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Enhancing Performance Operation of 2 MW Solar Hybrid Distributed Generation on 11kV Nnamdi Azikiwe University Distribution Network

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ABSTRACT
Providing safe operation of electric power distribution network is paramount to quality electricity delivering to its consumers. Nnamdi Azikiwe university through the initiative of the federal government set up a 2 MW solar hybrid distributed generation (DG) system to feed electricity into the single line university 11 kV distribution network. However, the operation of this solar hybrid DG has been marred with incessant trips most times while been in operation. In a bid to eliminate these trips, this paper presents a study case simulations with Electrical Transient Application Program (ETAP) 19.0 software on the 11 kV distribution network in order to enhance performance operation of the solar hybrid DG. The single line 11 kV distribution network was split into three sections networks for simulations on three different load values 1, 2 and 3 of 1.6, 1.8 and 2.0 MW respectively. For load value 1 of 1.6 MW, simulations performed indicated that single line network had 16 buses on marginal undervoltage while three sections network had no bus undervoltage. For load value 2 of 1.8 MW, single line network had also 16 buses on marginal undervoltage while three sections network had no bus undervoltage. For load value 3, single line network had 20 buses on marginal undervoltage while three sections network had 2 buses undervoltage. At load value 3, it is right to say that the solar hybrid DG should not be operated at this supply as trips will set in due to the marginal undervoltage experienced also with three sections network. The results of the simulation with ETAP 19.0 software verified that three sections networks should be adopted and implemented since it outperformed that of single line network.

Keywords: Enhancement operation, Solar hybrid, Distributed generation, Distribution network, ETAP

I. INTRODUCTION

Nigeria's electricity sector is charged with responsibilities to generate, transmit and distribute electric power in megawatts (MW) to meet basic household and industrial needs [1].Conventional power plants are designed on a large scale, centralized and built far from load center thereby requiring transmission and distribution networks[2]. Nigeria transmission and distribution systemsare technically weak, making it more sensitive to major disturbances such as inadequate equipment infrastructure, line vandalization, poor voltage stability profiles, overloading of transformers, poor staff capacity and development [3]. High voltage transmission on the grid is safely operated if analyzed with power flow computation, estimation of its technological state conducted and as well as simulations on further grid process and procedures. The solar PV power inverters usually present a wide grid integration benefit which traditional distribution networks failed to cover [4]. Smart grid electricity concepts include; power systems integration, information and communication technology that provides end user interaction [5].Renewable energy sources (RES) now contribute good percentage of the required electric power against only 5% about 20 years ago in countries such as Germany where PV systems and other RES systems are contributing immensely in a way to replace conventional bulk power plants [6].The technology of distributed generation is to incorporate energy systems (mostly renewable energy systems) to distribution systems that are close to the consumer load [7]. While Integrating DG systems into a distribution network, it's important to observe the network performance by simulations [8].

One major goal of this paper is to evaluate performance of solar hybrid DG integrated into 11 kV distribution network of Nnamdi Azikiwe university then, implement and verify its improvement operation by simulating on Electrical Transient Application Program (ETAP) 19.0 software; a comprehensive analysis program software for design and testing power systems. Studying this system by simulation enables us to carefully observe its performance and thereby improve on its performance.

II. RESEARCH METHOD

This paper focuses on improving performance of solar hybrid DG integrated into 11 kV distribution network of Nnamdi Azikiwe university. To improve operation of the solar hybrid DG, the 11 kV distribution network is a single line which do not encourage sectioning power supply. This means that it's a one-way power supply from the solar hybrid plant to the distribution network. In improving performance, the single line distribution network is split into three sections for electricity distribution. Simulations using ETAP 19.0 software are conducted as analysis on bus voltages, power generation capacity and losses in comparison between the three sections and single line distribution networks.

