all classrooms and auditoriums)

iii. Residential buildings (hostels, staff quarters, guest house, security posts)

iv. Workshop/Lab buildings (Laboratories, workshops, filling station)

It is essential to note that some of these buildings serve combined purposes, but for this study, the characteristics of such buildings were viewed independently.

This validation approach is dependent on the assumption that an appliance, depending on the use history, can be accessed at any time many times a day. This analysis implements a P_{Start} beginning likelihood feature to decide when an appliance would be triggered. For each move, P_{Start} is specified, obtaining a value between 0 and 1. The P_{Start} value differs for a number of equations. When the system is off, the activation will be tested with P_{Start}. Activation happens when it is greater than a random number provided by a machine between 0 and 1. Then the consumer period of the unit can be applied to the overall load curve of the household. When the end of a usage period is completed, the device is switched off and checks are carried out for initiation of the device again.

The PStart function is determined by the following function***:***

PStart (A, Δt comp,, h)= P hour(A,h) x f(A,d) x P step(Δt comp) x P sat(A) *(1)*

The average daily energy usage in a building was estimated using the following formula by active and standby consumption parameters:

[3600 x W standby + f = Napp W name x tcycle]/ (3.6 x 106) Day/day KWh

(2)

N=1 N=1

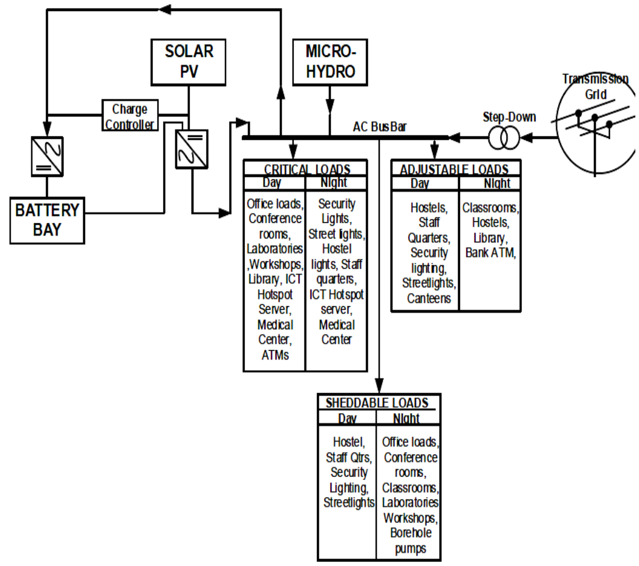

Fig 1: Priority-based Load Classification of the University

The distribution and capacities of diesel generators in the Federal University Otuoke (FUO) and the various buildings with the average hourly diesel consumption is shown in Table II.

B. An Estimated Fuel Consumption of Diesel Generator

The fuel consumption of any generator device varies base on the capacity, speed, loading and timing of injector via nuzzle settings. The fuel consumption does not constant but can only be determined or estimated under the control of the following inevitable factors such as;

i. Speed of the engine

ii. Loading measure of the engine

iii. Injector and nuzzle timing

iv. Capacity of the engine via the number of cylinders

The above factors subjected the estimated value to increase and decrease in volume of fuel estimated as consumption within the period of time by ± 15%.

From the experimental figure that I carried out, it was observed that when 50 litres of fuel was poured into the 45KVA (4 cylinder engine) the fuel consumption fall within the range of 7 hours 30 minutes to 8 hours 30minutes. In the sense, the average hour considered is 8 hours for the 45KVA generator engine to consume 50litres of diesel fuel.

Therefore, when the 45KVA generator device is operated for 7hours 30minutes with high or full loading measure and the estimated fuel consumption was 50litres. Then, another 50litres of fuel poured into the same device and consumed within hours of 8hours 30minutes after load has been reduced to minimal rate.The average hourly consumption of litres for the 30KVA generator is calculated as follows;

	Volume of Fuel Poured(VFP)	**Operational Time taken (T)**	**Operational Mode**
Experiment i	50 litres	7 hours 30 minutes	Full/ High Loading
Experiment ii	50 litres	8 hours 30 minutes	Reduced loading
Total	100 litres	16hours 00minutes	

$$\text{Average VFP} = \frac{VFP1+VFP2}{2} \quad (3)$$
$$= \frac{50+50}{2}$$
$$= \frac{100}{2}$$
$$= 50litres$$

Note: Volume of Fuel Poured (VFP)

$$\text{Average 'T'} = \frac{T1+T2}{2} \quad (4)$$
$$= \frac{7{:}30 + 8{:}30}{2}$$
$$= \frac{16}{2}$$
$$= 8\text{hours}$$

Operational Time Taken ("T")
Note that; Fuel poured into generator = Fuel consumption by the generator
To determine the fuel consumption in an hour of the generator operation;
The Average Time Taken for 50 litres of Diesel to be consumed = 8 hours
The estimated fuel consumption under an hour = X hour
Therefore;
Since Estimated Fuel Consumption (EFC) within 8n hours = 50 litres
Time taken to consume 50 litres 'T' = 8hours
Estimated Fuel Consumption (EFC) within an hour = X litres
Time Taken "t"= 1 hour
Since Fuel poured into the device(generator) is proportional to operational time taken of the device, then:

$$EFC\ 50_L = T \quad (5)$$

$$EFCX_L = t \quad (6)$$

$$EFCX_L = \frac{EFC50L\ x\ t}{T}$$

$$EFCX_L = \frac{50\ x\ 1}{8}$$

$$EFCX_L = 6.25 \text{ litres}$$

The estimated fuel consumption under an hour is equal to 6.25 litres/hour

Table II

Average Hourly consumption of diesel generators in FUO

GEN. NO.	**LOCATION**	**CAPACITY (PF = 0.8)**	**FULL-LOAD CONSUMPTION PER HOUR (Liters)**
1.	Administrative Block	200KVA	56.02
2.	West Campus	750KVA	215.37
3.	East Campus	400KVA	106.04
4.	University Library	100KVA	28.01
5.	Science Laboratory	100KVA	28.01
6.	University ICT Data Centre	100KVA	28.01
7.	FUO Girl's Hostel A	250KVA	70.03
8.	FUO Girl's Hostel B	250KVA	70.03
9.	Mama Jonathan Girl's Hostel	45KVA	15.92
10.	Faculty of Engineering	400KVA	106.04
11.	Institute of Foundation Studies	45KVA	15.92
12.	FUO Medical Centre	50KVA	18.45
13.	Powel ICT Library	30KVA	6.25
14.	Staff Quarters	250KVA	70.03
15.	VC/DVC Lodge	100KVA	28.01
16.	Registrar/Bursar/Librarian Lodge	100KVA	28.01
	Total		**890.15litres**

