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Modeling and Simulation of Campus Solar-Diesel Hybrid Microgrid using HOMER Grid (SPGS Nnamdi Azikiwe University Awka Campus as a case Study)

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ABSTRACT

This work models and simulates a Campus Solar-Diesel Hybrid, Microgrid (CSDHMG) for the School of Postgraduate Studies (SPGS) sub-grid at Nnamdi Azikiwe University Awka, Anambra State, Nigeria. The exact location of the SPGS sub-grids was selected at the set up stage, which enabled the download of one year solar global horizontal Irradiance (GHI) resources forecast from NASA satellite for the selected location. An electrical load estimation of the installed electrical loads carried out at the sub-grid gave the load profile input required for the simulation of SPGS sub-grids in HOMER Grid. The estimated installed electrical loads for SPGS were 84.15kW and were used to generate a customized load profile in HOMER for the sub-grid. The modelled SPGS sub-grid was simulated with thousands of visible simulation results arranged from the most optimized option to the least. An option was chosen which most closely described the utility grid availability at the SPGS sub-grid. From the selected simulation result of the SPGS sub-grid, the following required components were specified 295kW of PV modules, 52 strings of 1kW Lead Acid Battery Energy Storage System (BESS), converter size of 145kW and Diesel Generator size of 100kW. Further analysis was done using the HOMER grid simulation results, based on readily available components in the market to give the following results for the SPGS sub-grid; 950 pieces of 300W solar PV modules, 60 pieces of LA batteries, 100kW size of diesel Generator, 80 pieces of 60A, 48V, maximum power point tracking(MPPT) charge controllers, 25mm^2 cable size for solar-PV to BESS and 145kW size of converter.

KEYWORDS: *HOMER grid, SPGS Sub-grid, CSDHMG, Lead Acid (LA) batteries, Global Horizontal Irradiance (GHI), Maximum Power Point Tracking(MPPT), NASA.*

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I. INTRODUCTION

Steady electricity is one of the vital tools to any nation's economic growth. It encourages industrialization as companies will not need to incur unnecessary exorbitant cost in running diesel generators [1]. Small and medium Scale enterprises will comfortably thrive with steady electricity and that will increase employment opportunities, thus impacting positively on the nation's GDP [2]. With the obvious challenges faced by the Nigerian electric power sector, ranging from low electricity generation, aging and insufficient transmission grids nationwide, energy theft, increasing electric energy demand, to mention but a few, there is dare need to shift from the conventional electricity provision options of bulk generation, transmission /distribution and diesel generators, to Distributed Generation (DG) options, that are able integrate several renewable energy resources for electricity provision[3]. This brings in the concept of microgrids and minigrids which able to integrate the distributed generation with the other conventional methods of electricity generation, while managing the entire system to ensure cost-effective and reliable electricity supply. [4] and [5] defined a microgrid as a local energy network, offering integration of Distributed Energy Resources (DER) with local elastic loads, which can operate in parallel with the main grid or in an intentional island mode to provide a customized level of high reliability and resilience. Microgrids and minigrids will go a long way in alleviating the terrible challenges posed by power instability in Nigerian Tertiary institutions. Nigerian Tertiary institutions, which are our main focus of study, will run their activities more efficiently and tertiary education will become more affordable to the poor masses if microgrids and minigrids are deployed in campuses of Nigerian tertiary institutions. The current high cost of tertiary education in Nigeria is traceable to many factors including the high running cost of tertiary campuses, of which the cost of providing electricity is a major contributor to. Taking

Nnamdi Azikiwe University Awka Anambra State Nigeria as a case study, monthly the cost of providing electricity takes about 40% of the total cost of running the university [6]. This cost includes both the cost of buying diesel for the various diesel generators and the payment of electricity bills. Even with all these heavy expenses on electricity, it is still very difficult to realize steady power supply and this has impacted negatively on the research output of the University. Most students who require steady power for their research experiments have to go outside to pay heavily in order to implement their researches, others that cannot afford the cost, are compelled to manipulate their research results, thereby negatively affecting the quality of research output.

Microgrids are viable solutions to these noted challenges. This is because they will integrate distributed generation from renewable resources into the system and will drastically reduce the stress on the main utility grid. With distributed generation, individuals, tertiary institutions and companies can generate and manage the bulk of the electricity they need from available renewable resources, drastically reducing their dependence on the main utility grid. This is the idea behind the campus solar-diesel hybrid microgrid. This microgrid design integrates distributed solar energy generation from Photo-voltaic (PV) modules into the existing conventional electricity system. The solar energy is the primary source of power to the microgrid; the diesel generator and the utility grid serve as backup power sources, in the event of cloudy weather conditions or routine maintenance. This implies that as long as the solar power system has sufficient energy to supply electricity to the entire microgrid, electricity is not demanded from the utility grid or the diesel generators.

However, the deployment of a microgrid or a minigrid is a capital intensive investment and requires careful consideration in component selection to ensure that the most cost effective yet reliable microgrid is achieved [7]. Thus there need to make a proper feasibility study and microgrid design to ensure that a reliable system is achieved. HOMER grid, a software simulation tool developed by the US National Renewable Energy Laboratory (NREL), for the simulation of microgrid systems with behind the meter scenarios is a very helpful tool to achieve the above aim. HOMER grid leverages on its robust technology and ability to forecast several renewable resources available at the different locations to deliver simulation results that are very close to the real life scenarios, dimension microgrids accurately and presents the best optimized feasible options. HOMER grid uses the load profile supplied, to generate hundreds or even thousands of feasible microgrid configuration options arranged from the most optimized and cheapest option to the least. HOMER is an acronym for Hybrid Optimization of Multiple Energy Resources. The school of Postgraduate Studies (SPGS) in NAU Awka campus was selected for the purpose of this simulation.

II. LITERATURE REVIEW

II.1 Microgrid Technology

According to [5] a microgrid as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the main grid. The microgrid should be able to connect and disconnect from the main grid to enable it to operate in both grid-connected or island-mode. According to [8], the major features of a micro-grid are as follows;

- Ability to operate in both island and grid-connected modes.
- It appears as a single controlled entity to the main grid.
- It intelligently combines interconnected loads and the distributed power generation sources (that is, ability to manage the available energy to supply designated loads).
- Provision of high levels of power quality and reliability for end-uses.
- Designed to accommodate total system energy requirements.
- Smart energy management to provide most reliable and stable power supply, while leveraging on renewable resources to minimize the total cost operation.