The study flowchart model is presented in figure 2.1

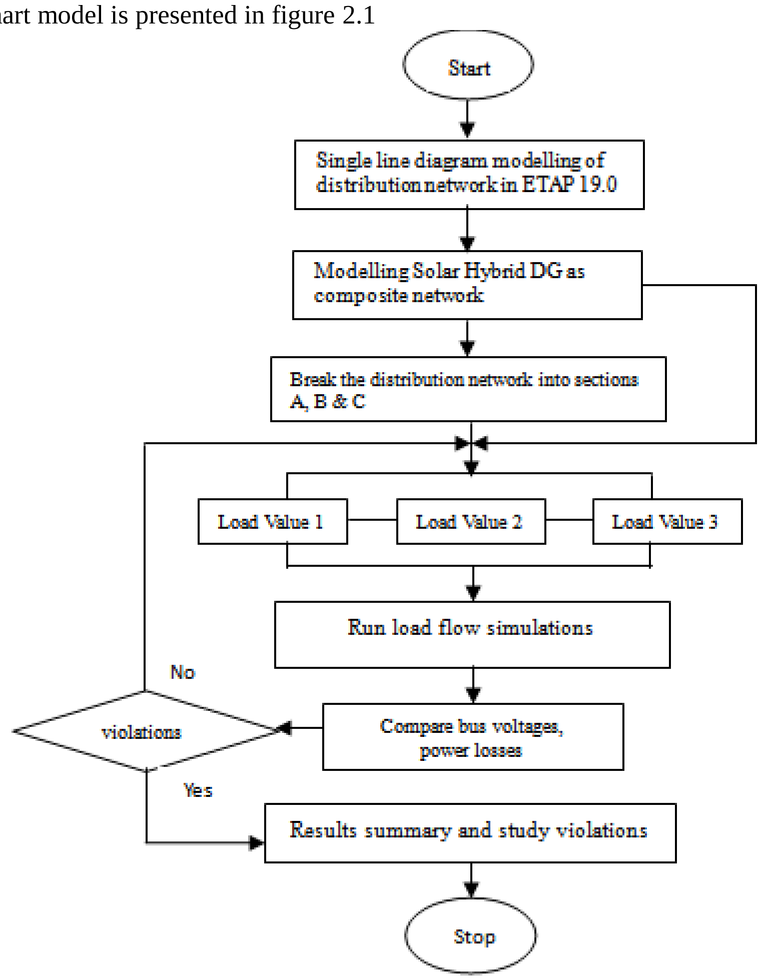

Figure 2.1: Research method flowchart

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The distribution network is supplied from Agu-Awka injection sub-station where a 15 MVA transformer stepped down available 33 kV to 11 kV for distribution (Nworabude et al, 2023). This 11 kV distribution line upon entering the university premises was terminated at the gate for switching between the utility grid and the solar hybrid DG. Also at this termination point is a metering circuit installed for energy billing by the utility company – Enugu Electricity Distribution Company (EEDC). The utility grid has been the only source of electricity before the installation of the solar hybrid DG in the university campus. Figure 2.2 represents the university distribution network as drawn in ETAP 19.0 software.

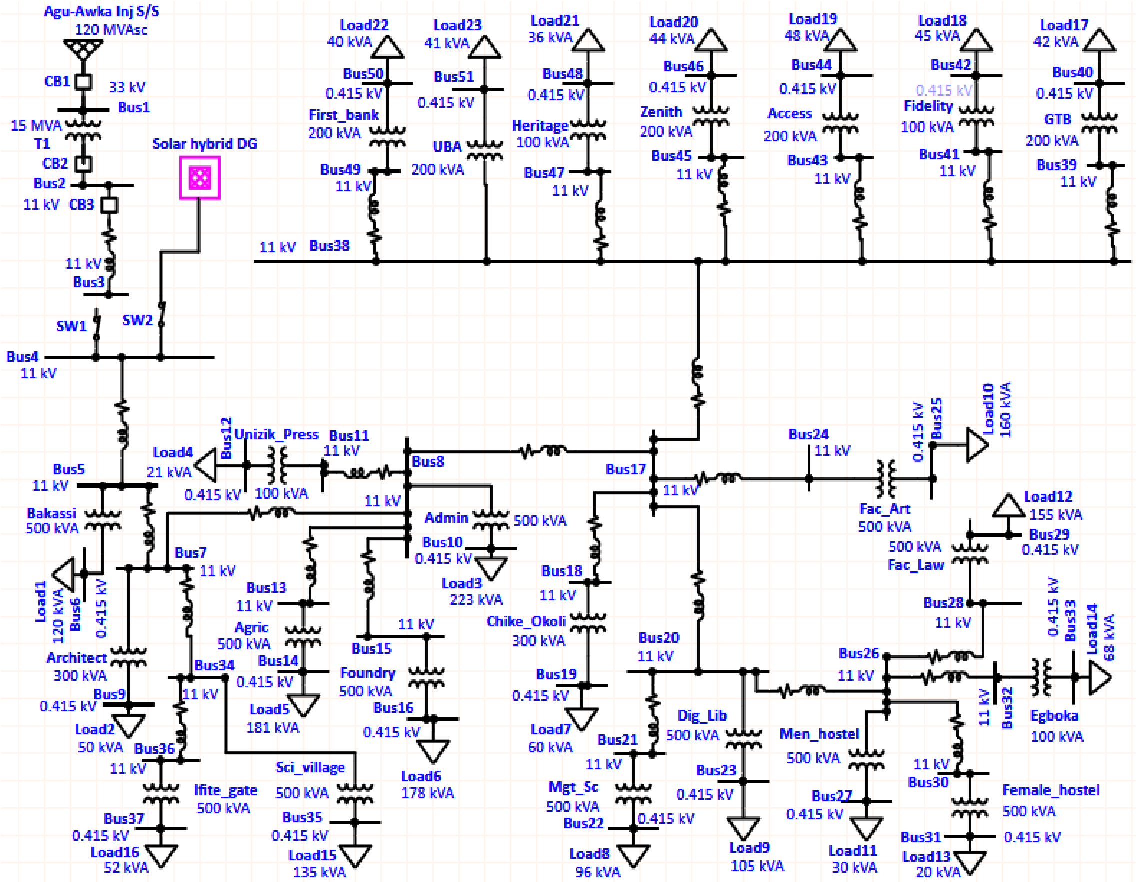

Figure 2.2: Single line Nnamdi Azikiwe University Network in ETAP software

Having presented the utility grid network, a solar hybrid DG installed within the university premises is presented. The hybrid DG consists of the following [8]:

- 2 twin solar modules array comprising 3840 solar panels rating 325 W each
- 1440 deep cycle batteries housed in 4 battery containers
- 2 twin converters, each connected to 2 battery containers
- 4 diesel generators with capacity of 2 at 595 kW each and another 2 at 340 kW each
- 7 transformers in total, 6 step-up and 1 step-down

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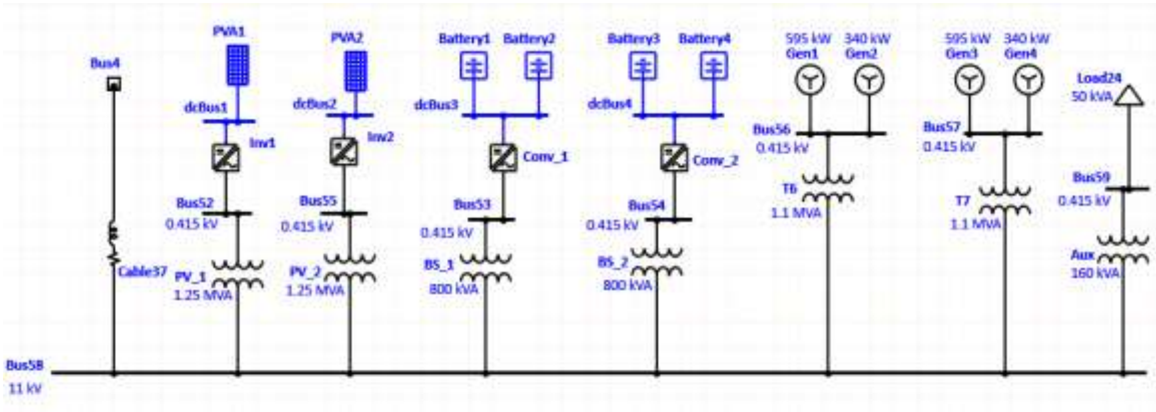

Figure 2.3: Solar Hybrid DG circuitry

The solar hybrid DG circuitry is connected to the university distribution network from bus 4using armoured cable labelled cable 37 as shown in figure 2.3. At bus 4 in figure 2.2 is aring main unit (RMU) for switching electricity supply from utility grid and solar hybrid DG. Switch 1 and 2 represent switches for utility grid and solar hybrid DG respectively.

Table 2.1: Distribution Load Network Data

S/N	**Name of Substation**	**Transformer Rating (kVA)**	**Conductor Route Length (km)**	**Load values (KVA)**		
				1	**2**	**3**
1	Bakassi	500	0.5	98	101	120
2	Architect building	300	0.2	35	38	50
3	Admin block	500	1.1	175	188	223
4	Unizik press	100	0.85	21	21	21
5	Science village	500	1.7	121	130	135
6	Ifite gate	500	2.25	52	52	52
7	Agric	500	0.2	142	160	181
8	Foundry (Engineering)	500	0.7	140	165	178
9	Chike Okoli	300	0.45	45	58	60
10	Faculty of Art	500	0.4	102	118	160
11	Digital library	500	0.5	60	95	105
12	Men hostel	500	0.1	26	30	30
13	Management Science	500	0.3	96	96	96
14	Faculty of Law	500	0.4	101	120	155
15	Egboka	100	1.05	20	62	68
16	Female hostel (Emelda)	500	1.35	20	20	20
17	GTB	200	0.5	42	42	42
18	Fidelity bank	100	0.45	45	45	45
19	Access bank	200	0.45	48	48	48
20	Heritage bank	100	0.4	36	36	36
21	UBA	200	0.35	41	41	41
22	First bank	200	0.45	40	40	40
23	Zenith bank	200	0.5	44	44	44
24	Auxiliary	160	-	50	50	50
	Total	8160		**1600**	**1800**	**2000**

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Table 2.1 presents parameters of the university distribution network showcasing transformer ratings, connecting conductor route length and different load values 1, 2 and 3 for 1.6 MW, 1.8 MW and 2.0 MW respectively. The table presents these parameters as inputted into ETAP software for the purpose of simulating the distribution network under the different load values as presented. The university distribution network modelled in figure 2.2 is simulated with power supply from the solar hybrid DG on three different load values 1, 2 and 3. These simulations depict the current scenario of operation of the distribution system where power is supplied from the solar hybrid DG which most times is marred with trips. The trips experienced necessitate further study in order to identify its cause and to proffer remedy to it.