C. **The Proposed Micro Grid System**

The components(modules) of the proposed microgrid design include:

i. Two 500kW Solar Farms
ii. A 100kW MicroHydro Plant

iii. The existing diesel generators
iv. An extensive battery bank
v. Grid control inverters (Island)
vi. PV inverter
vii. Plant monitoring and control
viii. Sensors
ix. Communication network

While the design features of the energy resources that are renewable will be highlighted, our main focus will be on the major grid components.

i. PV Component Sizing

The average daily estimated energy consumption for the University in kWh was estimated to be 2283.1 x 24 = 54794.40 kWh. Considering load factor of 0.38 for load usage and plant capacity factor of 0.22, the average estimated kWh for the PV array is 0.38 x 0.22 x 54794.40 = 4580.81 kWh/day

The total useful daily sun periods (hours)in FUO campus is between 8am and 4pm. This is approximately 8 sun hours.

Thus, 4580.81 kWh / 8 sun hours = 572.60 kW

Using an efficiency factor of 0.72, our array size should be 572.60/ 0.72 = 795.28 kW

This result on the sizing of PV array was validated by running it through Alternative Energy (altE) off-grid Solar calculator software on [7]

ii. The 500kVA Solar Farm

The 500 kVA solar farms in the proposed design each consist of two wings of 1000 solar arrays. Each wing consists of four streams of 270 x 250W monocrystalline solar panels. Each stream of 250 panels is connected to give an output voltage of 48-96 volts corresponding with that of the respective PV inverter rating and the battery bank arrangement. Depending on the cost, PV inverters can be cascaded to feed the grid control inverter and the connected AC load.

iii. PV Inverter

It is a wall-mounted transformer-less inverter with two maximum power point (MPP) trackers which converts the current of the PV array stream directly into grid compliant alternating current and feeds it into the grid and monitoring/ control system.

Alternative AC Sources

These will include the diesel generators and the proposed micro-hydro plant.

a. The 100 kW micro hydro plant

This can be harnessed from the existing Opara stream flowing through the University. Although previous studies showed that the flow rate of the stream can barely support 70kW, recent damming technologies can enable us optimize this output for our proposed design. Fig 2 shows the estimated cost of installing Hydro power plants per kW. The plant under consideration is a micro-hydro which falls into the kW range of 10-100kW.

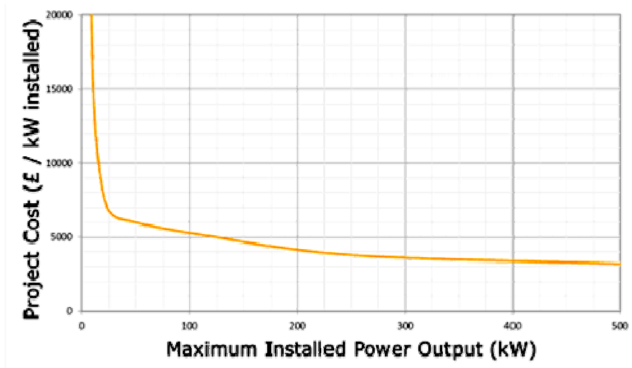

Fig 2: Estimated cost of installing Hydro power plants per kW excluding dam/pump storage cost (www.renewablesfirst.co.uk).

Table III
Proposed Hybrid Plant Specifications

PROPOSED PLANT	ESTIMATED CAPACITY
Solar PV (PPV)	1000 kW
Micro-Hydro (PHYDRO)	100 kW
Diesel Generator (PDiesel)	2.536kW (distributed)
Battery Bank (PBattery)	17.83MWh

D. Software Design Methodology

The various expectations of the microgrid should be known and noted in order to guide the design considerations for the grid-control software algorithm. It is expected that a real-time monitoring and control mechanism be established to monitor various parameters of the network. It is also imperative that all the factors which affect the grid both directly or indirectly need to be identified. These include:

i. Time of day
ii. Instantaneous load demand
iii. Purpose of load

iv. Probability of load usage
v. Power outage indices
vi. Sensor control
vii. Voltage stability
viii. Bus voltage control
ix. Load priority
x. Capacity of available plants
xi. Availability status of plant
xii. Cost of generation
xiii. Cost of consumption
xiv. Remote monitoring & control

The smartness and operation of this smart microgrid can be narrowed down to the following factors

i. **Plant availability:** This research proposes the use of two 500 kW solar farms and a 100kW microhydro plant along with the existing installed diesel generating plants. It is imperative that the solar farms handle the bulk of daytime loads while the microhydro and diesel plants supply the network during the night time. Also, the network is designed with a robust battery bank to ensure that critical loads are constantly fed. At this point we also consider the **float voltage** and the **state of charge** (SOC) of the battery.

ii. **Nature of the Load:**At this point, it is significant to specify the nature of the load being serviced at each point in time and to develop a load schedule algorithm. The various loads are based on

- The purpose of the building, The loads were divided into **Residential, Staff Office, Classroom, Industrial,** etc.
- The load priority (Fig 1) under which we have **Critical, Sheddable and Adjustable loads**.

iii. **Time of the day:** The dailyroutines or activities of the University were created according to the load scheduling of time modes. We have DAY mode, EVENING mode and NIGHT mode.

iv. **Generation Cost:** On both generation and consumption, this factor helps us to detect whether we are saving or incurring more running cost. Hence it is essential to define energy management strategies for both plant and consumers sides, with the aim of minimizing energy wastage and cost of generation and maximize available energy for consumption. Also, a pricing policy would be developed to enable the facility pin-point when the cost of generation is cheapest and when the consumers can channel their peak loads.

