Design And Simulation Of A Microgrid System For A University Campus In Nigeria

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Outline

- Introduction
- Literature review
- Research objectives
- Design and sizing of microgrid system
- Dynamic simulation
- Reduced order model
- Monitoring of the system
- Conclusion
- Research contributions
- Future work
- Publications
- References

Introduction

- Nigeria is a developing nation with enormous oil, gas, hydro, and solar resources for the generation of electricity for the geometric increasing population.
- Presently, she has a population of over 216 million people with a potential of generating 12,522MW from the existing grid network but only 4,000MW can be dispatched due to her weak transmission capacity.
- This has led to massive load shedding and frequent power outages on the grid network.
- The rate of charge of 1kWh of electrical energy is very high, hence, communities, businesses and industries find it difficult to cope with this high price of electricity to maximise profit.
- To eradicate these challenges of constant power blackout and high electricity tariffs, a microgrid system is proposed.
- This thesis is focused on the design and simulation of a microgrid system for a university campus in Nigeria.

Literature review

- Iwuamadi O. C. and Dike D. O. (2012), despite its long history, electricity generation has been very slow and had deteriorated over the years in Nigeria. This is rarely expected given the country's enormous endowment in natural resources that facilitate and enhance electricity production. While the generation, transmission, and distribution (GTD) deteriorated, the demand for electricity exponentially increases continuously. This has led to the electricity company been incapable of providing minimum acceptable international standards of electricity service reliability, accessibility, and availability for the past three decades [28].
- Omorogiuwa E. and Ike S. (2014) said that Nigeria power system is faced usually with problems of insufficient generation and transmission lines, resulting in the overloading, and stressing of the network beyond their thermal limit because of the increasing load demand [29].

Literature review con’d

- Evbogbai M. J. E. and Ogbikaya S. (2019), in their work stated that the solar energy is available for everybody, hence if harnessed, can sustain the electrical energy need for meaningful development in Nigeria. Although the initial cost implication may be high, but on the long run, it is more economical because of its renewable nature, less maintenance cost, and its environmental friendliness. Hence, for sustainable development to take place in Nigeria, the government, corporate bodies, and individuals should focus on photovoltaic power generation as one of the most viable options that could drive the civilization for ever [27].

Research objectives

- To do a literature review on microgrid system.
- To determine the load profile (kWh) of the university community selected.
- System design and sizing of the campus microgrid would be done with the aid of Homer Pro and other software such as OpenSolar, PVWatts and REopt to obtain the optimal PV size of the selected site.
- The dynamic simulation of the campus microgrid would be done on MATLAB/Simulink software.
- To design the reduced order model of the campus microgrid system with the aid of MATLAB/Simulink software.
- To design the monitoring system for the campus microgrid.

Design and sizing of the campus microgrid system

Campus location

The proposed site location for this research is Edo State University Uzairue, Auchi, Edo State, Nigeria (7° 8'8.25''N, 6°18'28.13''E) located at Kilo-meter 7, Auchi-Abuja Road, Iyamho-Uzairue, Edo State, Nigeria.

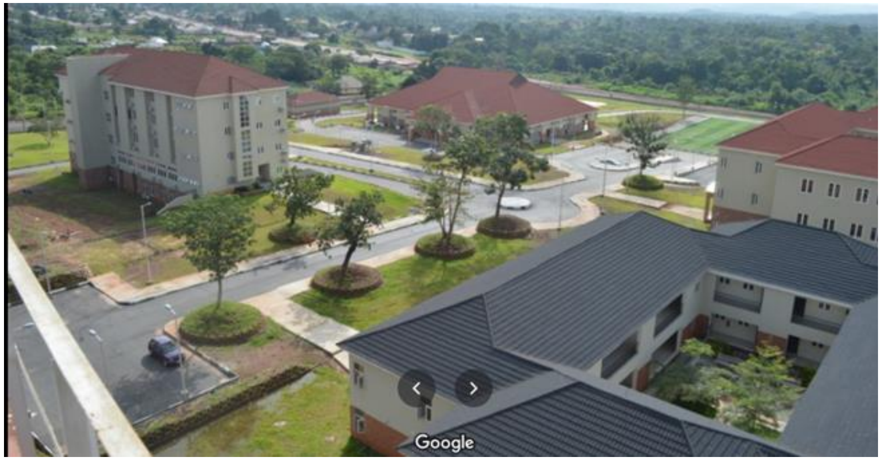


Fig. 1: Overview of part of the University campus.

Fig. 2: Google map of part of the University campus

Methodology

- The load profile (kWh) of the selected university community was determined based on the electrical load of the campus.
- The load profile obtained was then used to design and size a campus microgrid for the university community consisting of PV panel, grid system, generator, inverter and electrical load with the aid of “HOMER” Pro software.
- The dimension of the area required for the system installation was determined with the aid of PVWATT software.

Methodology con’d

Table 1: Summary of maximum possible electrical load installed in the university

S/N	Description	Total electrical load in Kilowatts (kW)
1	Administrative building	269.238
2	Faculty of Law building	64.008
3	Male hostel	370.6
4	Female hostel	207.636
5	Auditorium building	168.796
6	Engineering workshop building	152.135
7	Faculty of science building	225.608
8	Faculty of social science building	84.938
Total load		1542.959

In kVA, total electrical load installed =1542.959/0.8=1928.699kVA

Methodology con’d

Table 2: Energy consumption of Edo State University Uzairue from October 2020 to September 2021

Month	Previous meter reading (kWh)	Present meter reading (kWh)	Energy consumption (kWh)	Cost of energy consumption (₦)
October	3635000	3655000	20000	1,043,600.00
November	3655000	3689000	34000	1,774,120.00
December	3689000	3781000	92000	4,800,560.00
January	3781000	3836000	55000	2,869,900.00
February	3836000	3893000	57000	2,974,260.00
March	3893000	3986000	93000	4,852,740.00
April	3986000	4097000	111000	5,791,980.00
May	4097000	4254000	157000	8,192,260.00
June	4254000	4324000	70000	3,652,600.00
July	4324000	4411000	87000	4,539,660.00
August	4411000	4516000	105000	5,478,900.00
September	4516000	4604000	88000	4,591,840.00
Annual energy consumption			969000	50,562,420.00
Daily energy consumption			2654.795	138,527.20

Methodology con’d

Fig. 3: Location of University campus on “HOMER” google map

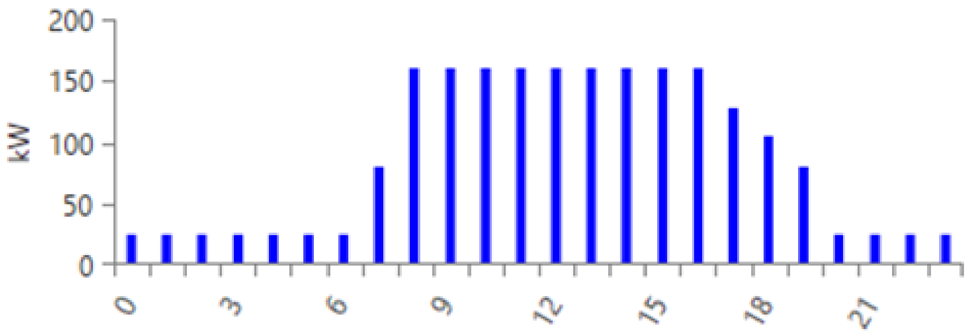


Fig. 4: Commercial daily load profile of campus

Methodology con’d

Solar Irradiance

The average solar radiation per annum is 5.10 kWh/m2/day for the site location based on average monthly Global Horizontal Irradiance (GHI) Data for the considered site.

Fig. 5: Graph of monthly solar irradiance of the selected site

Modeling and sizing

- Based on the load profile of the selected site, the components size is chosen.
- A hybrid power system of the site consisting of the grid system, solar panel of 0.5kW, diesel generator of 1.5MVA and inverter of 500kW is designed and simulated with the aid of "HOMER" Pro Energy software to accommodate its annual energy (kWh).
- The schematic diagram of the hybrid power system obtained is shown in Figure 6.