The Microgrid structure assumes an aggregation of loads and Distributed Energy Resources (DERs) (which majorly should be renewable energy sources) operating as a single system providing both power and cooling as the case may be [9]. The required flexibility in the control of Distributed Energy Resources (DERs) is provided via power electronics interfaced with embedded systems. Therefore, the DERs must be power electronic based or compatible with power electronic components. This enhances the ease of integration and control of the different DERs that make up the microgrid, thus enabling the resulting microgrid to be controlled and operated as a single aggregate system. This control flexibility is what makes the system smart and allows the microgrid to present itself to the bulk power system as a single controlled unit. Each DER unit is integrated together in a plug-and-play fashion to meet the customers' local needs [10]. These needs include increased local reliability, cost-effectiveness, steady power availability and security. The major components of a microgrid structure include the interface, control and protection requirements for each DER as well as microgrid voltage control, power flow control, intelligent load sharing during intentional islanding, intelligent load shedding if need be, stability, and over all operation [11].

The ability of the microgrid to operate in a grid connected mode as well as smooth transition to and from the island mode is another very important feature of the microgrid technology.

[11] Presented the classification of MG based on the purpose for which they are put to use. Several categories of MG were identified, namely, Campus Environment/Institutional MGs, Remote “Off-grid microgrids”, military base microgrids, Commercial and Industrial (C and I) microgrids, Community/Utility microgrids.

2.1.1 Hybrid Microgrids

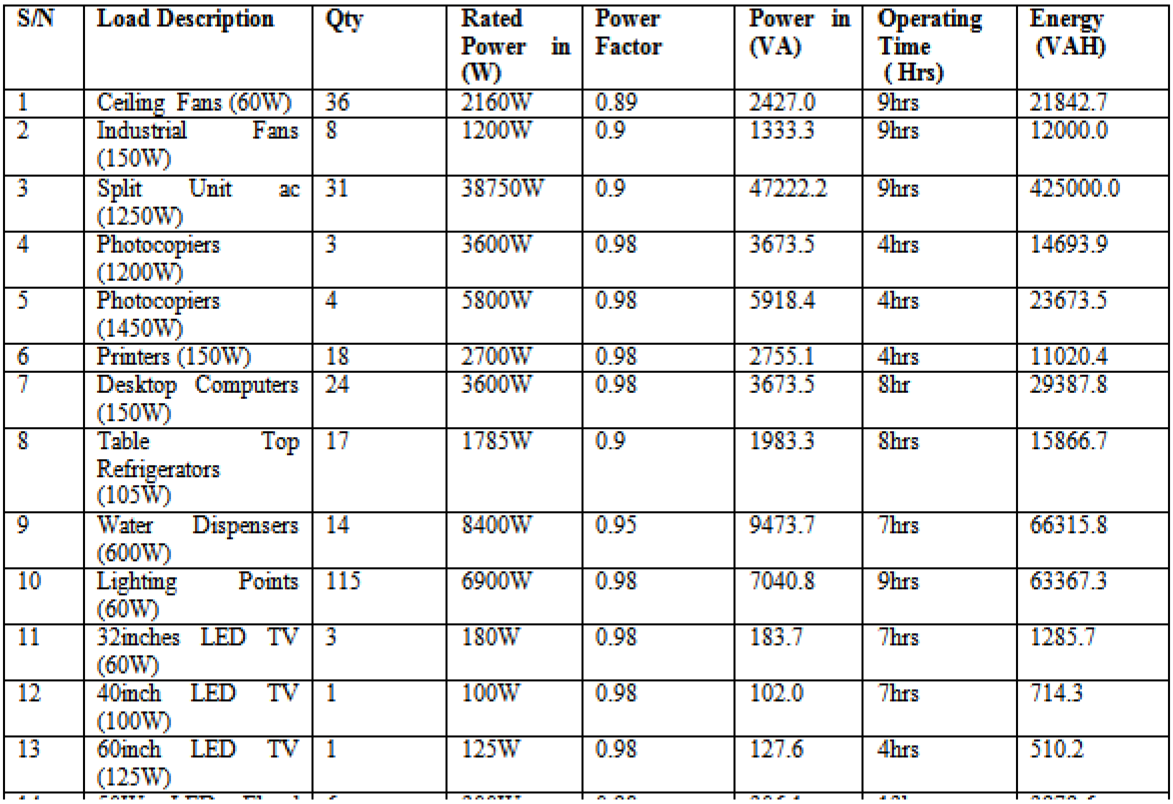
Hybrid microgrids are microgrids that have more than one form of input power sources integrated together to supply the microgrid [12]. Examples of hybrid microgrids are, hybrid solar-wind microgrid, hybrid solar-diesel micro-grid e.t.c. Hybrid microgrids are much more efficient than MGs that are based on one energy source. This high efficiency is achieved from the proper management of various energy sources to the MG. In such MGs, the percentage power outage is very minimal, and the stability of the entire microgrid is always very high.

III. METHODOLOGY

III.1 Electrical Load Estimation at the SPGS Sub-grid NAU Awka Campus

To ensure that a very reliable and cost effective model was developed, certain careful steps were taken to gather all the requirements for the development. First, there was a careful electrical load estimation of existing installed electrical loads at the SPGS sub-grids. These electrical loads were carefully studied to determine both their rated capacity and hours of daily operation. This study enabled the generation of the load profile for the sub-grid, with which accurate dimensioning of the various components required to setup the micro-grid was realized using the HOMER Grid software. These components include the PV modules, the battery Energy Storage System, the maximum power point tracking (MPPT) solar charge controllers, the dc cable connectors.