E. Proposed Energy Management System (EMS)

Based on the load scheduling, the energy management system will be subdivided into: Generation and Storage section; Consumer section and Distribution section

The generation and storage portion of the EMS is as follows:

i. Battery charging price estimation

ii. Power output rate of photovoltaic and micro-hydro turbine modules in 24-hour device operation;

iii. Power produced by batteries in cycles of charge and discharge.

F. Consumer-Side Energy Management Flow

The consumer side EMS behavior is based on

i. Time of the day: Day mode, Evening mode and night mode

ii. Plant availability: PV, Micro-hydro, battery bank, diesel generator

iii. Active load monitoring: This is based on load prioritization –Critical loads, Adjustable loads, Sheddable loads.

It will be necessary to describe a typical time modes guiding the energy usage in the University when all activities are in full swing.

a. Day Mode (0800-1559 hours)

The system clock sends a signal to the controller via the island to switch to DAY mode once the time is exactly 8am. By this time, University staff activities is usually expected to have commenced, thus office, classroom, conference room and laboratory loads are set as critical loads (Crit_D). A preset value of Crit_D= 300 kW was chosen. Some of the hostel loads may still be on by this time, although for this mode, their priority level falls from critical to sheddable, or adjustable, depending on the main source of supply during the previous mode (NIGHT mode). The main source of generation for the DAY mode is the PV farm. The system will keep on checking the load status and the availability of the other generating sources until the time frame for the next mode is reached. Whenever the active load exceeds the preset value for the critical load, an alternative source (Micro-Hydro or diesel plants) is either added to the generation mix, or the designated sheddable loads (Shed_D) and adjustable loads (Adj_D) are tripped and modified accordingly. Figure 3 illustrates the flow diagram for the day mode of the consumer-side EMS.

b. Evening Mode (3:59pm –11:59pm)

During this mode, office and loads are categorized under EVENING mode sheddable loads (Shed_E), however, classroom and laboratories will still fall under adjustable loads (Adj_E), as some practical and tutorial classes may still be on for some hours. Also, the University library closes by 6pm, thus the reading rooms are under adjustable loads. The major loads that fall under critical loads are residential and hostel loads, street-lights and canteens within the hostel vicinity.

The primary generation choice here is the micro-hydro plant with the critical load value Crit_E set at 100kW. The battery bank and the diesel generators can serve as backup depending on the active loads after all necessary shedding and adjustments have been made.

c. Night Mode (12:00 am –07:59am)

During this period, the residential loads and all security and street lights in the University are under the critical loads (Crit_N). Office, library and classroom loads are completely shedded (Shed_N). Canteen loads and laboratory loads can fall under adjustable loads (Adj_N).

The micro-hydro plant continues to be the primary source in this period with the diesel generators and battery bank serving as backup. Figure 5 illustrates the flow diagram for the night mode of the consumer-side EMS.