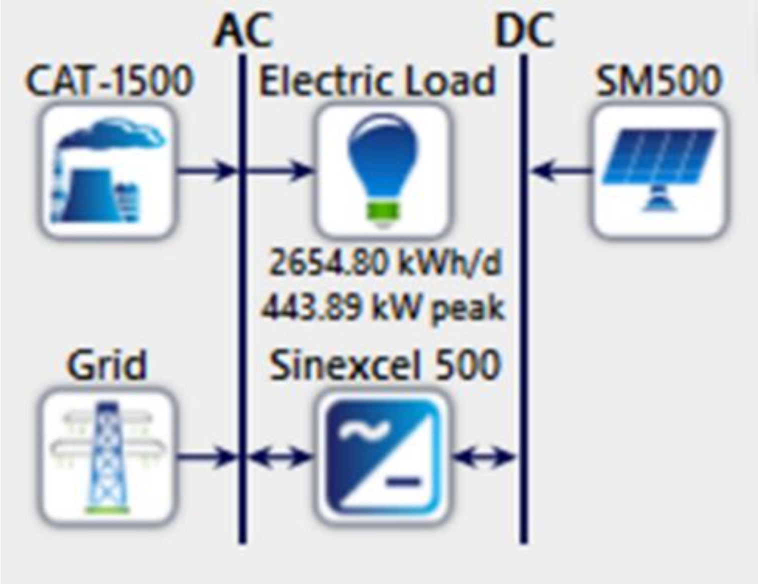


Fig. 6: Schematic diagram of hybrid power system

Modeling and sizing con'd

- The designed system will need 3,726 PV solar modules of 500W.
- The dimension of the area required for the system installation is 17,696m2 based on PVWATT software, as shown in Figure 4.
- Required land is available on campus for this installation as shown in Figure 7.

Fig. 7: Location of the installed solar system on campus using PVWATT

Result and Discussion

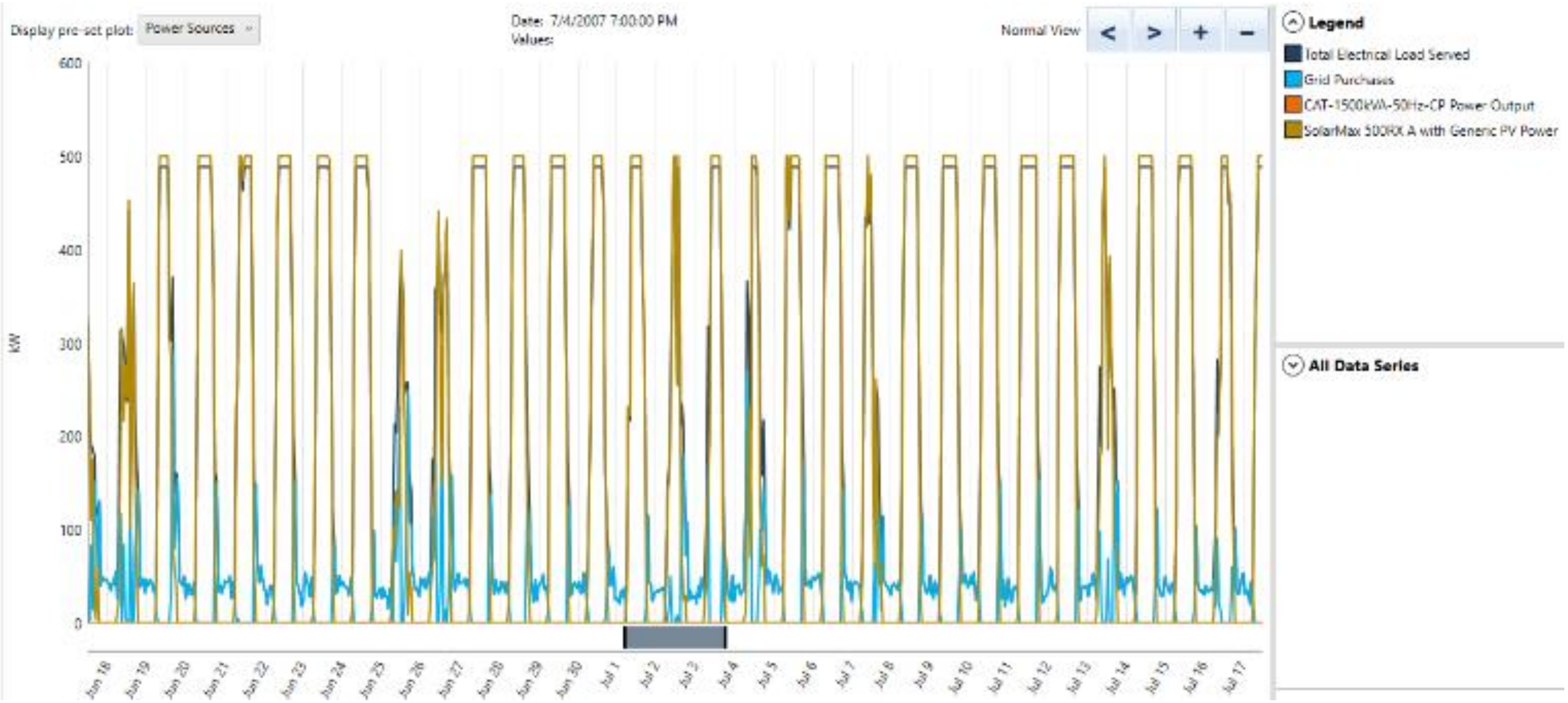


Fig. 8: Graph showing power generation and total electrical load served for one month

Result and Discussion con’d

Table 3: Simulated result of system sizing by “HOMER” Pro

System Architecture:
SolarMax 500RX A with Generic PV (1,863 kW/500 kW)
CAT-1500kVA-50Hz-CP (1,200 kW)
Sinexcel 500kW (489 kW)
Grid (999,999 kW)
HOMER Cycle Charging

Total NPC:	₦150,666,500.00
Levelized COE:	₦6.20
Operating Cost:	₦34,458,160.00

Sinexcel 500kW Emissions
Cost Summary Cash Flow Compare Economics Electrical Fuel Summary CAT-1500kVA-50Hz-CP Renewable Penetration SolarMax 500RX A with Generic PV Grid

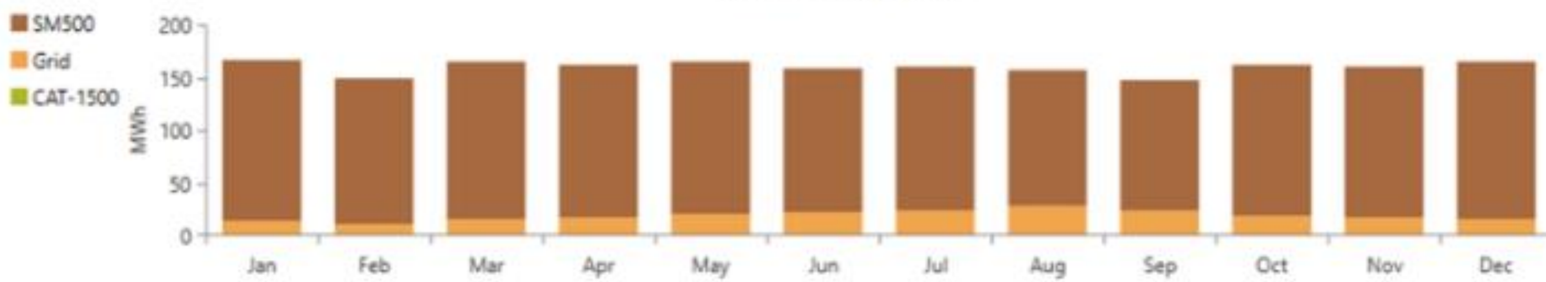
Production	kWh/yr	%
SolarMax 500RX A with Generic PV	1,689,698	88.0
CAT-1500kVA-50Hz-CP	0	0
Grid Purchases	229,643	12.0
Total	1,919,341	100