In a way to identify the cause of trips, this study redesigned the distribution network of figure 2.2 into figure 2.4 breaking the network into three sections labelled A, B and C. the purpose of breaking the network into sections is to reduce losses experienced via a single line connection thereby eliminating trips experienced during operation of the solar hybrid DG.

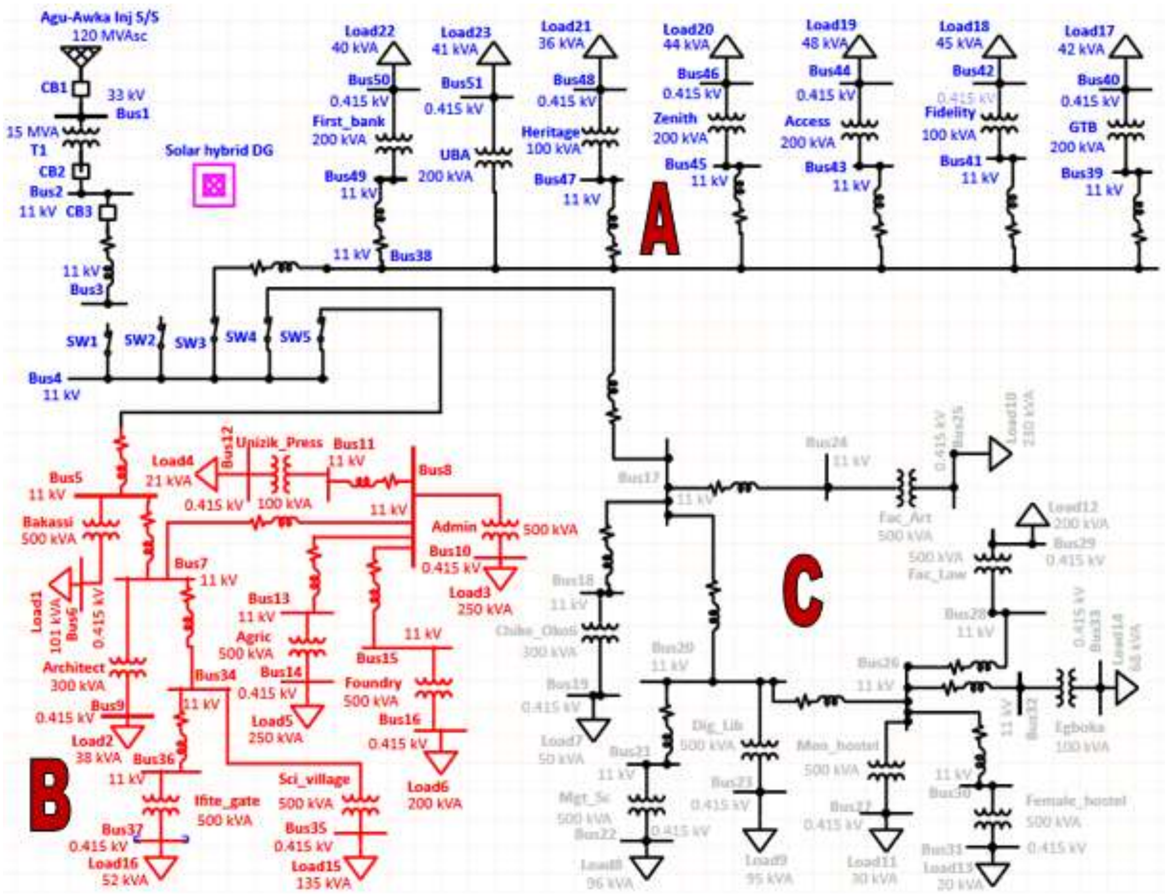

Figure 2.4: Nnamdi Azikiwe University Network in three sections A, B and C

The distribution network in sections separated to tap from the connection point of bus 4 with switches SW3, SW4 and SW5 for section A, B and C respectively. At bus 4 which is the point of connection of the solar hybrid DG supply, three switches (SW3, SW4 and SW5) were created with each covering a part of the single line network. The network now in sections is simulated with load values 1, 2 and 3 of table 2.1 to its compare results with that of when the network is on a single line. These simulations should depict the enhance performance operation of the distribution system where power supplied from the solar hybrid DG is safe from trips.