The existing electrical loads at the SPGS sub-grid and their hours of operation are presented in Tables 1. The table is made up eight columns which are; Serial Number (S/N), Load description, Quantity (Qty), Rated Power (W), Power Factor (PF), Power(VA), Operating time (Hrs) and Energy in (VAH). The Load description describes the electrical load being estimated, the Qty column gives the quantity of the loads, Rated power (W) refers to the power of the electrical load as indicated on its name plate, Power factor refers to the power factor of the electrical load as indicated on its name plate also. The Power (VA) refers to the apparent power which is given by the Rated power divided by the power factor. Time in Hours refers to the operating time of the electrical load being estimated while the Energy in VAH is given by the apparent power (VA) multiplied by the operating time.



S/N	Load Description	Qty	Rated Power in (W)	Power Factor	Power in (VA)	Operating Time (Hrs)	Energy (VAH)
1	Ceiling Fans (60W)	36	2160W	0.89	2427.0	9hrs	21842.7
2	Industrial Fans (150W)	8	1200W	0.9	1333.3	9hrs	12000.0
3	Split Unit ac (1250W)	31	38750W	0.9	47222.2	9hrs	425000.0
4	Photocopiers (1200W)	3	3600W	0.98	3673.5	4hrs	14693.9
5	Photocopiers (1450W)	4	5800W	0.98	5918.4	4hrs	23673.5
6	Printers (150W)	18	2700W	0.98	2755.1	4hrs	11020.4
7	Desktop Computers (150W)	24	3600W	0.98	3673.5	8hr	29387.8
8	Table Top Refrigerators (105W)	17	1785W	0.9	1983.3	8hrs	15866.7
9	Water Dispensers (600W)	14	8400W	0.95	9473.7	7hrs	66315.8
10	Lighting Points (60W)	115	6900W	0.98	7040.8	9hrs	63367.3
11	32inches LED TV (60W)	3	180W	0.98	183.7	7hrs	1285.7
12	40inch LED TV (100W)	1	100W	0.98	102.0	7hrs	714.3
13	60inch LED TV (125W)	1	125W	0.98	127.6	4hrs	510.2

14	50W LED Flood Lamp (Security lighting)	6	300W	0.98	306.1	13hrs	3979.6
15	Conference hall Public Address System (1000W)	1	1000W	0.98	1020.4	5hrs	5102.0
16	Giant Standing a.c (2600W)	2	5200W	0.9	5777.8	5hrs	28888.9
17	50W LED indoor light	19	950W	0.95	1000.0	5hrs	5000.0
18	Water pumps (0.75kW)	2	1500W	0.9	1666.7	4hrs	6666.7
Total			**84150W**		**100763.2 VA**		**780891.2 VAH**

Table 1 Electrical Load Estimation for the SPGS NAU Sub-grid

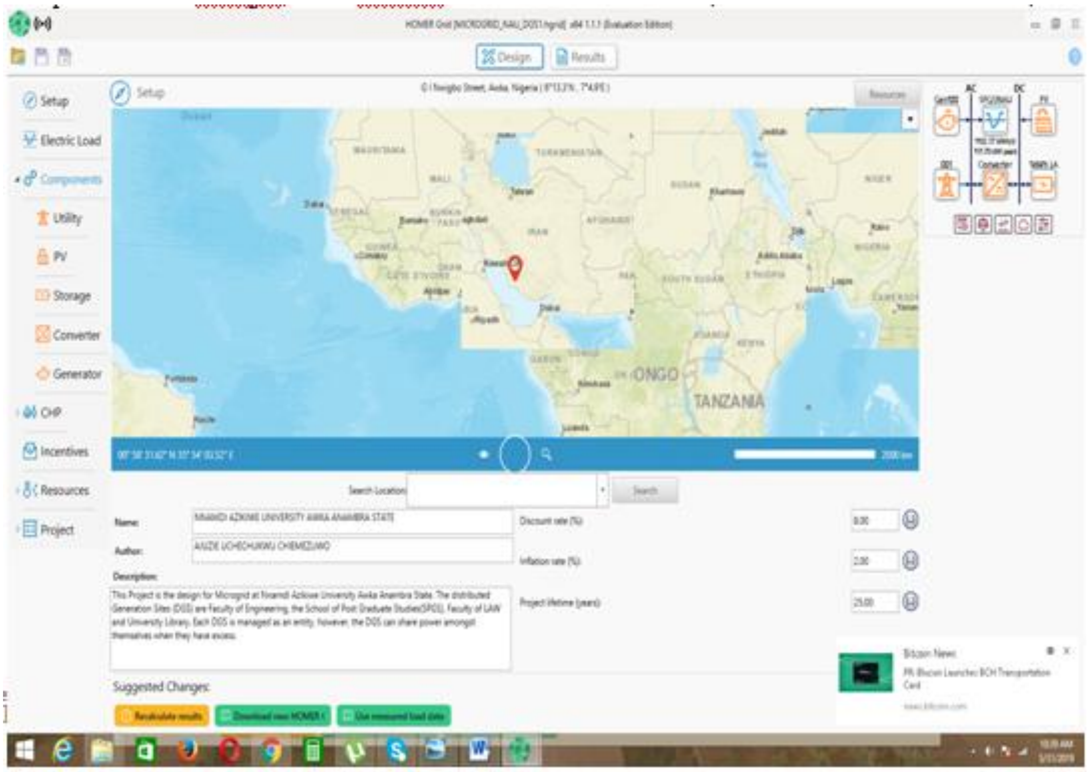
III.2 Modelling of the SPGS Sub-grid using HOMER Grid

III.2.1 Setup in HOMER Grid

The setup section is first part of HOMER Grid modelling and Simulation. Very important parameters of the Microgrid being modelled are setup at this stage, in order to generate accurate simulation results. These parameters include ;

- Microgrid Location (that is, the coordinates in the world map); here, the exact coordinated of the microgrid location can be inputted or the location can be selected from the world map. This is very important, because solar resources of the location will be downloaded and used for the simulations.
- Microgrid name; in this case NAU SPGS sub-grid
- Author's Name; the name of the microgrid model author
- Brief description of the microgrid being modelled.
- Some sensitivity constraints, like inflation rate and discount rate, both in percentage.
- Microgrid life time in years.

Figure 1 shows the setup page of the HOMER grid model and simulation for the SPGS sub-grid.



