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Original Article

Short Circuit Evaluation of Grid-Connected Photovoltaic System "Case Study of Nsukka Electricity Distribution Network"

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Abstract - *The complexity of the electricity grid and the exponential increase in energy demand have made the system more vulnerable to failure. This research is focused on short circuit analysis of 30- a bus Nsukka 33/11 kV electricity distribution network incorporated with a 12MW photovoltaic system. The system was designed and simulated using the Electrical Transient Analyzer Program (ETAP). The simulations of various types of faults were performed before and after integrating the PV system in the grid when the fault was applied to bus 3, 20, 33 and 34, respectively. The simulation outcome produced fault current values (kA, rms) of 5.808, 5.386, 5.030, 4.430 and corresponding values of 6.758, 6.198, 5.606, 4.632kA. It was inferred that the 3-phase fault posed the greatest magnitude of fault current and hence was chosen as the point of reference for selecting the appropriate device for optimal functionality. Furthermore, the values of fault current after the integration of PV were slightly higher because the grid operates as a near-zero impedance source and also provides safe means that disrupt the impact of the abnormal current flow of such magnitude in line with International Electrotechnical Commission's standards 60909.*

Keywords - *ETAP, Grid-tied, Photovoltaic system, Nominal voltage, Peak current, Short circuit.*

1. Introduction

The susceptibility of power system networks in recent times is not only a result of weather variation, animal interference, obsolete infrastructure, or high load demand variability; rather, it is attributed to the incorporation of renewable energy resources, e.g. photovoltaic hydro, nuclear and wind, etc, into the existing utility grid.

In other words, the more extensive and complex the network without a preventive mechanism could result in system failure or total collapse [1]. Moreover, electrical infrastructures, especially power transformers, Inverters, cables, etc., are highly capital intensive, so a sufficient protection system is required to sustain the system and prevent breakdown.

Photovoltaic energy has created a very positive impact towards mitigating the intractable short circuit challenges in the grid. Therefore, it is crucial to comprehend the multiple dynamics of the grid system, which guarantees the stability and dependability of power networks [2, 3]. During a short circuit investigation with a grid-connected photovoltaic (PV) system, the peak current is slightly higher compared to a conventional utility network because the grid functions as a near-zero impedance source, a much larger current can flow through the system when a fault occurs, effectively "forcing" the PV inverter to output its maximum possible current due to the sudden voltage drop at the point of connection [4].

The intent of this research is on short circuit analysis of grid-tied photovoltaic system "case study of 33/11 kV Nsukka electricity distribution network.

Short circuit investigation is a power system technique to determine the amount of abnormal current flow in a system in the event of a fault.

The difference between the calculated values and actual equipment ratings is performed to ensure that the system can accommodate or withstand the effect of failure without breakdown [5].

The effects of such faults are usually astronomical in the network. Short circuits cannot completely be eradicated and hence can be minimized by adequately using the calculated or simulated values of protective electrical devices like transformers, cables, switch gears, circuit breakers, and fuses during the planning and designing stages. [6, 7]. The primary basis of short circuit analysis is to ascertain the steady-state solution for the power system [8]. When proper interrupting ratings are selected, the electrical equipment and personnel are protected against inimical impact faults [9]. The ongoing research on the coordination of protection will enhance the speedy detection and tripping of the system in the event of a fault.

The previous research work on this subject matter did not wholly address the issue of sporadic system breakdown due to an inefficient model that will accommodate the impact of abnormal current flow to mitigate the possibility of electrical hazard and avert the risk of fire or total collapse. The diagrams of three-phase (balanced) and unbalanced faults in the power system are shown in Figure 1.0 -4.0 below [10-11].