III. RESULTS AND DISCUSSIONS

Based on simulations performed on the distribution network both for single line and three sections, the bus voltage drops are presented. These simulations results conducted for load value 1 are presented thus:

Table 3.1: Load value 1 - Bus voltages for single line vs three sections distribution network

Bus ID	Nominal kV	Voltage (single line)	Voltage (three sections)
Bus1	33	33	33
Bus2	11	11	11
Bus3	11	11	11
Bus4	11	10.916	10.917
Bus5	11	10.887	10.902
Bus6	0.415	0.41	0.41
Bus7	11	10.876	10.897
Bus8	11	10.825	10.877
Bus9	0.415	0.41	0.411
Bus10	0.415	0.407	0.409
Bus11	11	10.824	10.877
Bus12	0.415	0.408	0.41
Bus13	11	10.824	10.876
Bus14	0.415	0.407	0.409
Bus15	11	10.821	10.874
Bus16	0.415	0.407	0.409
Bus17	11	10.764	10.848
Bus18	11	10.764	10.848
Bus19	0.415	0.403	0.406
Bus20	11	10.758	10.842
Bus21	11	10.757	10.841
Bus22	0.415	0.405	0.408
Bus23	0.415	0.404	0.407
Bus24	11	10.763	10.846
Bus25	0.415	0.405	0.408
Bus26	11	10.758	10.841
Bus27	0.415	0.406	0.409
Bus28	11	10.756	10.84
Bus29	0.415	0.405	0.408
Bus30	11	10.757	10.84
Bus31	0.415	0.406	0.409
Bus32	11	10.757	10.841
Bus33	0.415	0.405	0.408
Bus34	11	10.866	10.887
Bus35	0.415	0.409	0.41
Bus36	11	10.864	10.885
Bus37	0.415	0.409	0.41
Bus38	11	10.761	10.905
Bus39	11	10.761	10.905
Bus40	0.415	0.405	0.411
Bus41	11	10.761	10.905
Bus42	0.415	0.404	0.409
Bus43	11	10.761	10.905
Bus44	0.415	0.405	0.41

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Bus45	11	10.761	10.905
Bus46	0.415	0.405	0.41
Bus47	11	10.761	10.905
Bus48	0.415	0.404	0.41
Bus49	11	10.761	10.905
Bus50	0.415	0.405	0.411
Bus51	0.415	0.405	0.411
Bus52	0.415	0.415	0.415
Bus53	0.415	0.414	0.414
Bus54	0.415	0.414	0.414
Bus55	0.415	0.415	0.415
Bus56	0.415	0.415	0.415
Bus57	0.415	0.415	0.415
Bus58	11	10.965	10.967
Bus59	0.415	0.412	0.412

Table 3.1 shows bus voltages for the distribution network when simulated as single line and three sections network. The bus voltage shown with colour tag indicates buses within marginal undervoltage of less than 98 % of the nominal kV. Critical undervoltage level was set at less than 95 %. Single line network had over 30 marginal undervoltage buses while that of three sections had just 1marginal undervoltage bus for both the 11 kV and 0.415 kV buses. This 1 undervoltage bus in the three sections is not considered a threat since it was on the 0.415 kV bus which is not the voltage supplied by the solar hybrid DG.

Concentrating only on 11 kV buses, single line network had 16 buses on marginal undervoltage while three sections network had no bus undervoltage.

Table 3.2: Load value 2 - Bus voltages for single line vs three sections distribution network

Bus ID	Nominal kV	Voltage (single line)	Voltage (three sections)
Bus1	33	33	33
Bus2	11	11	11
Bus3	11	11	11
Bus4	11	10.904	10.905
Bus5	11	10.871	10.889
Bus6	0.415	0.409	0.41
Bus7	11	10.859	10.884
Bus8	11	10.8	10.862
Bus9	0.415	0.409	0.41
Bus10	0.415	0.406	0.408
Bus11	11	10.8	10.861
Bus12	0.415	0.407	0.41
Bus13	11	10.799	10.86
Bus14	0.415	0.406	0.408
Bus15	11	10.796	10.857
Bus16	0.415	0.406	0.408
Bus17	11	10.729	10.817
Bus18	11	10.729	10.817
Bus19	0.415	0.401	0.404
Bus20	11	10.721	10.809
Bus21	11	10.72	10.808

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Bus22	0.415	0.404	0.407
Bus23	0.415	0.401	0.404
Bus24	11	10.728	10.815
Bus25	0.415	0.404	0.407
Bus26	11	10.721	10.808
Bus27	0.415	0.404	0.408
Bus28	11	10.719	10.807
Bus29	0.415	0.403	0.407
Bus30	11	10.72	10.807
Bus31	0.415	0.404	0.408
Bus32	11	10.718	10.806
Bus33	0.415	0.401	0.405
Bus34	11	10.848	10.873
Bus35	0.415	0.408	0.409
Bus36	11	10.846	10.871
Bus37	0.415	0.409	0.41
Bus38	11	10.727	10.894
Bus39	11	10.726	10.893
Bus40	0.415	0.404	0.41
Bus41	11	10.726	10.893
Bus42	0.415	0.402	0.409
Bus43	11	10.726	10.894
Bus44	0.415	0.404	0.41
Bus45	11	10.726	10.894
Bus46	0.415	0.404	0.41
Bus47	11	10.726	10.893
Bus48	0.415	0.403	0.409
Bus49	11	10.726	10.893
Bus50	0.415	0.404	0.41
Bus51	0.415	0.404	0.41
Bus52	0.415	0.415	0.415
Bus53	0.415	0.413	0.414
Bus54	0.415	0.413	0.414
Bus55	0.415	0.415	0.415
Bus56	0.415	0.415	0.415
Bus57	0.415	0.415	0.415
Bus58	11	10.96	10.961
Bus59	0.415	0.412	0.412

Table 3.2 shows bus voltages similar to that of table 3.1 but have more buses affected within marginal undervoltage range. Single line distribution network had 34 buses with undervoltage while three section networks had 4 buses affected. It is important to also note that all marginal undervoltage experienced with three sections network are all at the low voltage 0.415 kV which will not cause any serious threat to the operation of the solar hybrid DG since it is not its nominal voltage of operation.