Name: NNAMDI AZIKIWE UNIVERSITY AWKA ANAMBRA STATE

Description: This Project is the design for Microgrid at Nnamdi Azikiwe University Awka Anambra State. The distributed Generation Sites (DGS) are Faculty of Engineering, the School of Post Graduate Studies(SPGS), Faculty of LAW and University Library. Each DGS is managed as an entity, however, the DGS can share power amongst themselves when they have excess.

Discount rate (%): 8.00

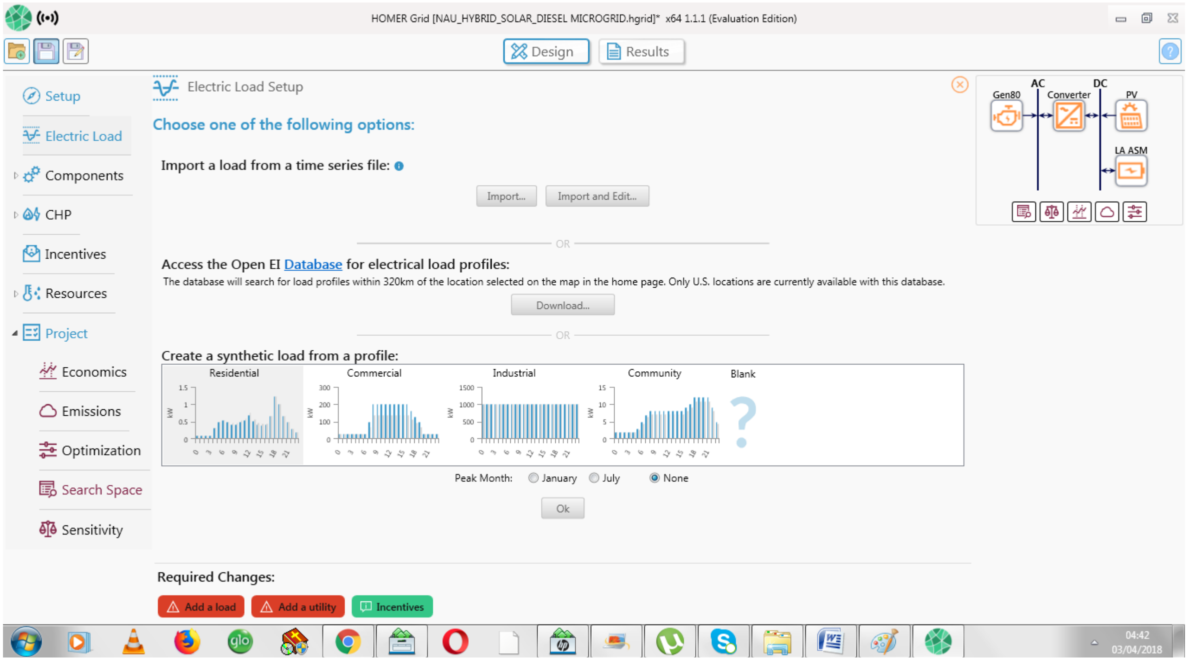
Inflation rate (%): 2.00

Project lifetime (years): 25.00

Figure 1: HOMER Grid setup for SPGS sub-grid

III.2.2 SPGS Sub-grid Load Profile

Immediately after setting up the parameters required at the setup, the software expects the characterization of the load profile of the microgrid to be modelled and simulated. To do that, the electric load icon is selected, four major load profile models namely residential, commercial, industrial and community load profile models are available for selection, in addition, custom load profile may also be import into HOMER GRID. From the study at the SPGS sub-grids, the best suited load profile model is the commercial load profile model. Figure 2 shows the load profile model selection for the SPGS sub-grid, while figure 3 shows the selected load profile.



Choose one of the following options:

Import a load from a time series file:

Access the Open EI Database for electrical load profiles:

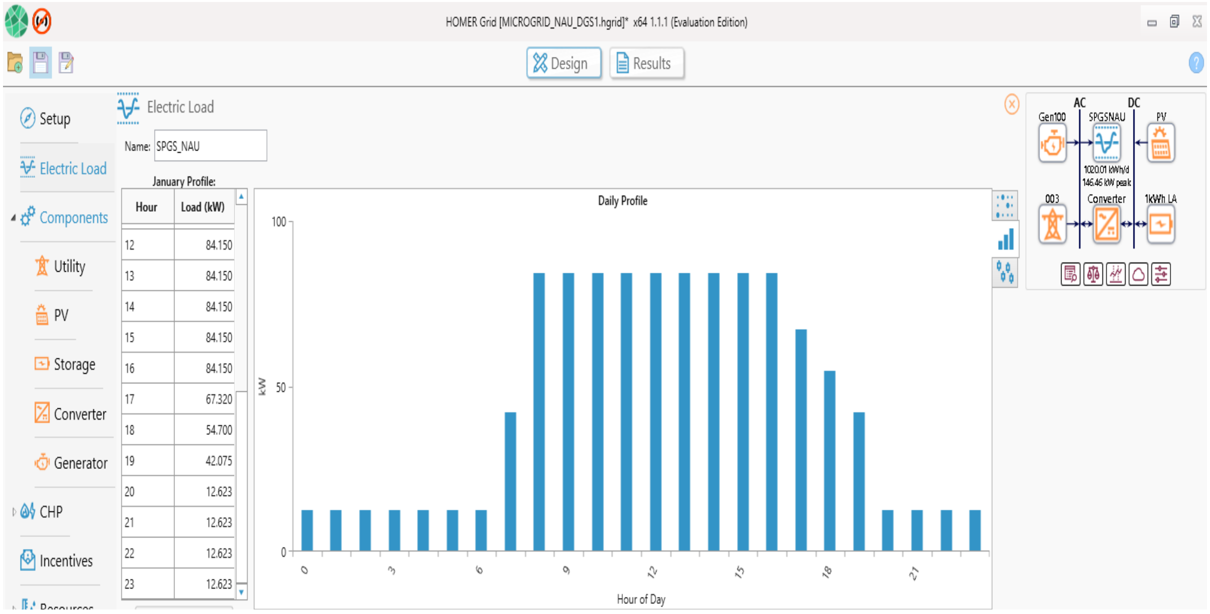
The database will search for load profiles within 320km of the location selected on the map in the home page. Only U.S. locations are currently available with this database.