Consumption	kWh/yr	%
AC Primary Load	969,002	51.5
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	910,970	48.5
Total	1,879,972	100

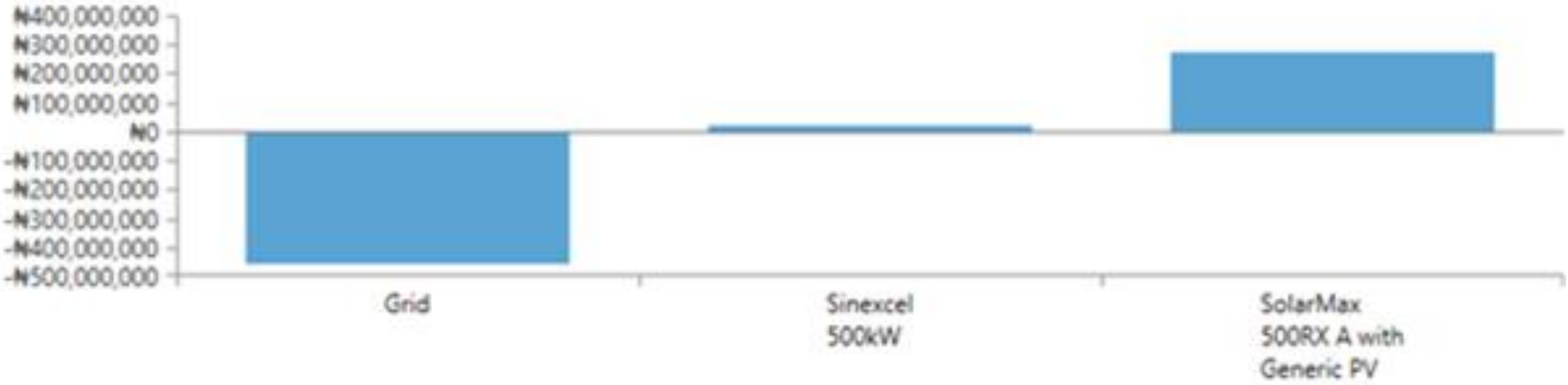
Quantity	kWh/yr	%
Excess Electricity	1,376,458	71.7
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	87.8	%
Max. Renew. Penetration	102	%

Monthly Electric Production



Result and Discussion con’d



Component	Capital (₦)	Replacement (₦)	O&M (₦)	Fuel (₦)	Salvage (₦)	Total (₦)
Grid	₦0.00	₦0.00	-₦459,594,017.08	₦0.00	₦0.00	-₦459,594,017.08
Sinexcel 500kW	₦15,290,947.59	₦13,508,598.46	₦1,976,739.80	₦0.00	-₦1,831,533.27	₦28,944,752.59
SolarMax 500RX A with Generic PV	₦279,500,976.56	₦0.00	₦481,767.13	₦0.00	₦0.00	₦279,982,743.70
System	₦294,791,924.15	₦13,508,598.46	-₦457,135,510.14	₦0.00	-₦1,831,533.27	-₦150,666,520.79

Fig. 9: Cost summary of system

Result and Discussion con’d

Table 4: System economics

Architecture									Cost	
				SM500 (kW)	SM500-MPPT (kW)	CAT-1500 (kW)	Grid (kW)	Sinexcel 500 (kW)	NPC (₦)	Initial capital (₦)
						1,200	999,999		₦654M	₦0.00
				1,863	500	1,200	999,999	489	-₦151M	₦295M

Metric	Value
Present worth (₦)	₦804,314,300
Annual worth (₦/yr)	₦62,217,230
Return on investment (%)	24.8
Internal rate of return (%)	29.0
Simple payback (yr)	3.43
Discounted payback (yr)	3.95

The challenges in this design was the large PV size of 1,863kW required for system installation

Conclusion

- In this research, a microgrid consisting of the grid system, 3,726 solar panel of 0.5kW, diesel generator of 1.5MVA and inverter of 500kW installed in an area of 17,696m2 at a cost of ₦295 with a simple payback of 3 years and 5 months was designed with the aid of "HOMER" Pro to meet the load demand of the university community at a reduced cost of electricity bill by 88.0%.
- Site details, load data and microgrid system design has been presented.
- Analysis indicates that the proposed system makes economic sense and will greatly help the university bring down its electricity bill, this will also help the university reduce its CO_2 emissions.
- The challenges in this design was the large PV size of 1,863kW required for system installation.

Dynamic simulation of system of campus microgrid

To solve this problem of large PV size obtained in system design with the aid of Homer Pro software, other software such as OpenSolar, PVWatts and REopt were used to design the same system to obtain optimal PV size.

Methodology

- Based on the annual energy consumption of the selected site location of 969,000kWh;
- The microgrid system was design with OpenSolar software to determine PV size.
- Design of microgrid system in PVWatts environment to obtain PV size.
- Design of campus microgrid system with REopt software to obtain PV size.
- Results obtained was then compared to that obtained from the HOMER Pro software to determine the optimal PV size of the system.
- Based on the optimal PV size selected, the system was then simulated in MATLAB/Simulink software to determine its dynamics.

System sizing

Simulation from PVWatts

PVWatts Calculator

RESULTS

967,113 kWh/Year*

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	5.53	85,879	11,164
February	5.80	81,845	10,640
March	5.96	92,340	12,004
April	5.51	83,657	10,875
May	5.05	78,874	10,254
June	4.65	71,768	9,330
July	4.51	72,440	9,417
August	4.66	74,950	9,744
September	5.01	77,664	10,096
October	5.31	83,995	10,919
November	5.42	81,916	10,649
December	5.25	81,785	10,632
Annual	5.22	967,113	$ 125,724

Location and Station Identification

Requested Location	Edo State University Uzairue, Auchi, Nigeria
Weather Data Source	(INTL) ACCRA/KOTOKA INTL, GHANA 436 mi

Requested Location	Edo State University Uzairue, Auchi, Nigeria
Weather Data Source	(INTL) ACCRA/KOTOKA INTL, GHANA 436 mi

Latitude	5.6° N
Longitude	0.17° W

PV System Specifications *(Commercial)*

DC System Size	670.5 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	8°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Economics

Average Retail Electricity Rate	0.130 $/kWh

Performance Metrics

Capacity Factor	16.5%

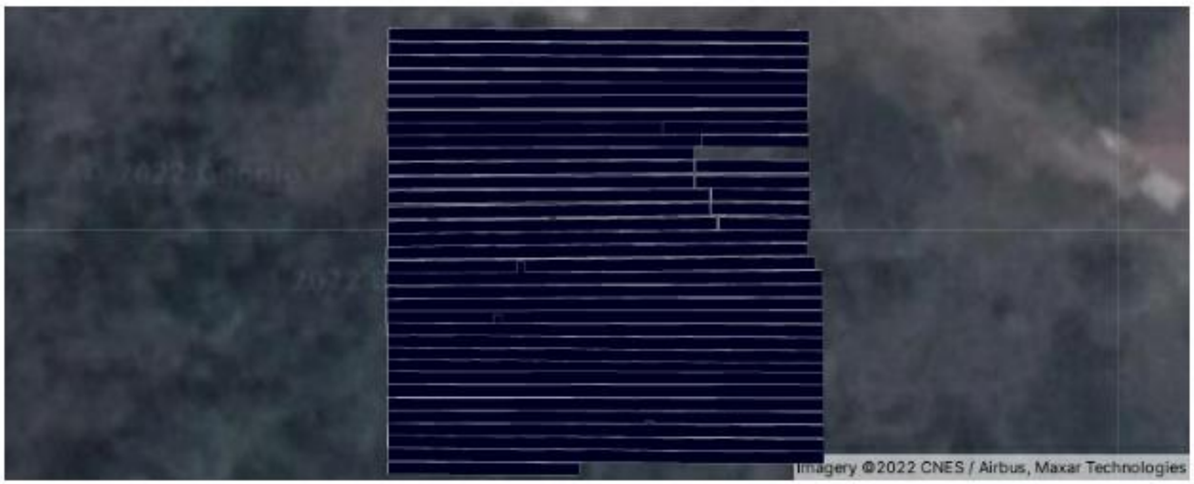
Fig. 10 Simulation from PVWatts showing system PV size