Concentrating only on 11 kV buses which should pose threat to the operation of the solar hybrid DG, single line network had also 16 buses on marginal undervoltage while three sections network had no bus undervoltage.

Table 3.3: Load value 3 - Bus voltages for single line vs three sections distribution network

Bus ID	Nominal kV	Voltage (single line)	Voltage (three sections)
Bus1	33	33	33
Bus2	11	11	11
Bus3	11	11	11
Bus4	11	10.892	10.893
Bus5	11	10.856	10.875
Bus6	0.415	0.409	0.409
Bus7	11	10.842	10.869
Bus8	11	10.777	10.844
Bus9	0.415	0.408	0.409
Bus10	0.415	0.405	0.407
Bus11	11	10.776	10.844
Bus12	0.415	0.406	0.409
Bus13	11	10.775	10.843
Bus14	0.415	0.405	0.408
Bus15	11	10.772	10.84
Bus16	0.415	0.405	0.407
Bus17	11	10.698	10.791
Bus18	11	10.698	10.791
Bus19	0.415	0.4	0.403
Bus20	11	10.689	10.782
Bus21	11	10.688	10.781
Bus22	0.415	0.402	0.406
Bus23	0.415	0.399	0.403
Bus24	11	10.696	10.789
Bus25	0.415	0.402	0.406
Bus26	11	10.688	10.781
Bus27	0.415	0.403	0.407
Bus28	11	10.686	10.779
Bus29	0.415	0.402	0.405
Bus30	11	10.687	10.78
Bus31	0.415	0.403	0.407
Bus32	11	10.686	10.779
Bus33	0.415	0.4	0.403
Bus34	11	10.831	10.858
Bus35	0.415	0.407	0.409
Bus36	11	10.829	10.856
Bus37	0.415	0.408	0.409
Bus38	11	10.695	10.882
Bus39	11	10.695	10.882
Bus40	0.415	0.403	0.41
Bus41	11	10.695	10.882
Bus42	0.415	0.401	0.408
Bus43	11	10.695	10.882
Bus44	0.415	0.403	0.41
Bus45	11	10.695	10.882
Bus46	0.415	0.403	0.41

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Bus47	11	10.695	10.882
Bus48	0.415	0.402	0.409
Bus49	11	10.695	10.882
Bus50	0.415	0.403	0.41
Bus51	0.415	0.403	0.41
Bus52	0.415	0.415	0.415
Bus53	0.415	0.413	0.413
Bus54	0.415	0.413	0.413
Bus55	0.415	0.415	0.415
Bus56	0.415	0.415	0.415
Bus57	0.415	0.415	0.415
Bus58	11	10.954	10.956
Bus59	0.415	0.412	0.412

Table 3.3 shows even more voltage drops experienced in the buses for both single line and three sections network. The single line network had 39 marginal undervoltage buses while three sections network had 10 marginal undervoltage buses. Here, during load value 3 simulation results, concentrating of 11 kV buses only, single line network had 20 buses on marginal undervoltage while three sections network had 2 buses undervoltage. 2 of 11 kV buses is involved with marginal undervoltage in three section network which may be of threat to the operation of the solar hybrid DG. It is right to say that the solar hybrid DG should not be operated under load value 3 status as trips may set it.

Analysis of simulations results explained the reason for trips experienced while in operation of the solar hybrid DG on single line supply to the distribution network. For all load values of 1, 2 and 3 simulated, buses on the 11 kV nominal voltage experienced marginal undervoltage which is a threat to the safe operation of the solar hybrid DG. Trips experienced during operation of the DG can be attributed to be due to marginal undervoltage on the 11 kV nominal voltage buses that pose threat to its operation causing it to shut down abnormally.