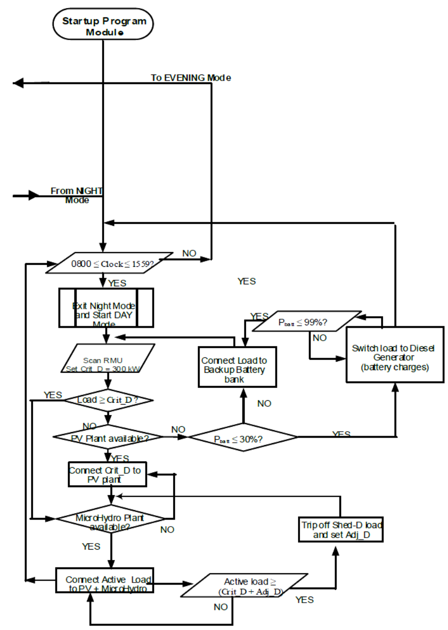

Fig 3: Flow diagram for the DAY mode of the consumer-sideEMS

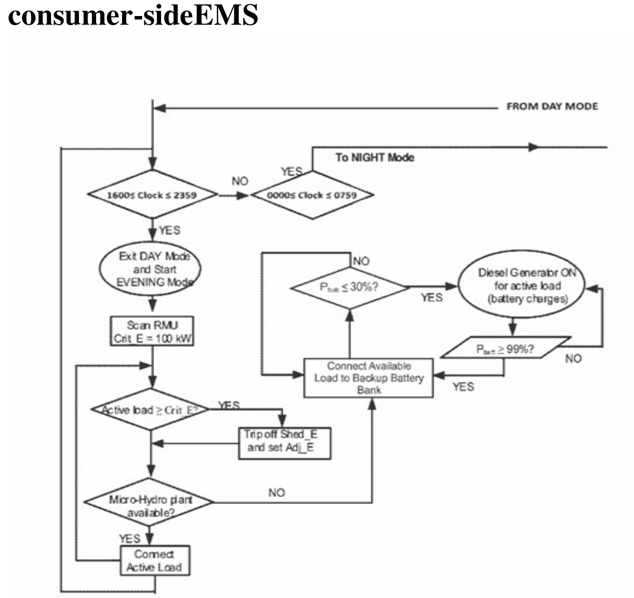

Fig 4: Flow diagram for the EVENING mode of the consumer-side EMS

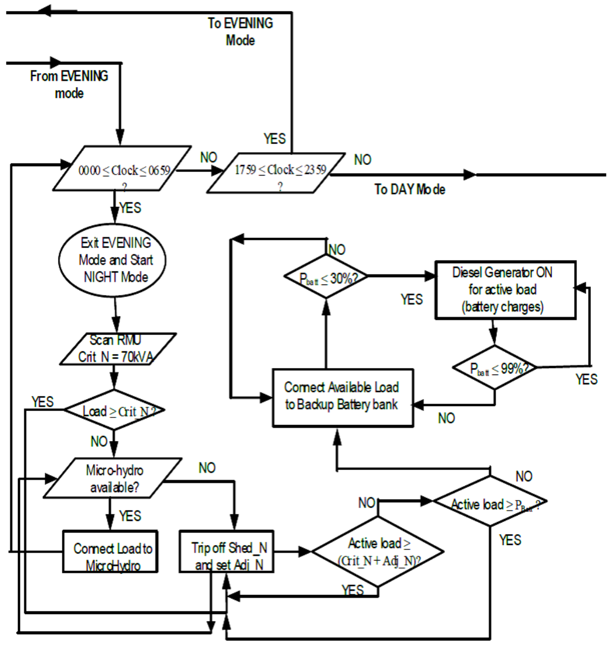

Fig 5: Flow diagram for the NIGHT mode of the consumer-side EMS

The consumer side of the energy management system will account for:

i. Load monitoring of the various load centers using smart devices such as sensors and RMUs (Remote Monitoring Units) installed in the various buildings (offices and classrooms especially).

ii. Real-time clocking feeds to determine which modes to switch to and set priority levels for the loads.

iii. Calculate load specifications for each mode according to regular and weekday periods

Table IV
Estimated load readings for the 24 hour period

Time in Hours(Hrs)	Weekday Consumption (KW)	Weekend Consumption (KW)
8:00	1504.9664	1021.22746
9:00	1248.31787	1189.66214
10:00	1268.961	1162.435
11:00	1435.59	1304.15
12:00	1402.60717	1108.67324
13:00	1458.523964	1140.966186
14:00	1447.18579	1023.353327
15:00	1677.15682	1012.516529
16:00	1784.57573	1133.018206
17:00	1576.22264	1081.85219
18:00	1626.13047	1102.71033
19:00	1551.91055	1012.99297
20:00	1256.90675	991.44077
21:00	1252.15677	974.65736
22:00	1089.81879	1038.19794
23:00	860.4299	846.72212
00:00	742.151	861.0005
1:00	740.4619	770.3325
2:00	758.26893	583.22287
3:00	763.519338	559.760455
4:00	785.82392	394.05234
5:00	40.1029	402.4662
6:00	916.577415	636.782248
7:00	1184.7198	910.70414

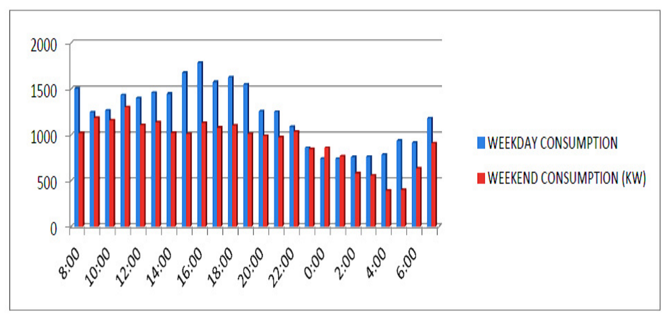

Fig 6: Estimated load demand for weekday and weekend

For the DAY mode, the average load requirement is 1469.77 kW for week day and 1121.8 kW for weekends. The critical load (Crit_D) was set to 50% of the required load. Crit_E (Critical load for Evening mode) and Crit_N (Critical load for Night mode) were each set to 45% of load requirement. Thus in the day, the Crit_D should be supplied at least 700kW and 500kW for weekends.

G. Energy Pricing Policy

It is also important to know how much the University spends per kWh at each point in time for the following reasons:

a. To adopt a tariff plan assuming each of the buildings supplied would have to pay for their energy usage

b. To help the users cut down on their energy usage during peak periods and maximize usage when cost of generation is much lower.

This pricing policy will look at four (4) cases as follows:

i. Case 1: Running purely on diesel generators for 24 hours for the smooth running of University activities

ii. Case 2: The current state of diesel generator usage and the available supply from the utility.

iii. Case 3: Installing a 1MW solar plant and a 100 kW micro-hydro plant and running solely on it.

iv. Case 4: Combining Case 1 and Case 3 using the consumer-decision-making algorithm

i. Case 1

From the information on Table 2, assuming the diesel generators supply the only power to the University, we can see that at full load, 890.15 liters is used up in one hour. Using the gross calorific value of diesel, 1 liter of diesel at N227.76 generates 11.1kWh of electricity.

Considering the current maintenance costs of about N800,000 per month, we can choose to double this amount for the 24 hour operation. Also, the total market and installation cost of the diesel generators as at 2021 is N404, 260,000. Also to be considered is the overhead cost of 15 plant operators(as one operator handles two Generator plants) the average salary scale of N40,000 per month (CONTISS Level 4) was tentatively assumed (because of difficulty in getting the exact figures from the bursary department). A useful life of 10 years was also considered for the diesel generators.

Thus, the estimated cost of running on generators only for a day is

(890.15 liters/hr x 24hrs x N227.76/liter) + (N1,600,000/30 days) + ((N324,990,000)/(10 x 365) + (15 x N40,000/30) = N5028145.225/day

Thus the total kWh generated in 24 hours (assuming 0.7 load factor and 0.75 availability factor) is 890.15 x 24 x 11.1 x 0.7 x 0.75 = 124496.379 kWh.

Thus the price per kWh for this case will be **N40.39/kWh**

ii. Case 2

From the data in Table 2, the University currently consumes about 57859.75 liters weekly (48958.25 liters per weekday and 8901.5 liters during weekends), assuming all the generators are fully loaded to installed capacity. Also, for an average working day, power is available from the generators for roughly 11 hours every day (6 hours in the day and 5 hours at night), for a total installed load capacity of 2283.05kW while the utility supply is available for an average of 3-4 hours every day.

The current tariff for FUO on 33kV feeder on the utility grid is N39.93/kWh (information from Port Harcourt Electricity Distribution Company). Assume that about 60% of the University load is connected to the utility grid. Thus the energy pricing method for this case will vary a bit.