System sizing con’d

Simulation from OpenSolar software

Recommended System Option

683.645 kW	$50,389	$1,504,019	$1,504,019
System Size	Estimated Annual Electricity Bill Savings	Total System Price	Net System Price



Your Solution

Solar Panels
LG Electronics Inc.
683.645 kW Total Solar Power
1873 x 365 Watt Panels (LG365Q1C-A5)
969,063 kWh per year

Fig. 11 Simulation from OpenSolar software showing system PV size

System sizing con’d

Simulation from REopt software

Technologies Selected	
PV	

Site and Utility	
Site Location	Auchi, Nigeria (7.066864499999999, 6.274773400000001)
PV & wind space available	Land
Annual energy charge ($/kWh)	$0.13
Annual demand charge ($/kW/month)	$1.05

Load Profile	
Typical electric load profile type	simulated campus
Campus total electric energy consumption (kWh)	969,000
Building #1	SecondarySchool (100% of total energy consumption)

Results for Your Site

REopt

Your site at Auchi Nigeria evaluated on February 13, 2022

These results from REopt summarize the economic viability of PV, wind, battery storage, and/or CHP at your site. You can edit your inputs to see how changes to your energy strategies affect the results.

Your recommended solar installation size

658 kW

PV size

Measured in kilowatts (kW) of direct current (DC), this recommended size minimizes the life cycle cost of energy at your site.

This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size.

Fig. 12 Simulation from REopt software showing system PV size

System sizing con’d

Table 5: Comparison table showing the simulated results obtained from the different software used to determine the system PV size for the microgrid system of the university campus

S/N	Software Used	Annual Energy Consumption (kWh)	System PV Size (kW)
1	HOMER Pro	969,000	1868.00
2	OpenSolar	969,063	683.65
3	PVWatts	967,113	670.50
4	REopt	969,000	658.00

Dynamic Simulation

- Based on the system sizing a PV of 675.2kW was selected for the system design.
- PV consist of 96 cell modules each of 500W with 25 connected in series and 54 in parallel.
- The inverter of the system was selected based on the PV size as 700kW.
- A utility grid and a generator of 1.5MVA rating was incorporated to the network through breaker 2 and 3, which is controlled by toggle switch 2 and 3.
- The electric load of the university campus is also connected and varied through breaker 4 which is controlled by toggle switch 4 to network.

Dynamic Simulation con'd

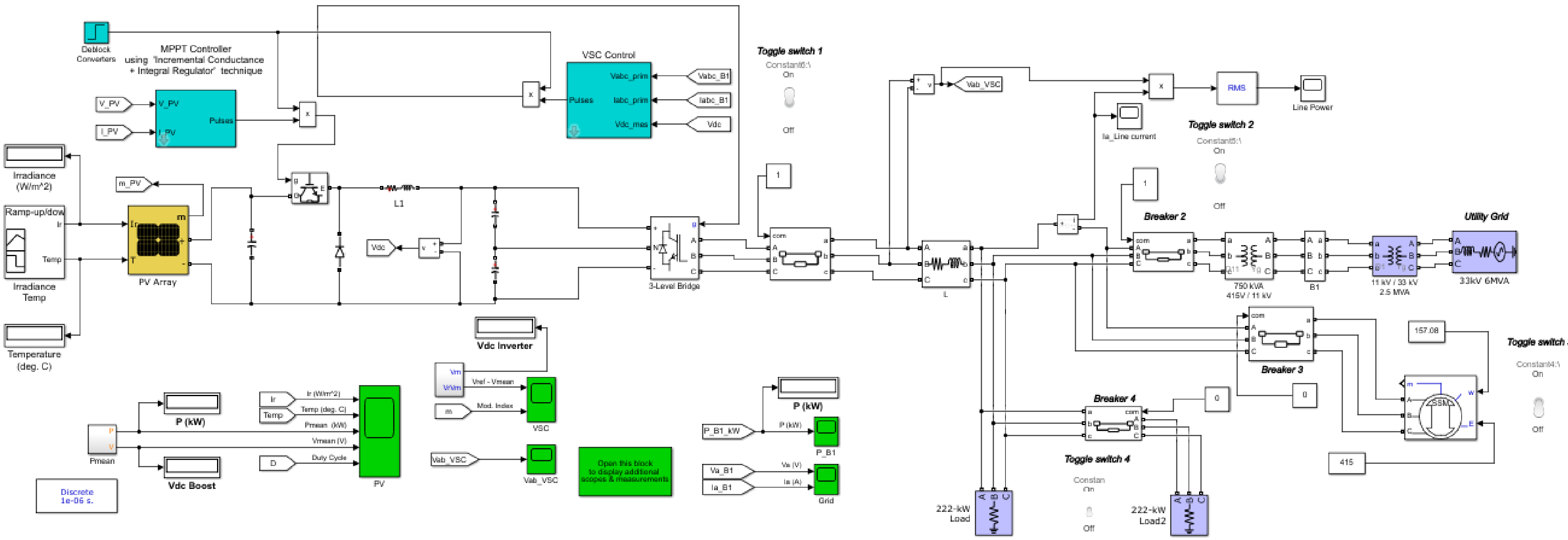


Fig. 13: Dynamic simulation of campus microgrid in MATLAB/Simulink software

Dynamic Simulation con'd

For the purpose of analysis, the system dynamics are considered in three cases;

- PV + Grid mode i.e normal operating condition of the proposed system.
- PV + Generator mode i.e when the grid fails.
- Generator only i.e when the generator supplies energy to the entire load of the system.