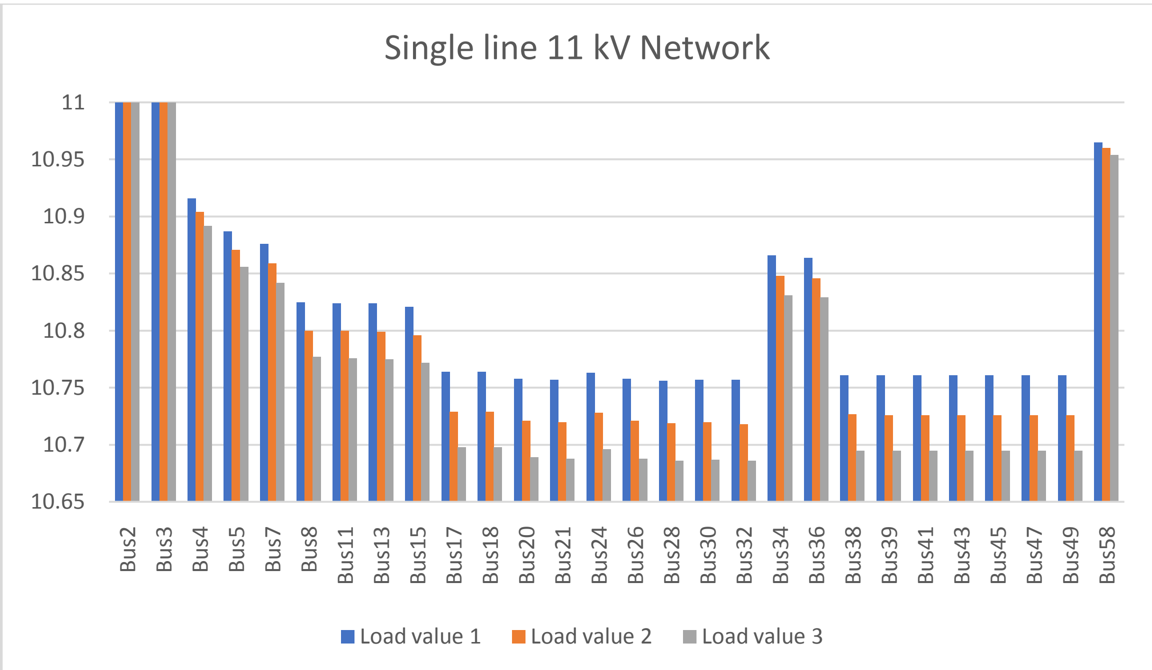

Figure 3.1: Graph of 11 kV buses on single line distribution network

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The graph of figure 3.1 and 3.2 present 11 kV buses for single line and three section distribution networks simulated on load values 1, 2 and 3. The values of the graph were extracted from tables 3.1, 3.2 and 3.3 for only 11 kV buses on load values 1, 2 and 3 respectively. Observing both graphs carefully, 11 kV buses of three section performed better than that of single line network. Figure 3.1 had its lowest voltage value below 10.7 kV on buses 17 – 32 then buses 38 – 49. Figure 3.2 had its lowest voltage value below 10.8 kV on buses 17 – 32.