During those days when there is utility supply and the remaining 40% load is supplied via diesel generators, the daily cost per kWh is

[(60% x 2283.05kW x N39.93 x 4hrs) + (0.4 x 2283.05kW x **N40.39**x 11hrs) +(N800,000/30)]/ (24 x 2283.05kW) = **N11.89/kWh**

iii. Case 3:

When two 500kW solar farms and a 100kW microhydro plant are used neglecting Case 1 and 2, using current market cost of N60,000 per solar panel, N120,000 per deep cycle dry cell battery and N6,500,000 for the combined off-grid inverters with charge controllers and installation cost of N2,500,000, a pre-maintenance life of 10 years including warranty period, and installation cost of a 100kW microhydro plant at £5300/kW

(4308 panels x N60,000/panel) + (1860 batteries x N120,000/battery) + (3 x N6500000/inverter) + (N967,000 (network equipment)) + (N2,500,000) + (N780/£ x £5300/kW x 100kW) = N918,047,000

The cost per kWh for Case 3 will be N918,047,000/(2283.05 x 24 x 10 x 365) = **N4.59/kWh**

iv. Case 4:

A combination of Case 1 and Case 3 where

- Case 3 is used only in the daytime from 8am to 6pm (battery bank can be used from 4-6pm)
- Case 2 is used from 6pm to 10pm).
- Case 3 comes into play again from 10pm to 6am using the battery bank
- Case 1 can be used to supplement the peak load usage in the early morning hours (6am to 8am)

Cost per kWh for Case 1 is N40.39and cost per kWh for Case 3 is N4.59

The usage from 8am to 6pm will cost an average of (N4.59/kWh x 10 hours) = N45.9/kW

The usage from 6pm to 10pm will cost an average (N11.89/kWh x 4 hours) = N47.56/kW

The usage from 10pm to 6am will cost average of (N4.59/kWh x 8 hours) = N36.72/kW

The supplementary usage from 6am to 8am will cost (N40.39/kWh x 2) = N80.78/kW.

The average cost/kWh for Case 4 will be N(45.9 + 47.56 + 36.72 + 80.78)/24= **N8.79/kWh**

IV. RESULTS AND DISCUSSION

From the data extracted it was necessary to ascertain the diesel price trend, placement of the distributed generators (DG), load shedding based on load prioritization and cost optimization.

The placement of DG's was done using the method of Bus Sensitivity (Modal Eigen-Value) analysis and employed the bus and line parameters of the network. Power flow and continuation power flow analysis was also done to justify the behavior of the network after placing the DG on the weakest bus. The cost optimization and load shedding were done using MATLAB programming.

Allocation of DGs was done considering the voltage sensitivity of the Network. The DGs were placed at the weakest bus or the bus which contributes more to the weakness of the Network. The justification of the network after the allocation of DGs were done using the voltage profile on a static and incremental load using both load flow and continuation power flow analysis. Table V gives account of the sensitivity analysis using eigenvalue method. The table reveals that the system is unstable due to the presence of a negative sign in the real Jacobian matrix. Fig. 7 shows the load flow study without DGs. Continuation power flow and eigenvalue analysis were also done on the network without DGs as revealed in Fig 8 and Fig 9.

Table V
Results for the placement of DGs

Placement of DGs on Busbar	LF violated bus	LF real power loss	LF reactive power loss	CPF violated bus	Loadability	CPF real power loss	CPF reactive power loss
No DG	16	0.02561	0.51211	17	2.1403	0.28332	5.6665
18 (solar)	9	0.00018	0.00366	16	2.3836	0.00169	0.3373
18 and 11 (solar)	3	0.00012	0.0024	15	3.808	0.00349	0.6979
18 (solar), 11 (solar), 7 (hydro)	0	0.0001	0.00193	13	4.1887	0.00578	0.11557

Considering the network behavior after running voltage stability test with load flow (LF) and continuous power flow (CPF) analysis without placing DG, 16 buses were violated with real and reactive power losses of 0.025 p.u and 0.51211 p.urespectively. A load of 2.1403 p.u can still be accomodated to the network without a total collapse with 17 voltage violated buses and real and reactive power losses of 0.28322 p.u and 5.6665 p.urespectively as seen in Table V and Fig 10. The real and imaginary parameter of the network without DGs is revealed.

The most affected bus which bears the negative sign is Bus 18. From the participation factor value for JlfrEig 7 indicates that bus 18 contributes more to the unstable state of the network with participation factor of **0.43683**. This shows that the first DG should be allocated to Bus 18. The first DG (500 kW solar) was placed at Bus 18 which is the weakest bus.

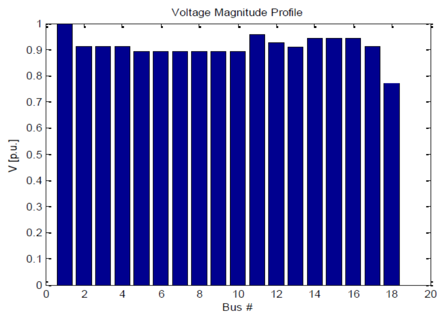

Fig 7: Load flow study without DG

In order to get a clearer picture of the steady-state voltage profile, continuation power flow analysis was done to ascertain the degree of divergence of the real and reactive components of the violated buses as seen in Fig 8, 9 and 10.