Result and Discussion

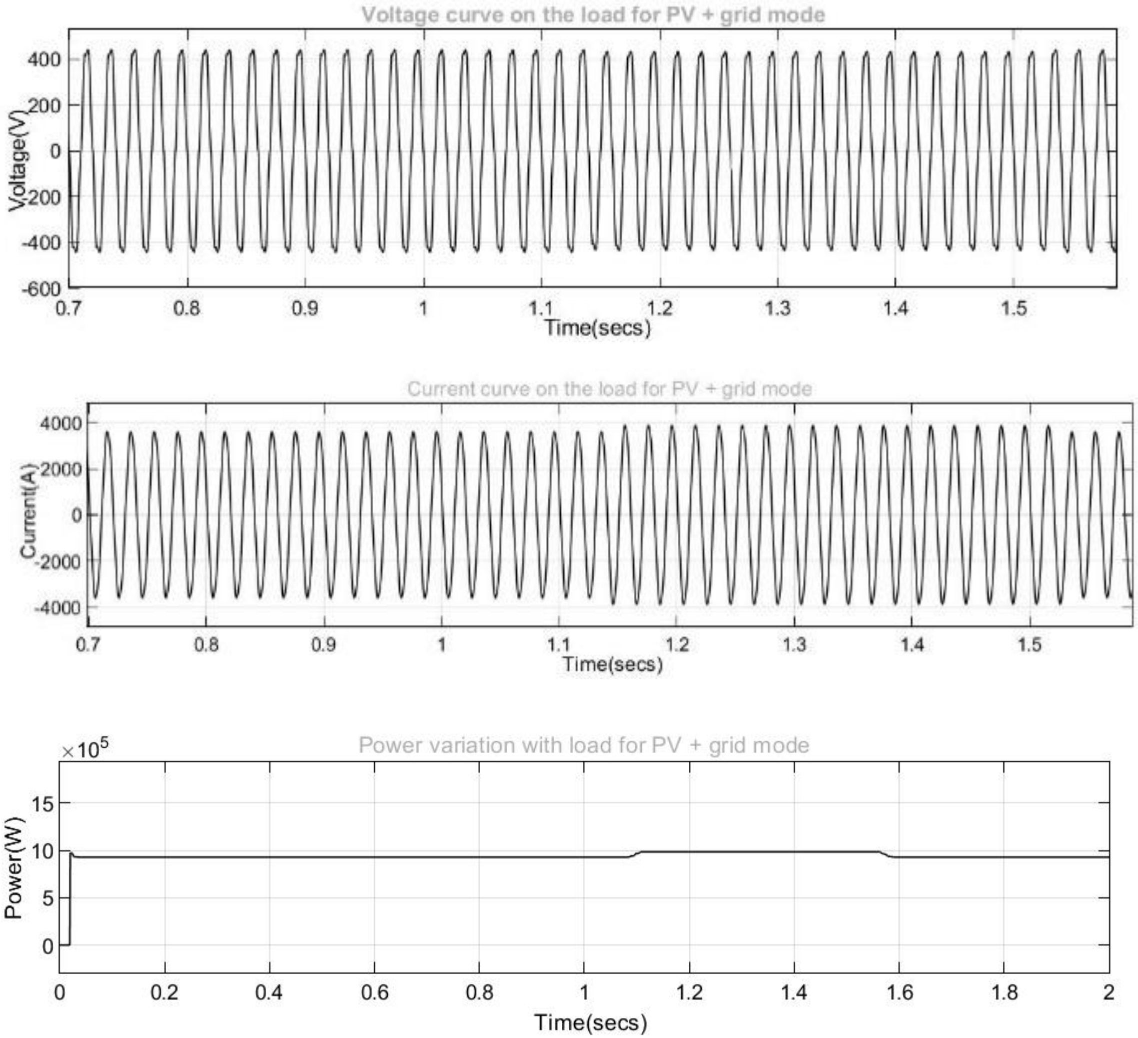


Fig. 14 Graphs of dynamic system during PV + Grid mode

Result and Discussion con’d

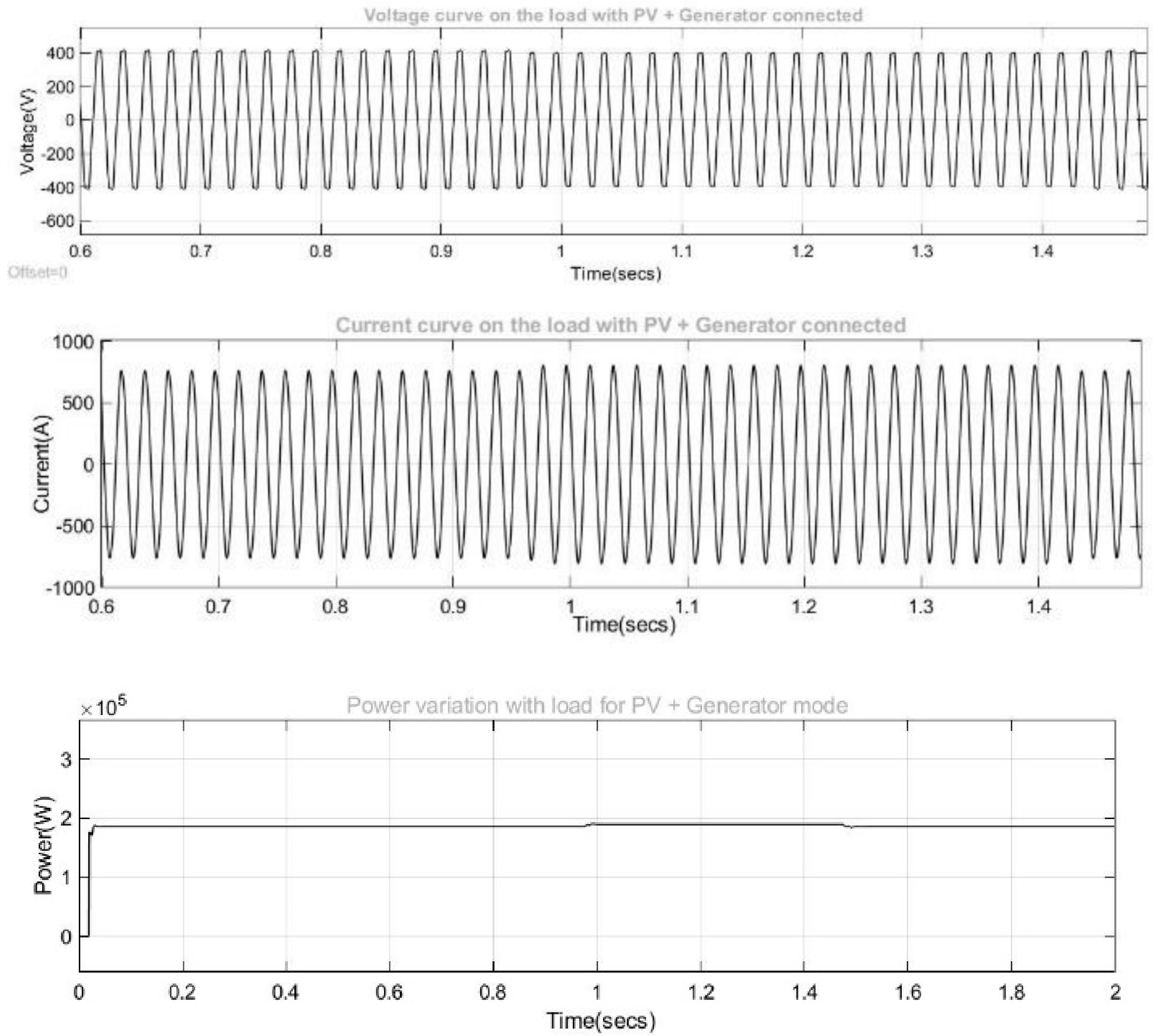


Fig. 15 Graphs of dynamic system during PV + Generator mode

Result and Discussion con’d

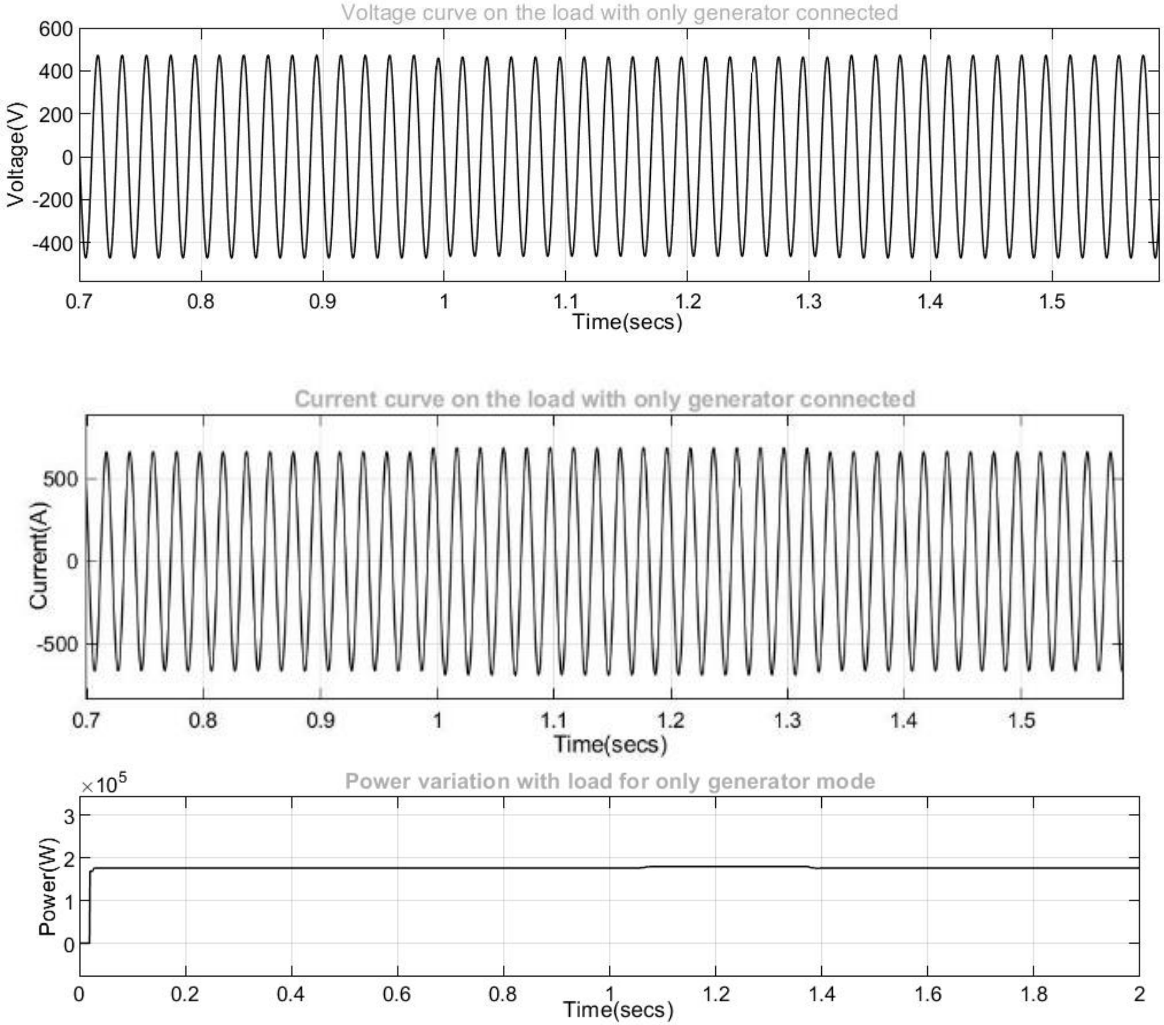


Fig. 16 Graphs of dynamic system during Generator mode only

Limitation: Dynamic simulation of the system was extremely slow

Reduced order model of campus microgrid

To solve the issue of slow simulation time, a reduced order model of the campus microgrid is designed.

Methodology

- The dynamic system realized was first linearized by linearized perturbation method with the aid of MATLAB/Simulink software.
- Then the reduced order model of the linearized system was obtained by model reducer using the balanced truncation method in MATLAB/Simulink environment.
- The speed of simulation of the reduced order model was compared to that of the original microgrid system.

System Linearization