Create a synthetic load from a profile:

Peak Month: ○ January ○ July ● None

Required Changes:

Figure 2: The Electric load profile selection



Name: SPGS_NAU

January Profile:

Hour	Load (kW)
12	84.150
13	84.150
14	84.150
15	84.150
16	84.150
17	67.320
18	54.700
19	42.075
20	12.623
21	12.623
22	12.623
23	12.623

Figure 3: Load profile for SPGS Sub-grid

Figure 3, shows the load profile screen shot for SPGS sub-grid NAU Awka campus, the graph above, clearly indicates that there is low consumption at the sub-grid between the hours of 12 midnight to 7.59am and from 6.30pm to 11.59pm. Table 2 shows the model of the HOMER grid 60 minutes step 24-hour Load Profile for Commercial Load profile category. This load profile was modified based on the result of the electrical load estimation at the sub-grid to get the custom load profile for the SPGS sub-grid as shown in tables 3

Table 2: HOMER grid 60 minutes step 24-hour load profile for Commercial Load profile Category using 200kW load Sample

Hours	**Week- Days Load Profile(kW)**	**Week -end Load Profile(kW)**
0	(15% x200)= 30.00	(15% x200)= 30.00
1	(15% x200)= 30.00	(15% x200)= 30.00
2	(15% x200)= 30.00	(15% x200)= 30.00
3	(15% x200)= 30.00	(15% x200)= 30.00
4	(15% x200)= 30.00	(15% x200)= 30.00
5	(15% x200)= 30.00	(15% x200)= 30.00
6	(15% x200)= 30.00	(15% x200)= 30.00
7	(50% x200)= 100.00	(70% x 50% x200)= 70.00
8	(100% x 200)=200.00	(70% x 100% x 200)=140.00
9	(100% x 200)=200.00	(70% x 100% x 200)=140.00
10	(100% x 200)=200.00	(70% x 100% x 200)=140.00
11	(100% x 200)=200.00	(70% x 100% x 200)=140.00
12	(100% x 200)=200.00	(70% x 100% x 200)=140.00
13	(100% x 200)=200.00	(70% x 100% x 200)=140.00
14	(100% x 200)=200.00	(70% x 100% x 200)=140.00
15	(100% x 200)=200.00	(70% x 100% x 200)=140.00
16	(100% x 200)=200.00	(70% x 100% x 200)=140.00
17	(80% x 200)= 160.00	(70% x 80% x 200)=112.00
18	(65% x 200)= 130.00	(70% x 65% x 200)=91.00
19	(50% x200)= 100.00	(70% x 50% x200)= 70.00
20	(15% x200)= 30.00	(15% x200)= 30.00
21	(15% x200)= 30.00	(15% x200)= 30.00
22	(15% x200)= 30.00	(15% x200)= 30.00
23	(15% x200)= 30.00	(15% x200)= 30.00

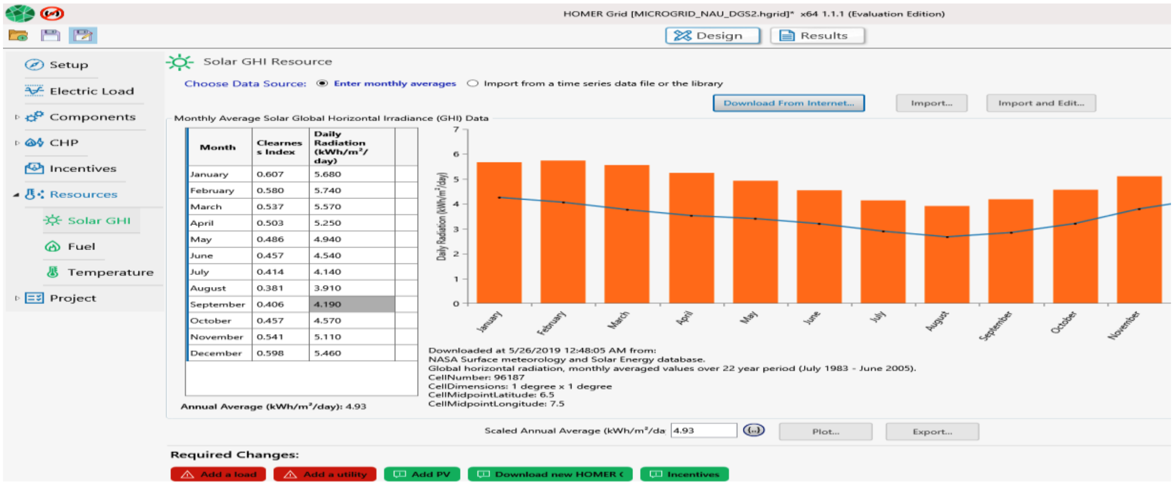
Table 3: Custom Daily Load profile modification for the SPGS sub-grid based on load estimation results for 6 months

Hrs	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**
0	12.623	12.623	12.623	12.623	12.623	12.623
1	12.623	12.623	12.623	12.623	12.623	12.623
2	12.623	12.623	12.623	12.623	12.623	12.623
3	12.623	12.623	12.623	12.623	12.623	12.623
4	12.623	12.623	12.623	12.623	12.623	12.623
5	12.623	12.623	12.623	12.623	12.623	12.623
6	12.623	12.623	12.623	12.623	12.623	12.623
7	42.075	42.075	42.075	42.075	42.075	42.075
8	84.15	84.15	84.15	84.15	84.15	84.15
9	84.15	84.15	84.15	84.15	84.15	84.15
10	84.15	84.15	84.15	84.15	84.15	84.15
11	84.15	84.15	84.15	84.15	84.15	84.15
12	84.15	84.15	84.15	84.15	84.15	84.15
13	84.15	84.15	84.15	84.15	84.15	84.15

14	84.15	84.15	84.15	84.15	84.15	84.15
15	84.15	84.15	84.15	84.15	84.15	84.15
16	84.15	84.15	84.15	84.15	84.15	84.15
17	67.32	67.32	67.32	67.32	67.32	67.32
18	54.7	54.7	54.7	54.7	54.7	54.7
19	42.075	42.075	42.075	42.075	42.075	42.075
20	12.623	12.623	12.623	12.623	12.623	12.623
21	12.623	12.623	12.623	12.623	12.623	12.623
22	12.623	12.623	12.623	12.623	12.623	12.623
23	12.623	12.623	12.623	12.623	12.623	12.623

III.2.3 Solar Global Horizontal Irradiance (GHI) Resources

The GHI resources was downloaded for the SPGS sub-grid location (7°56.9'N, 6°58.3'E) Awka. Figure 3 shows the 1 year GHI resources downloaded from NASA metrological database.



Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.607	5.680
February	0.580	5.740
March	0.537	5.570
April	0.503	5.250
May	0.486	4.940
June	0.457	4.540
July	0.414	4.140
August	0.381	3.910
September	0.406	4.190
October	0.457	4.570
November	0.541	5.110
December	0.598	5.460

Annual Average (kWh/m²/day): 4.93

Downloaded at 5/26/2019 12:48:05 AM from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 96187
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 6.5
CellMidpointLongitude: 7.5

Scaled Annual Average (kWh/m²/da 4.93

Figure 3: One year GHI resources downloaded from NASA database

To complete the microgrid modelling, utility grid was added, with the cost of energy/kWh, PV type was also selected (Flat PV modules of 300W each), type of battery energy storage system was also selected (Lead Acid (LA) 1kW was selected) and finally the diesel generator size set auto size option, thereby allowing HOMER grid to size it.

III.3 Simulation of the Modelled SPGS Sub-grid

After modelling all the parameters of the SPGS sub-grid, the model was simulated by clicking on the calculate result tab. Figure 4 presents the schematic representation the SPGS sub-grid model. The results would give the size of diesel generator if a fixed sized was not selected, the PV-module size in kW, the BESS stings, and the converter size. Screen shots of the simulation in progress and simulation results are shown in figures 5 and 6 respectively. HOMER Grid simulated more than 1000 possible combinations of the chosen energy sources and suggested the most optimized combination based on reduced Net Present Cost (NPC) and annual operating cost.

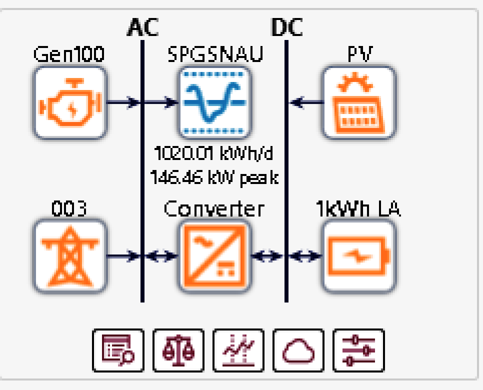
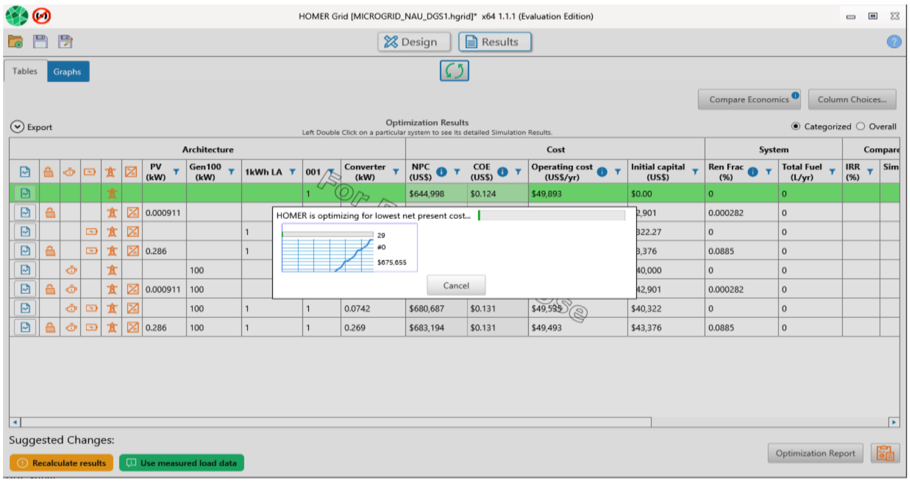