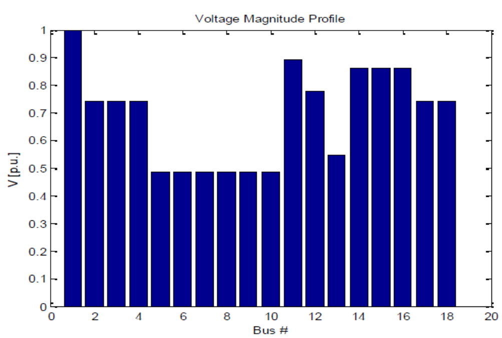

Fig 8: Continuation power flow study without DG

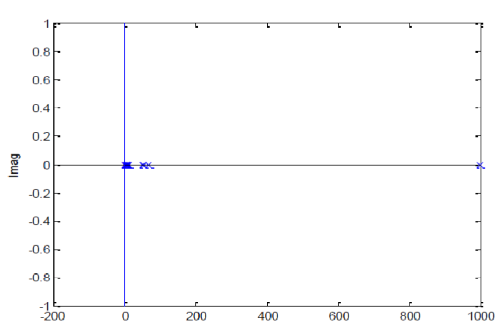

Fig 9: Eigen value analysis without DG

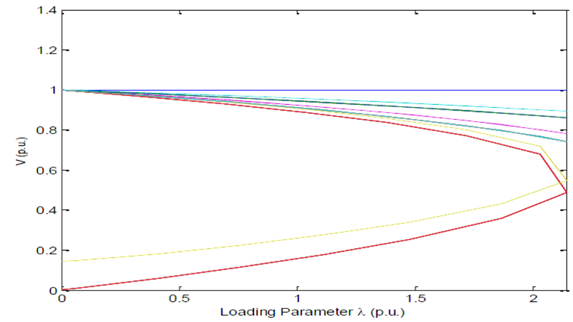

Fig 10: V-P curve without DG

The load flow and continuation power flow (CPF) analysis done by placing a 500kW DG at Bus 18, as revealed in Table V shows a significant improvement on the voltage violation which reduced to 9 buses (refer back to Table V). The real and reactive power losses were improved to 0.00018 p.u and 0.00366 p.u respectively as compared to when no DG is placed on the network. The first DG (500 kW solar) was placed at Bus 18 which is the weakest bus.

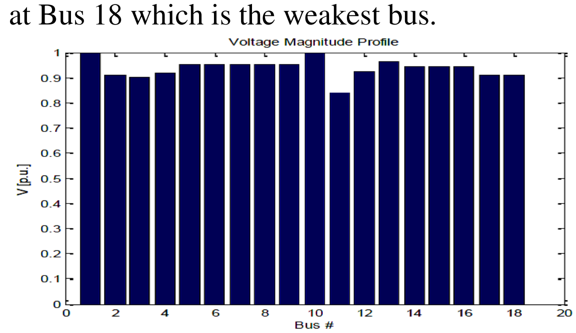

Fig 11: Voltage profile with 500kV solar at bus 18

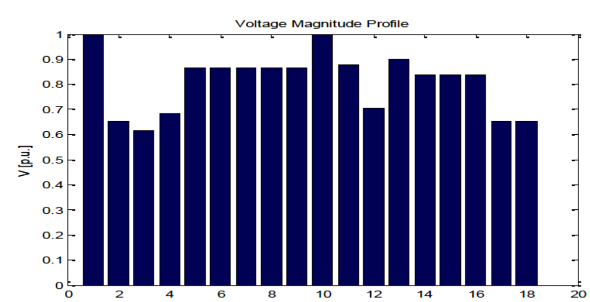

Fig 12: CPF voltage profile for 500KV solar at bus 18

The CPF analysis is shown in Fig 11 and Fig12. losses of 0.00169 p.u and 0.3373 p.u respectively. An additional load of 2.3836 p.u can be accommodated in the network without causing a collapse as can also be seen in Table 5. This shows a significant improvement as compared to the network without DG's although with some degree of divergence as shown in Fig 13 and improved stability of the voltage profile in Fig 14.

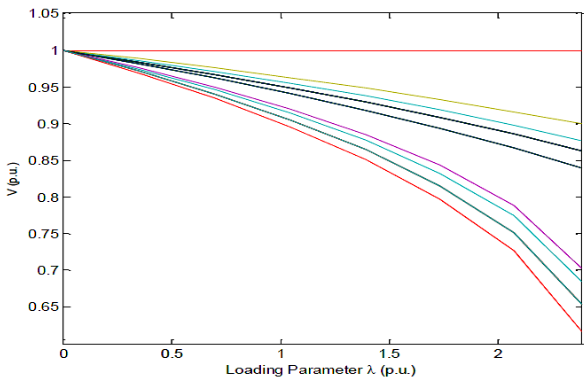

Fig 13: V-P Curve for 500kW solar at bus 18

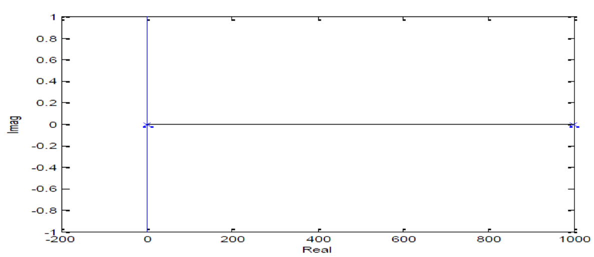

Fig 14: Eigenvalue result for 500kW solar at bus 18

For the sensitivity analysis, in order to determine where to place the next DG and to ascertain how stable the network is, a negative sign was not found in the Eigen value real Jacobian result which indicates a stable system with the lowest value at Bus 11, showing to be the most affected bus. The participation of all the buses to this effect were investigated, and the participation factor value for JlfrEig 3 indicates that bus 11 contributes more to the unstable state of the network with participation factor of **0.78219**. This shows that optimal performance will be achieved if the next DG (500 kW solar) is placed at Bus 11.