- Linearization of the dynamic system was carried out in MATLAB/Simulink environment with the aid of model linearizer by linearized perturbation method.
- Linearization was done based on the system multiple inputs (irradiance and temperature) and a single output which is the power (i.e., current × voltage).
- The transfer functions of the inputs with respect to the output was determined by linearized perturbation method.
- The resulting transfer function obtained was incorporated into the subsystem block of the nonlinear system to linearize the system as shown in Figure 17.

System Linearization con'd

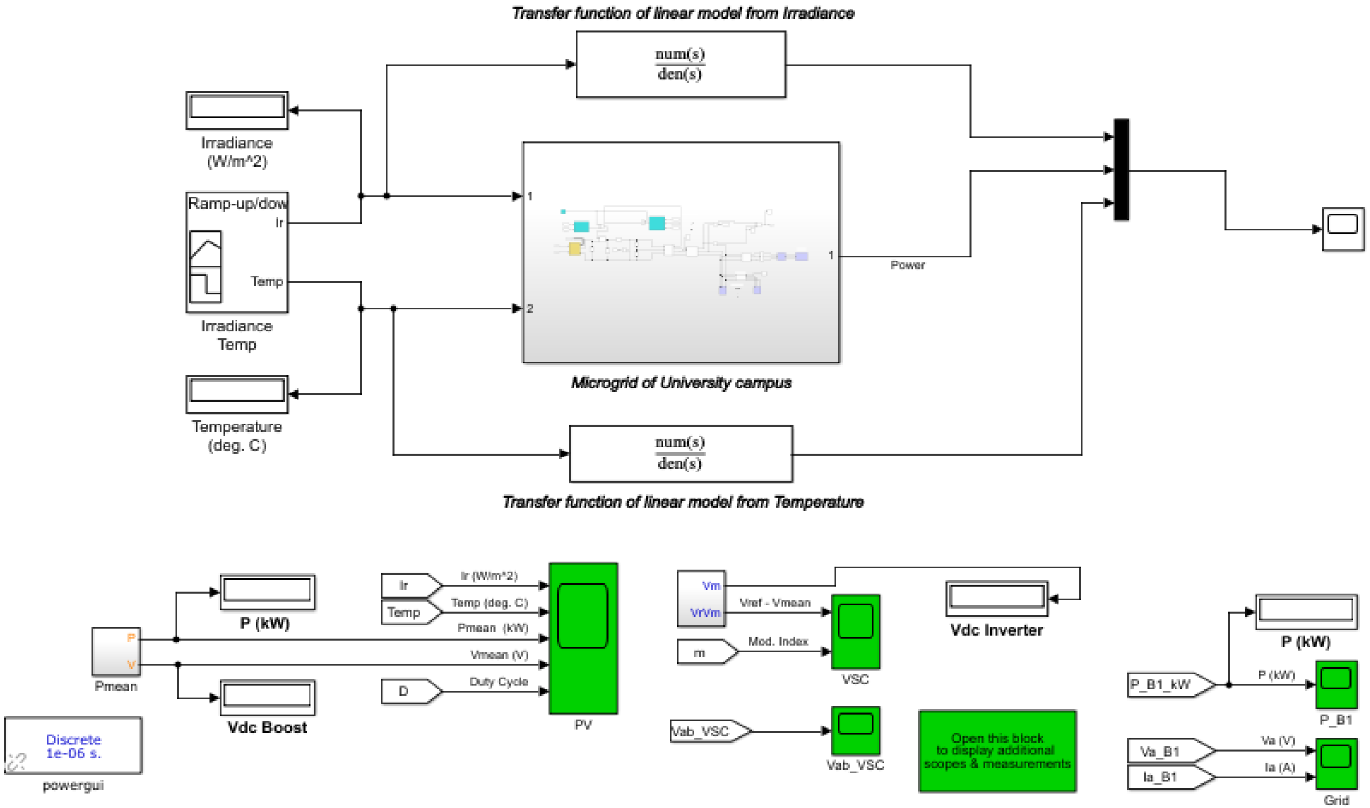


Fig. 17: Linearized microgrid model

System Linearization con’d

- With the aid of perturbation method, the linearized microgrid system was then simulated to determine the system response as compared to the step response of the nonlinear microgrid system.
- Then the reduced order model of the linearized model was achieved by model reducer with the help of balanced truncation method in MATLAB/Simulink with it 20 states reduced to 5 states as shown in Figure 18.