Figure 4: Schematic Representation of the SPGS sub-grid



Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

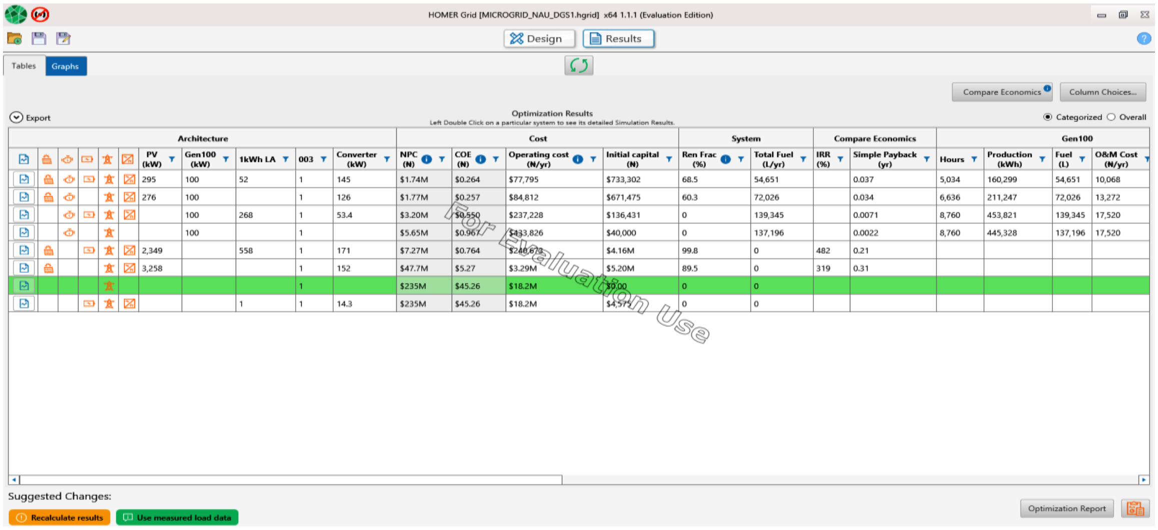
● Categorized ○ Overall

Architecture											Cost				System		Compare	
						PV (kW)	Gen100 (kW)	1kWh LA	001	Converter (kW)	NPC (US$)	COE (US$)	Operating cost (US$/yr)	Initial capital (US$)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Sim
●				●					1		$644,998	$0.124	$49,893	$0.00	0	0		
●	●			●	●	0.000911								2,901	0.000282	0		
●			●	●	●			1						322.27	0	0		
●	●		●	●	●	0.286		1						3,376	0.0885	0		
●		●		●			100							40,000	0	0		
●	●	●		●	●	0.000911	100							42,901	0.000282	0		
●		●	●	●	●		100	1	1	0.0742	$680,687	$0.131	$49,535	$40,322	0	0		
●	●	●	●	●	●	0.286	100	1	1	0.269	$683,194	$0.131	$49,493	$43,376	0.0885	0		

HOMER is optimizing for lowest net present cost...
29
#0
$675,655
Cancel

Suggested Changes:

Figure 5: Simulation in Progress



Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

● Categorized ○ Overall

Architecture											Cost				System		Compare Economics		Gen100			
						PV (kW)	Gen100 (kW)	1kWh LA	003	Converter (kW)	NPC (₦)	COE (₦)	Operating cost (₦/yr)	Initial capital (₦)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost (₦/yr)
●	●	●	●	●	●	295	100	52	1	145	$1.74M	$0.264	$77,795	$733,302	68.5	54,651		0.037	5,034	160,299	54,651	10,068
●	●	●		●	●	276	100		1	126	$1.77M	$0.257	$84,812	$671,475	60.3	72,026		0.034	6,636	211,247	72,026	13,272
●		●	●	●	●		100	268	1	53.4	$3.20M	$0.550	$237,228	$136,431	0	139,345		0.0071	8,760	453,821	139,345	17,520
●		●		●			100		1		$5.65M	$0.967	$433,826	$40,000	0	137,196		0.0022	8,760	445,328	137,196	17,520
●	●		●	●	●	2,349		558	1	171	$7.27M	$0.764	$240,673	$4.16M	99.8	0	482	0.21				
●	●			●	●	3,258			1	152	$47.7M	$5.27	$3.29M	$5.20M	89.5	0	319	0.31				
●				●					1		$235M	$45.26	$18.2M	$0.00	0	0						
●			●	●	●			1	1	14.3	$235M	$45.26	$18.2M	$4,575	0	0						

Suggested Changes:

Figure 6: SPGS Sub-grid simulation results

IV. RESULTS

From the results of HOMER Grid simulations, the most optimized option that best fits the sub-grid was selected and table 5 gives a summary of the simulation result.

Table 5: Component Requirements for SPGS Sub-grid Obtained from Simulation

Component	Name	Size	Unit
Generator	`Generic Medium Gen. Set (Size your own)	100	kW
PV	Generic Flat PV	295	kW
Storage	Generic 1kWh Lead Acid	52	String
System Converter	System Converter	145	kW
Dispatch Strategy	Homer Peak Saving		
Utility	Commercial		

IV.1 Dimensioning Analysis Based on Homer Grid Simulation Results for SPGS Sub-grid

The converter dc input voltage will determine the arrangement of the battery banks. Assuming the dc voltage input of the converter is 240 V dc, the arrangement of the BESS is achieved as follows

$$Converter\ input\ Voltage(V_{CONV}) = 240V$$

$$B_S = V_{CONV} \div V_B \quad (1)$$

Where V_B = Voltage of a single lead acid battery = 12 V dc and B_S = the number of batteries in series.

B_S = 240V ÷ 12 V = 20 batteries in series.

This implies that each battery bank will have 20 batteries connected in series.

$$B_T = B_S \times B_P \quad (2)$$

Where B_T is the total number of batteries that make up the BESS, B_S is the number of batteries connected in Series and B_P is the number of series banks batteries connected in parallel.

Therefore, the number of series bank to be connected in parallel (B_P) is given as

$$B_P = B_T \div B_S$$

Likewise, for the PV module arrangement, the series bank arrangement of the PV modules required to charge the 20 batteries in series is 10, since each PV module should charge 24V, that is, two batteries in series.

Therefore, the number of parallel bank of PV-module is given by (3)

$$PV_P = PV_T \div PV_S \quad (3)$$

Where PV_P is the number of series bank connected in Parallel, PV_T is total number of PV modules as provided by HOMER grid software and PV_S is the number PV modules connected in series

Also for the required solar charge controllers

The short circuit current on one solar PV module of rating, 300W, 36V can be deduced from (4)

$$P_U = V_U \times I_U \quad (4)$$

Where P_U is the power of a unit PV module, V_U is the voltage on a unit PV module and I_U is the short circuit current on a unit PV module

$$I_U = P_U \div V_U = 300W \div 36 = 8.33A$$

For the ten (10) PV modules connected in series, the same current flows through them.

Therefore the cumulative PV module current I_{PV} for each sub-grid can be calculated by multiplying I_U by the number of PV parallel bank (PV_P)

Thus

$$I_{PV} = I_U \times PV_P \quad (5)$$

In addition, the cumulative current of all the charge controllers (I_{SCC}) is given by

$$I_{SCC} = 1.2 \times I_{PV} \quad (6)$$

Also, the number of charge controllers required for the parallel banks (N_{SCCP}) is given by

$$N_{SCCP} = I_{SCC} \div I_{SU} \quad (7)$$

Where I_{SU} is the unit current rating of the charge controller

I_{SCC} is the total current of all the solar charge controllers

N_{SCC} is the number of solar charge controllers required for the parallel banks

However, solar charge controllers also has maximum voltage rating which determines how many will be connected in series. Assuming the voltage rating of a charge controller is V_{SCC}, then the number solar charge controllers, connected in series will be give by (8)

$$N_{SCCS} = V_{CONV} \div V_{SCC} \quad (8)$$

Where N_{SCCS} is the number of solar charge controllers connected in series.