Table VI

Eigen Values for the 18 buses with two 500kW solar plants at bus 18 & 11

Eigenvalue	**Most Affected bus**	**Real part**	**Imaginary Part**
EigJlfr # 1	Bus2	0.57135	0
EigJlfr # 2	Bus6	0.11632	0
EigJlfr # 3	Bus7	**0.02323**	0
EigJlfr # 4	Bus3	0.81642	0
EigJlfr # 5	Bus4	0.93132	0
EigJlfr # 6	Bus10	0.03477	0
EigJlfr # 7	Bus12	0.12027	0
EigJlfr # 8	Bus5	0.11632	0
EigJlfr # 9	Bus15	0.02919	0
EigJlfr #10	Bus8	0.11878	0
EigJlfr #11	Bus9	0.11878	0
EigJlfr #12	Bus13	0.11725	0
EigJlfr #13	Bus17	0.11725	0
EigJlfr #14	Bus15	0.11725	0
EigJlfr #15	Bus16	0.11725	0
EigJlfr #16	Bus1	999	0
EigJlfr #17	Bus11	999	0
EigJlfr #18	Bus18	999	0

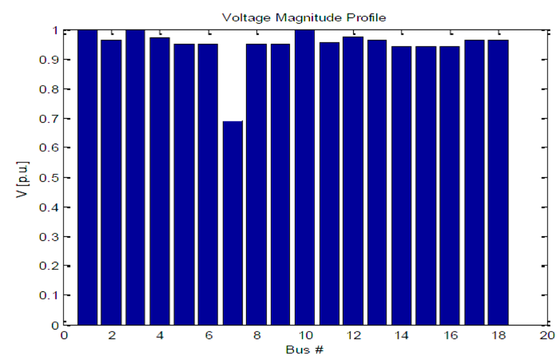

Fig 15: Voltage profile for two solar (bus 11 and 18)

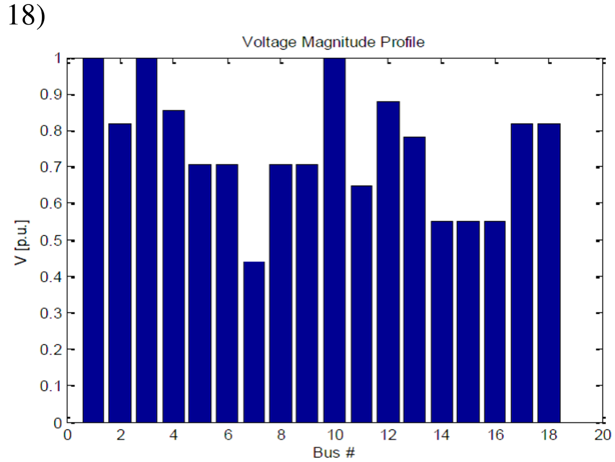

Fig 16: CPF for two solar (buses 11 and 18)

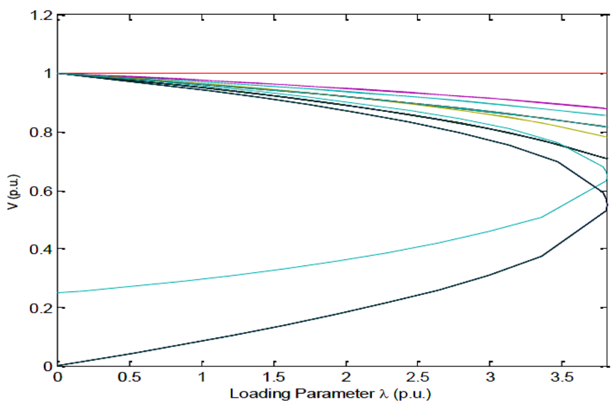

Fig 17: V-P plot for 2 solar (buses 11 and 18)

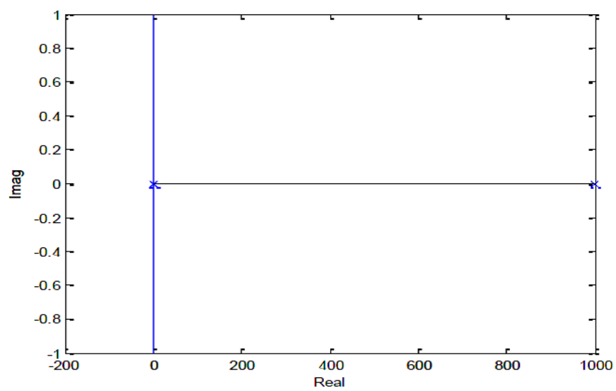

Fig 18: Eigenvalue result for two solar (buses 11 and 18)

For the sensitivity analysis on the best allocation of the next DG, stability was confirmed in the network, as no negative sign was found in the real Jacobian result. The most affected bus was Bus 7 with the lowest value of 0.02323. The participation factor result of **0.27687** for Bus 7 (EigJlfr # 3) shows that it contributes more to its own affected behavior. This shows that optimal performance will be achieved placing 100kW hydro at Bus 7 as shown in Table V.

If another DG was to be included to improve voltage stability,) it was clearly observed that Bus 16 is the least stable with a value of 0.02919 and validating its participation factor of 0.0021 on EigJlfr #14 as the most affected bus.

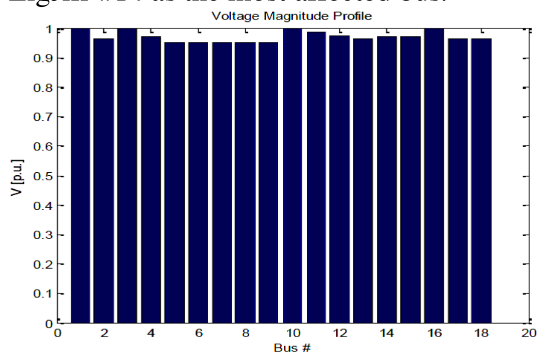

Fig 19: Voltage profile for two solar and hydro (7, 11 and 18)

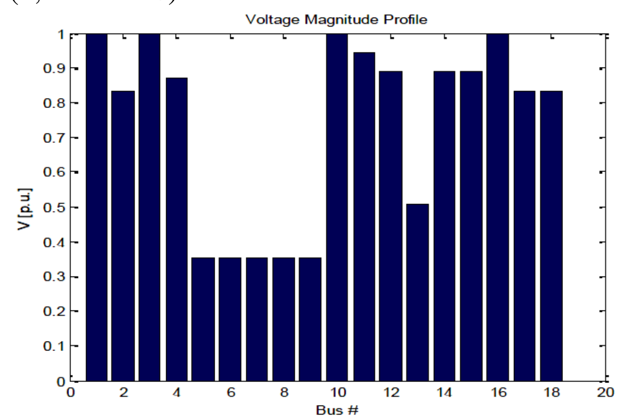

Fig 20: CPF voltage profile for two solar and hydro (7, 11 and 18)

Fig 21 shows a significant improvement in convergence when compared to the V-P curve without DGs as the reactive part (red lines) of the voltage profile becomes less significant while the system attains stability.