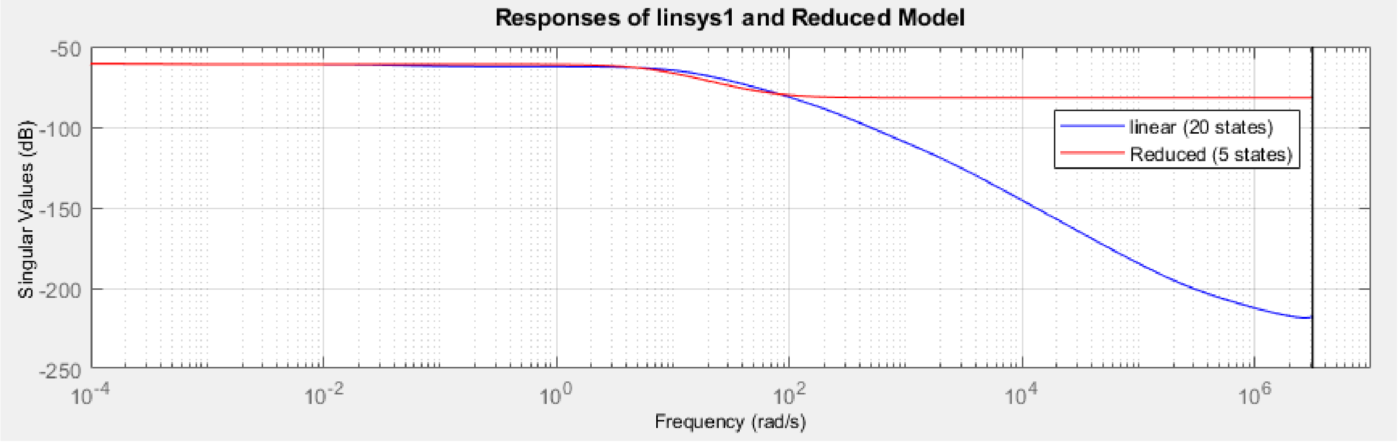


Fig. 18: Graph showing linear and reduced order model states

Result and Discussion

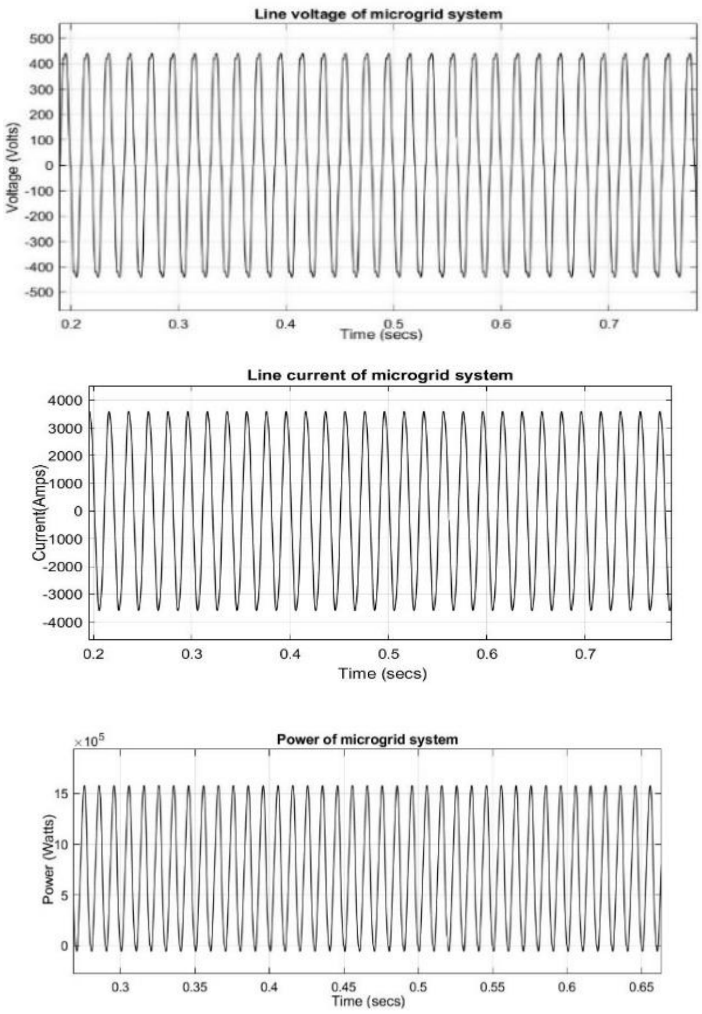


Fig. 19: Simulated results from microgrid system

Result and Discussion con’d

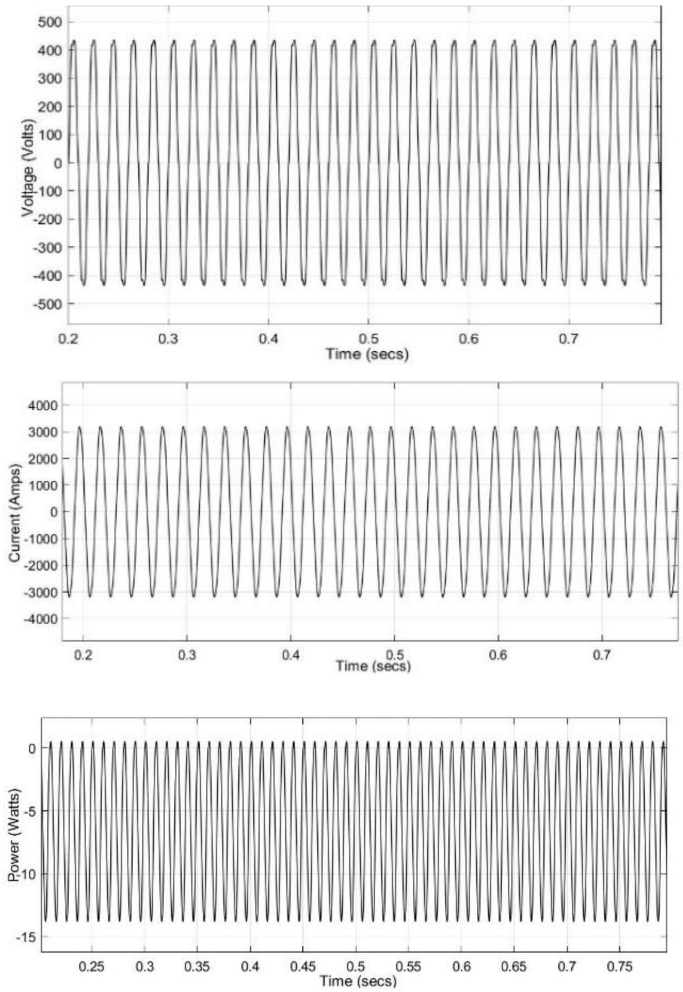


Fig. 20: Simulated results from reduced order model

Result and Discussion con’d

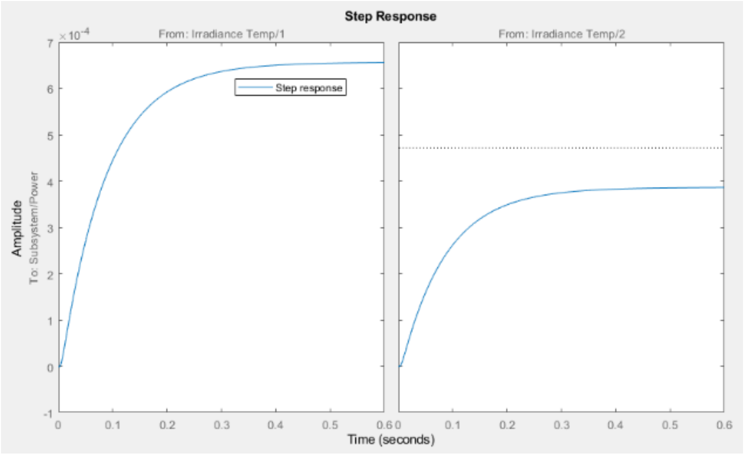


Fig. 21 Step response of nonlinear model

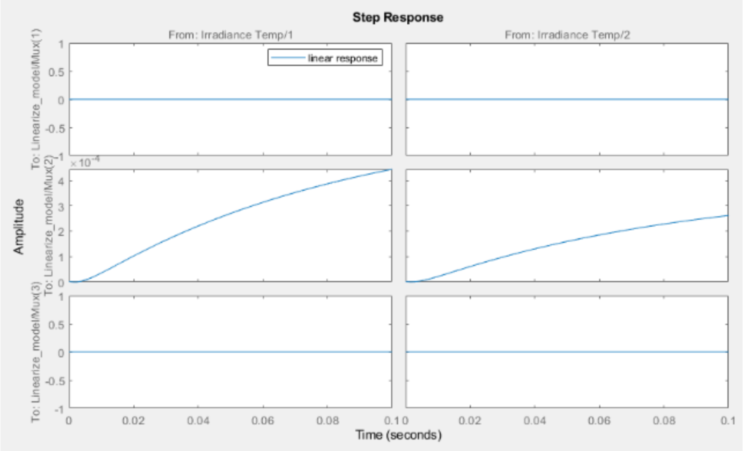


Fig. 22: Step response of linear model

The linear model obtained has a linear response when compared to the step response of the entire microgrid system.