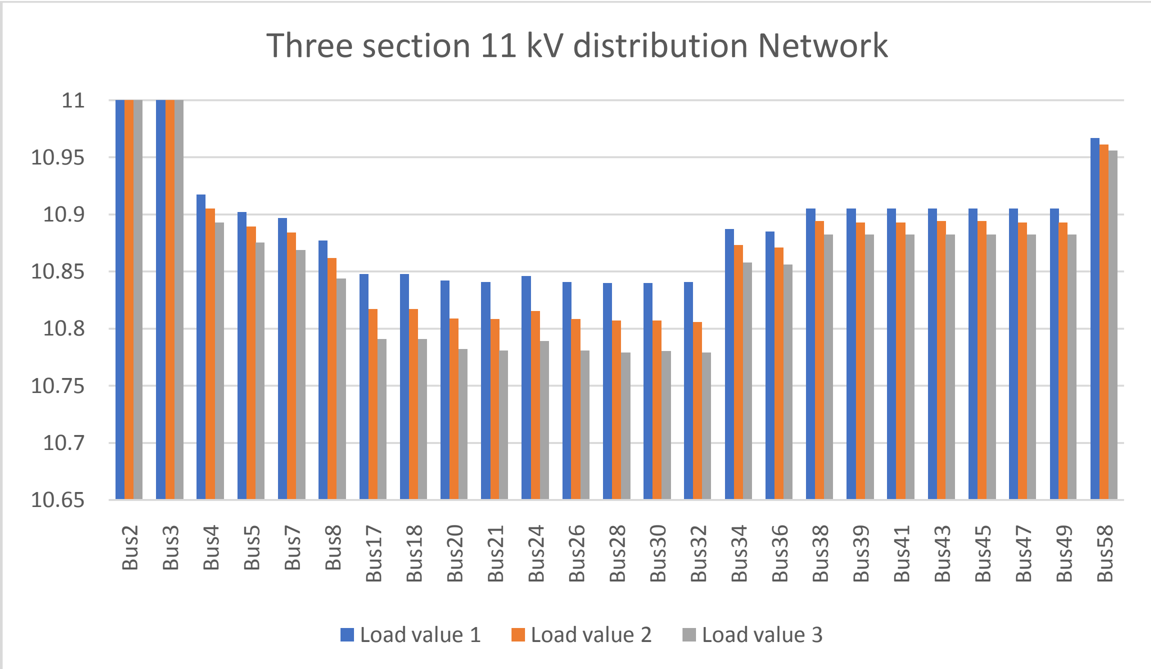

Figure 3.2: Graph of 11 kV buses on three sections distribution network

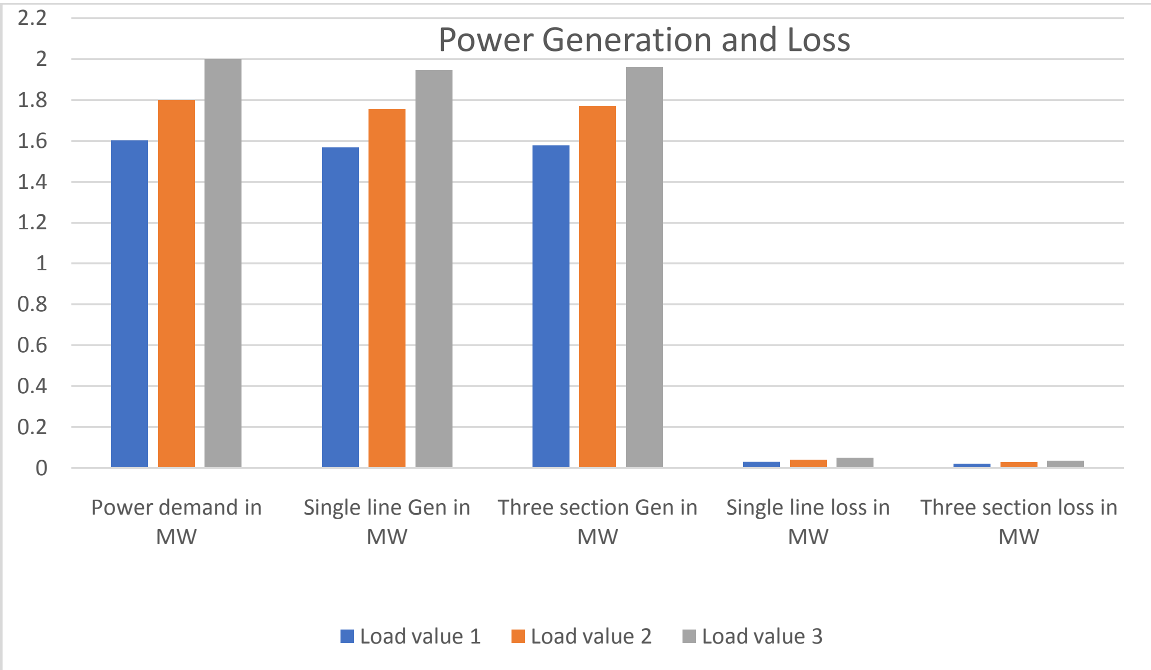

Figure 3.3: Graph of power generation and loss for single line vs three sections network on load value 1, 2 and 3

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The graph of figure 3.3 presents analysis on the load values simulations performance on single line vs three sections distribution network. Load values 1, 2 and 3 as presented in table 3.1, 3.2 and 3.3 represents the power demand in MW equivalent to 1.6, 1.8 and 2.0 MW respectively. Single line network had less power generated and more losses than three sections network. A distribution network with minimal power loss is highly desired for efficient energy system.

The three sections distribution network presented a better and safe operation profile for the solar hybrid DG installed at Nnamdi Azikiwe University Awka. This study findings can be considered and adopted for implementation to enhance performance operation of the DG.

IV. CONCLUSION

The simulations results and analysis of the solar hybrid DG integrated into 11 kV university distribution network which was carried out using ETAP 19.0 software presented a head way path for improved performance of the solar hybrid DG. The conclusion is presented thus:

1. Simulations on different load supply values from the solar hybrid DG into the single line 11 kV university distribution network was carried out on three different load values 1, 2 and 3 of 1.6, 1.8 and 2.0 MW respectively.
2. An improvement performance operationon 11 kV distribution network necessitated splitting the distribution network into three sections for simulations on load values 1, 2 and 3. The result of the simulationswere compared with the single line distribution network also simulated on load values 1, 2 and 3.
3. The analysis conducted verified that the three sections network outperformed single line distribution network since no 11 kV buses experienced marginal undervoltage for load values 1 and 2 of 1.6 MW and 1.8 MW respectively. During load value 3 of 2.0 MW, 10 buses experience marginal undervoltage with three sections network while 39 buses experienced marginal undervoltage with single line network.
4. The cause of trips is ascertained to be due to the single line distribution network utilised for supply from the solar hybrid DG. This single line network from simulations resultsanalysis showed that many 11 kV buses experienced marginal undervoltage for all load values 1, 2 and 3.
5. Analysis from simulations presents that supply from the solar hybrid DG when on three sections network should not exceed 1.8 MW so as to ensure safe operation of the solar hybrid DG.

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