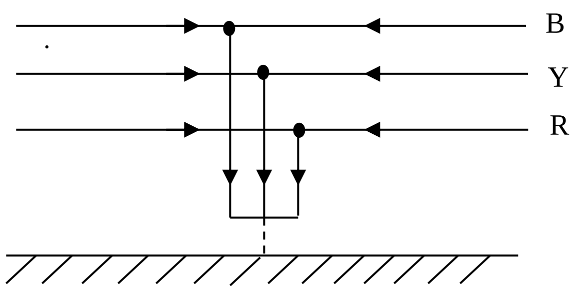

Fig. 1 Symmetrical 3- phase fault

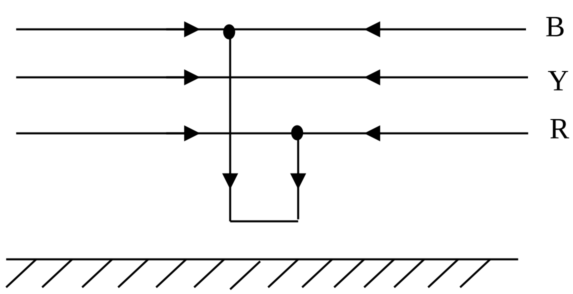

Fig. 2 Line--line fault

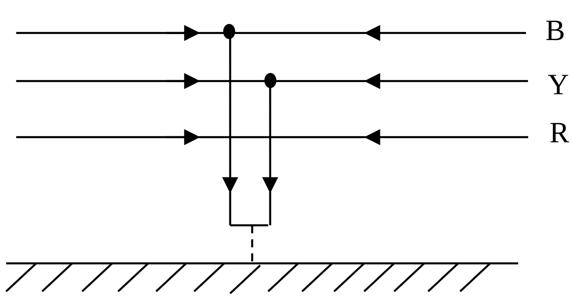

Fig. 3 Double line-ground fault

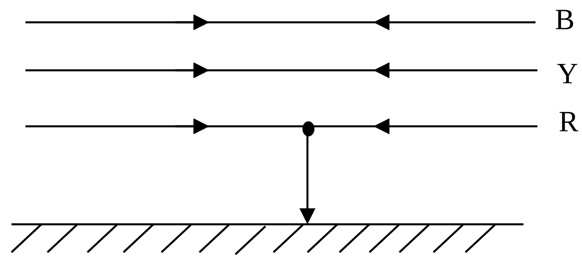

Fig. 4 Single line- ground

2. Theoretical Analysis

The variations of bus voltages can be computed using equation 1.0

$$\mathrm{V_{bus}(F) = V_{bus}(0) + \Delta V_{bus}} \quad (1)$$

$$\text{Fault current } \mathrm{I_F} = \frac{\mathrm{V_{(pu)}}}{\mathrm{X_{(th)}}} \quad (2)$$

$$\text{Short circuit, A} = \frac{\text{Base kva}}{\mathrm{X_{th}}} \quad (3)$$

$$\text{Short circuit, KVA} = \mathrm{V_{prefault}} \times \mathrm{I_F} \quad (4)$$

The 3-phase system voltages, namely, positive, negative and zero, are given below

$$V_a = V_{a1} + V_{a2} + V_{a3}\,; V_b = V_{b1} + V_{b2} + V_{b3};\ V_c = V_{c1} + V_{c2} + V_{c3} \quad (5)$$

The preliminary symmetrical short circuit current I_{sc} and power P_{sc} according to IEC 60909 standard is expressed mathematically in equations (6) and (7)

$$I_{sc} = \frac{cV_n}{\sqrt{3}Z_k} \quad (6)$$

$$P_{sc} = \sqrt{3}V_n I_{sc} \quad (7)$$

Where V_n = nominal voltage, Z_k = equivalent short circuit impedance, c = Factor refer to Table 1 of IEC 60909-0 [12]. The fault equations for L-G, L-L and L-L-G are expressed mathematically in Equation (8)-(10)

$$L_g = \frac{\sqrt{3}cV_n}{Z_1+Z_2+Z_0} \quad (8)$$

$$L_l = \frac{V_n}{Z_1+Z_2} \quad (9)$$

$$2L_g = \frac{\sqrt{3}cV_nZ_2}{Z_1Z_1+Z_1Z_2+Z_2Z_0} \quad (10)$$

Z_1, Z_2, Z_0 represents the short circuit impedance of +, - and 0 sequence network.

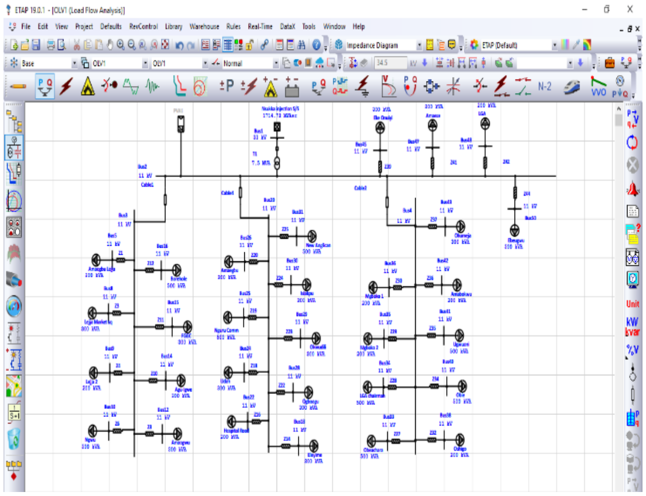

Fig. 5 Oneline diagram of 33/11kV Nsukka distribution network integrated with photovoltaic system