V_{CONV} is the converter input voltage which is also the cumulative voltage of the batteries in series (B_S)

Therefore, the total number of charge controllers required is given by (9)

$$N_{SCCT} = N_{SCCS} \times N_{SCCP} \quad (9)$$

In addition, the importance of calculating the accurate size of conductor to be used for interconnection between the PV modules and BESS cannot be overemphasized. This is because the size of cables used for connection between the PV modules and the battery banks can introduce a huge amount of energy losses if it is not properly calculated, bearing in mind that DC voltage is being transported at this stage. The standard practice is to try and keep the cable length as short as possible.

The cable size for the interconnection of the BESS to the PV modules at sub-grids was calculated as follows;
Using Ohm's Law

$$R = {}^{V}/_{I} \tag{10}$$

Also, $$R = \rho \frac{L}{A} \tag{11}$$

Where L is the length of cable, A is the cross sectional area, R is the resistance of the cable and ρ is the resistivity of the cable.
Substituting (12) into (13) gives

$${}^{V}/_{I} = \rho \frac{L}{A} \tag{12}$$

But $$\rho = {}^{1}/_{\delta} \tag{13}$$

Where δ is the conductivity of the cable.
Therefore, equation (12) becomes

$V/I = \frac{1}{\delta} \text{ x } \frac{L}{A} = \frac{L}{Ax\ \delta}$

Therefore $$A = \frac{LI}{V\delta} \tag{14}$$

L is the length of both the positive and negative wires,
Therefore

$$L = 2l \tag{15}$$

Where l is the distance between the PV modules and the BESS.
Substituting (15) into (14)

$$A = \frac{2l\ x\ I}{V\ x\ \delta} \tag{16}$$

V is the allowable voltage drop for efficient connection and loss minimization which is usually expressed as a percentage of the system voltage, which is the converter voltage. (Note $V_S = V_{CONV}$)

$$V = X\%\ of\ V_{CONV} \tag{17}$$

Therefore
The cross sectional area of the wire A is given as

$$A = {}^{(2l \ \times I)}\Big/_{\left(\frac{X}{100}\right) \times V_{CONV} \ \times \delta} \tag{18}$$

or $$A = {}^{(200 \times l \times I)}\Big/_{(X \times V_{CONV} \ \times \delta)} \tag{19}$$

IV.1.1 Required Components for the SPGS sub-grid

From Table 5 HOMER grid specified 295kW solar PV module bank for the SPGS sub-grid. Using Solar PV modules rated at 300W, 36V each, the required number of modules is given by
295000W ÷ 300W = 983.33 ≈ 984 pieces
The required BESS is 52 pieces of 200AH, 12V lead-acid batteries
While the required converter is 145kW
Assuming the dc voltage input of the converter is 240 V dc, this implies that 20 batteries must be connected in series as converter dc input voltage.
B_S = 20 batteries
B_T = 52 batteries
From (2), $B_T = B_S \times B_P$
B_P = 52 ÷ 20 = 2.6 ≈ 3 parallel banks.
Total number of batteries required (B_T) is now = 20 x 3 = 60 batteries, instead of 52 batteries. This little adjustment is important to balance the battery bank.

PV module arrangement,
For SPGS sub-grid,
PV_T = 984 PV modules, PV_S = 10 PV modules
PV_P = 948 ÷ 10 = 94.8 ≈ 95 parallel banks
Therefore
PV_T is now adjusted to 95 x 10 = 950 pieces of 300W, 36V PV modules

Number of Solar, Charge Controllers (SCC)
PV_P = 95 parallel banks
I_U = 8.33A

From (5),
I_{PV} = 95 x 8.33 = 791.35A
But from (6)
I_{SCC} = 1.2 x 791.35 A = 949.62A
Also from (7) using an MPPT 60A, 48V solar charge controller,
N_{SCCP} = 949.62A ÷ 60 =15.827 ≈ 16 parallel solar charge controller
From (8) , N_{SCCS} was calculated as shown
N_{SCCS} = 240 ÷ 48 = 5 solar charge controller connected in series.
(9) gives the total number of required solar charge controllers (N_{SCCT})
N_{SCCT} = 5 x 16 = 80 pieces of 60A, 48V Maximum Power Point Tracking (MPPT) solar charge controller.

Cable Sizing
Assuming 10meters cable length between the PV modules and the BESS
Using (19), the cross sectional area of the required cable A is given by

$$A = {(200 \times l \times I)} \Big/ {(X \times V_{CONV} \times \delta)}$$

l =10m, I = I_{PV} =791.35A, X = 5, δ = 56(for copper), Vs=V_{CONV} =240V

$$A = {(200 \times 10 \times 791.35)} \Big/ {(5 \times 56 \times 240)} = 23.552 \approx 24 \text{ mm}^2$$

A= 23.552mm^2 ≈ 24mm^2
However, 25mm^2 is readily available in the market.

Table 6 presents a the summary of Components dimensioned for SPGS sub-grid

SPGS Sub-grid	Batteries (200AH , 12 V)			PV Modules 300W/36V			Converter and Charge Controllers		Cable Size
	Parallel Banks (B_P)	Series Banks (B_S)	Total (B_T)	Parallel Banks (PV_P)	Serial Banks (PV_S)	Total (PV_T)	Converter (kW)	Solar Charge Controller	mm^2
SPGS	3	20	60	95	10	950	145	80	25

V. DISCUSSION

From the study done at the SPGS sub-grid, the maximum estimated cumulative wattage of all the installed electrical loads in kW is 84.15kW, this is maximum power demand from the sub-grid, applying the HOMER grid commercial load profile format shown in table 2, table 3 was generated. This the hour to hour load profile at the SPGS sub-grid, which depicts the power consumption pattern of the sub-grid. In addition, from the HOMER grid Simulation results, the components required to deploy the Campus solar-diesel hybrid microgrid (CSDHMG) at the SPGS NAU Awka, campus are as estimated above.

VI. CONCLUSION

Using HOMER grid modelling and simulation tool, the optimal component needed for the deployment of a Campus Solar Diesel Hybrid Microgrid was estimated, ready for deployment. HOMER Grid also estimated the Net Present Cost (NPC) of deployment of the microgrid to be $1,738,994, and the levelized Cost of Energy (COE) to $0.264.

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