Result and Discussion con'd

Table 6: Comparison table showing speed of simulation between university microgrid and the reduced order model at different sample time

Sample time (secs)	Microgrid model	Reduced order model
	Simulation time (secs)	Simulation time (secs)
1.0	86	20
2.0	222	48
5.0	589	120

The reduced order model achieved is more than 4 times faster in terms of simulation response time.

Design of Monitoring System for Campus Microgrid

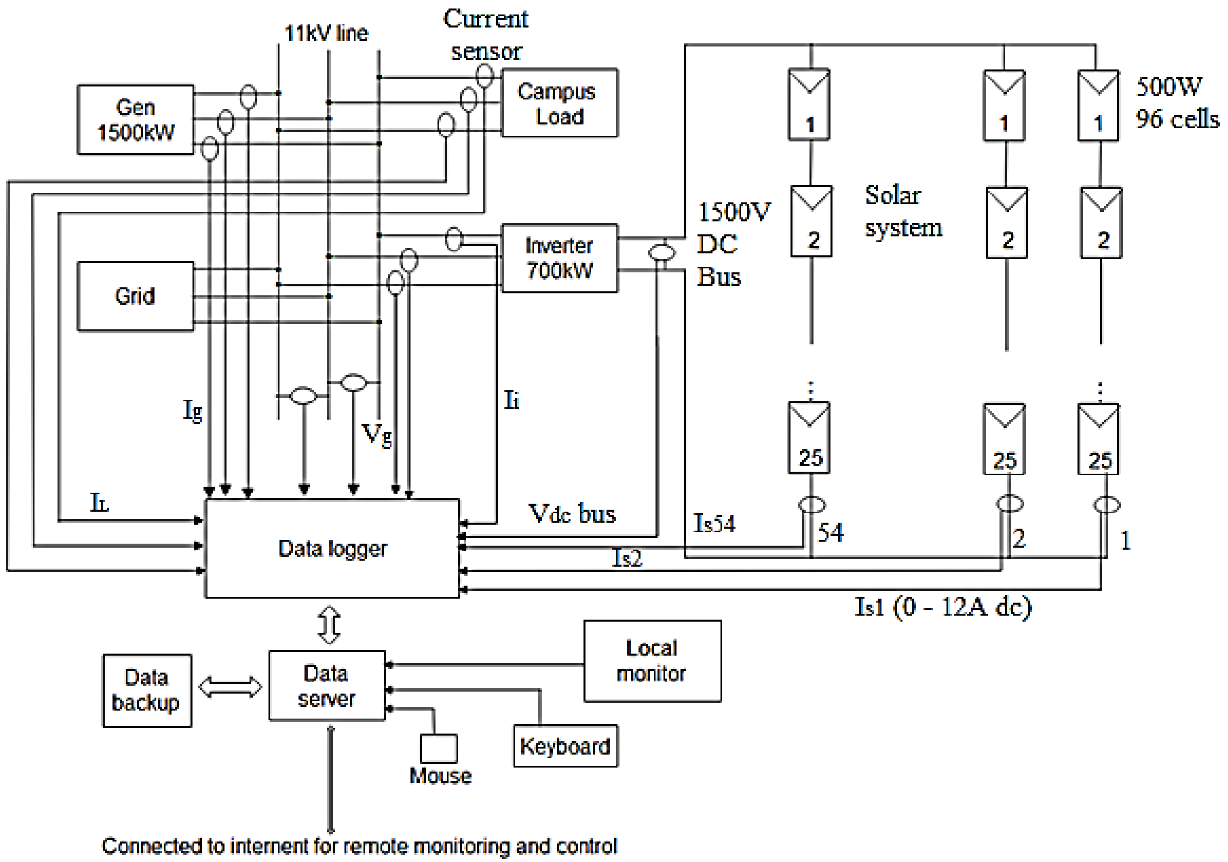


Fig. 23: Instrumentation layout of the monitoring system of campus microgrid system

Design of Monitoring System for Campus Microgrid con’d

Based on the campus microgrid system sizing and design presented in previous slides the monitoring technique of the microgrid system consists of:

- 54 number of dc current sensors (0 – 12) A
- One dc voltage sensor (0 - 1500) V
- 9 number ac current sensors (0 – 150) A
- 6 number ac voltage sensor of 11kV
- Data logger (ATS SmartDER device)
- Computer with internet
- However a custom system design is recommended to avoid data security issues and cost of software license always associated with commercial options.

Conclusion

- In this thesis, microgrid consisting of the grid system, 3,726 solar panel of 0.5kW, diesel generator of 1.5MVA and inverter of 500kW installed in an area of 17,696m2 at a cost of ₦295 with a simple payback of 3 years and 5 months was designed with the aid of "HOMER" Pro to meet the load demand of the university community at a reduced cost of electricity bill by 88.0%.
- Analysis indicates that the proposed system makes economic sense and will greatly help the university bring down its electricity bill, this will also help the university reduce its CO2 emissions.
- The challenges in this design was the large PV size of 1,863kW required for system installation.
- To overcome this problem of high PV size, OpenSolar, PVWatt and Reopt was used to design the same system for optimal PV size.

Conclusion con’d

- Based on the optimal PV size, a microgrid system consisting of a PV size of 675.2 kW comprising of 96 cell modules each of 500W, with 25 connected in series and 54 in parallel. Also, a utility grid system and a diesel generator set in case of emergency was design.
- The system was then simulated in MATLAB/Simulink environment to determine the dynamics of the university microgrid system.
- Simulated results indicates that the system realized has acceptable dynamics as it responds appropriately when a new state was introduced to the network by varying the electric load of the network for different cases considered.
- The limitation of this design was that the dynamic simulation was extremely slow

Conclusion con’d

- To speed up simulation time of the microgrid system, a reduced order model of the system was design which is more than 4 times faster in terms of simulation response time than the original microgrid system.
- The monitoring technique consist of 54 number of dc current sensors, one dc voltage sensor for monitoring of the dc part of the microgrid system. To monitor the ac part of the system, 9 number ac current sensors and 6 number ac voltage sensor of 11kV would be required.
- These sensors are connected to a data logger which is connected to a computer with internet for remote monitoring and control of the entire microgrid system.

Research Contributions

- Identification of power challenges faced by Edo State University Uzairue, Auchi, Edo State, Nigeria based on interruption and high cost of electricity.
- System design and PV sizing of a microgrid system for a university community in Nigeria with Edo State University Uzairue as a case study.
- Dynamic simulation of the campus microgrid system to determine the system response with variance in the electrical load.
- Design of a reduced order model for the university microgrid system to increase the speed of simulation of the system.
- Design of monitoring system for both the PV (dc) and the ac network of the campus microgrid system.

Further work

- Nigerian university communities are recommended to find funds for the implementation of microgrid system to have a reliable low-cost electricity that is readily available and stable with an affordable low initial capital cost of installation.

- In system design with PV sizing, optimization of the PV size (kW) should be considered by various software for the system sizing to obtain the optimal PV size required for the installation of the PV cells.

- It is also recommended that the dynamic behaviour of the designed system should be determined to know how the system would respond to variation in electrical load on the network.

- In designing a microgrid system, the monitoring system for both the dc and ac network should be considered to detect any abnormalities in the operation of the system.

Publications

- S.Ogbikaya and M. T. Iqbal "Dynamic Simulation of a Microgrid System for a University Community in Nigeria" 2022 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 01 – 04 June 2022, 10.1109/IEMTRONICS55184.2022.9795822.
- S. Ogbikaya and M.T. Iqbal, "Design and Sizing of a Microgrid System for a University Community in Nigeria" 2022 IEEE 12th Annual Computing and Communication Workshop and Conference (CCWC), 26 – 29 January 2022, 10.1109/CCWC54503.2022.9720908.
- S. Ogbikaya and M.T. Iqbal, "Design of a hybrid power system using Homer Pro and iHOGA", 30th IEEE NECEC conference, 18 November 2021.
- S. Ogbikaya and M.T. Iqbal, "Reduced order model of a microgrid system for a university community in Nigeria", manuscript has been submitted for publication in the Jordan Journal of Electrical Engineering.

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Thank you for the audience