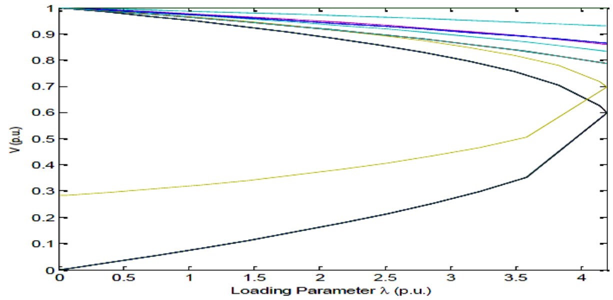

Fig 4.15: V-P curve for two solar and hydro (7, 11 and 18)

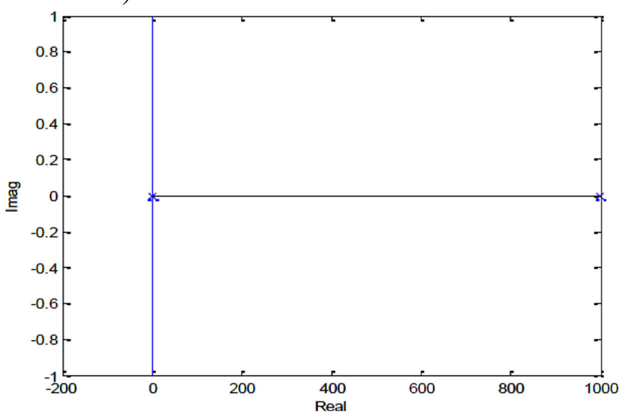

Fig 22: Eigenvalue result for two (500 kW) solar and 100kW microhydro (7, 11 and 18)

An optimal performance was achieved placing two 500 kW solar and 100 kW microHydro at Buses 18, 11 and 7 respectively. This point shows the best performance as no bus was violated. The load flow and continuous power flow results are shown in Fig 19 and 20. The real and reactive power losses are 0.008 and 0.00198 p.u respectively. CPF analysis shows an improvement in the real and reactive power to 0.00578 p.u and 0.11557 p.u respectively and accommodation of additional 4.1887 p.u loads without causing a collapse in the network. Fig 21 and Fig 22 show the voltage stability profiles after the two 500 kW and one 100 kW plants were placed on bus 18, bus 11 and bus 7 respectively. This gave the best result and optimum performance as compared to other placement above. The 18-bus network under discuss is shown in Fig 23.

Conducting sensitivity analysis shows that stability was confirmed as no negative sign was seen in the real Jacobian result.

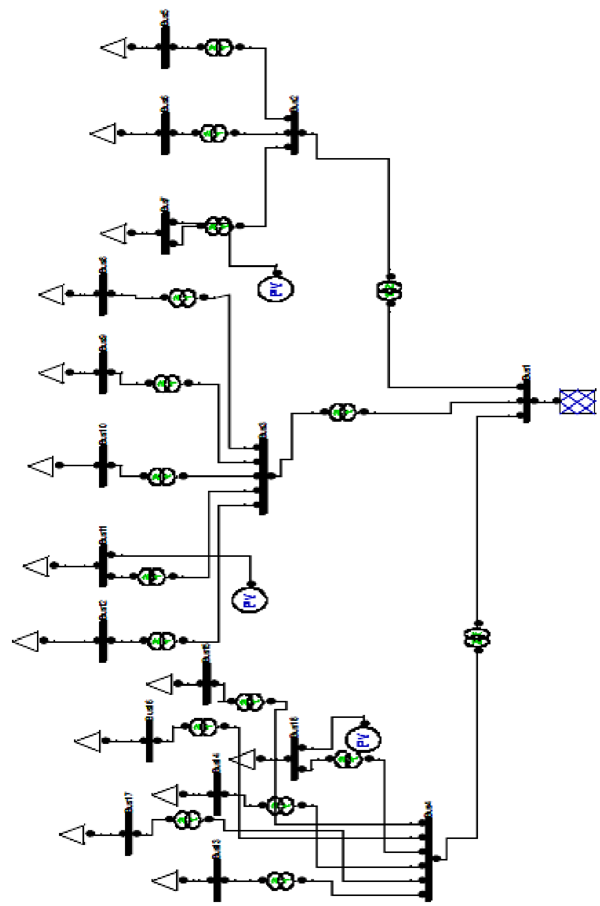

Fig 23: 18-Bus Network After Placement Of DGs

V. CONCLUSIONS

Results from the inventory were used for sizing and reconciling the proposed generating components with the estimated daily energy consumption. It was established that two 500kW Solar farms and one 100kW micro hydro plant

would suit the average installed load requirement. A feasible architecture was also adopted and Modified to accommodate real-time monitoring and switching system which will make it possible to obtain real-time information on energy production, storage and management for optimal load dispatch. The results generated shows that the proposed smart micro grid network will pin-point the exact buses affected by voltage instability and also which buses are responsible for them. There are also prospects of lower energy wastage if the necessary energy management measures are implemented.
It was observed that the most affected buses were bus 7, 11 and 18. The two solar plants connected on bus 11 and 18 and the microhydro plant connected to bus 7 yielded optimum results without violation of any bus with real and reactive power losses of 0.008 and 0.00198 p.u. Continuous power flow analysis shows an improvement in the real and reactive power to 0.00578 p.u and 0.11557 p.u respectively and accommodation of additional 4.1887 p.u loads without causing a collapse in the network.
Conducting sensitivity analysis shows that stability was confirmed as no negative sign was seen in the real Jacobian result.
Also, the load being serviced was classified based on 2 factors: Purpose and Priority.
Also the pricing policies that were experimented help to know and revels how much the University spends per kWh at each point in time.

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