3. Methodology

Nsukka –Onuiyi injection substation is fed via a 33 kV distribution line from New Heaven Enugu and stepped down to 11 kV, with a 7.5 MVA Power transformer. 11kV distribution comprises thirty buses, consisting of distribution transformers of various capacities [13]. The online diagram of the Nsukka distribution network was modeled with ETAP software, and the ratings of the network parameters like bus, line, and transformer data obtained from Enugu Electricity Distribution Company were specified and inserted into their positions in the diagram. Thereafter, short circuit simulation was initially performed without incorporating a 12MW photovoltaic system into the network when the fault was applied to 3,20,33 and 34, respectively, following IEC 60909 standards [14-16]. The process was equally repeated when a PV system was integrated into the grid. The modeled network is shown in Figure 5.

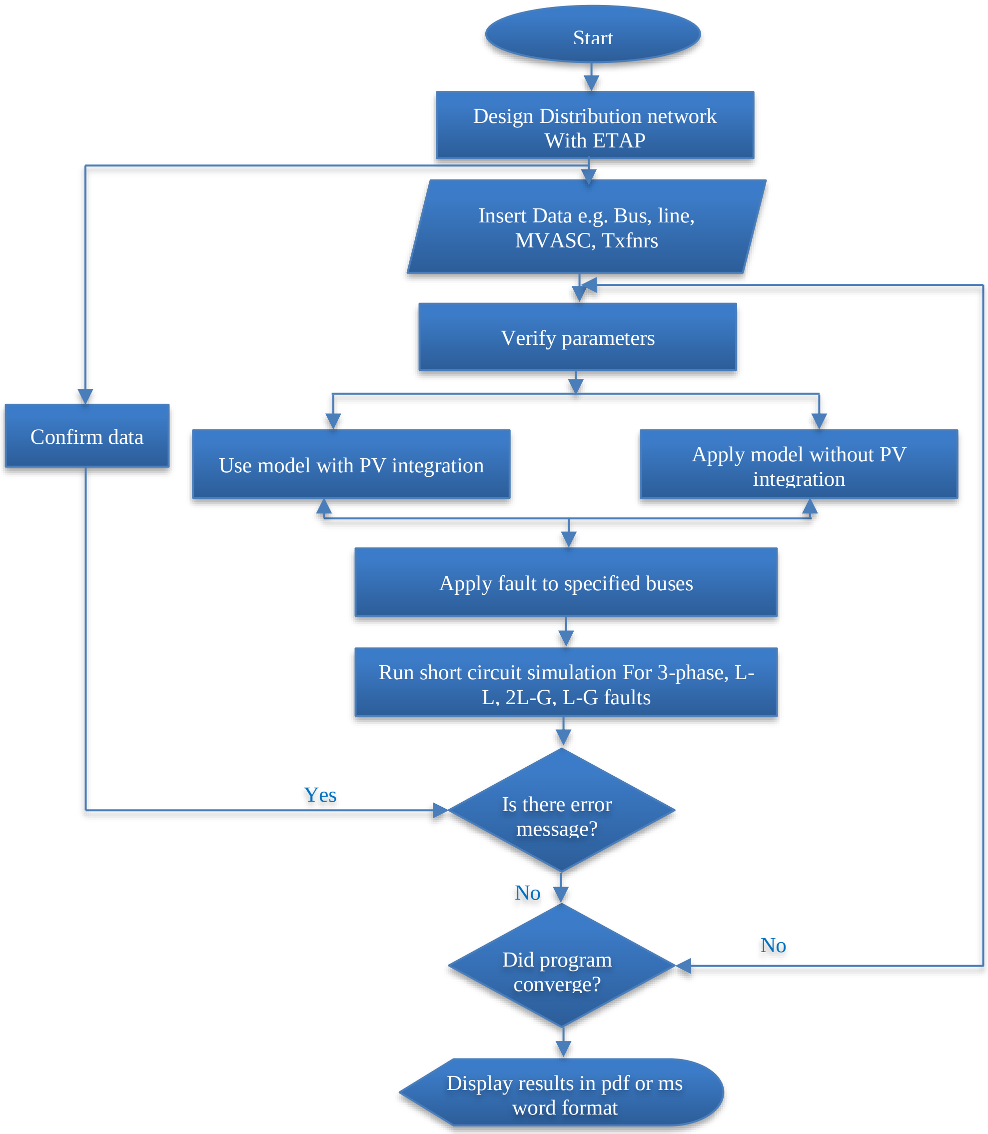

Fig. 6 Flowchart for implementation of fault analysis

4. Implementation

The proposed system was executed using Electrical Transient and Analysis software (ETAP 19.0). Various types of faults, namely, symmetrical 3-phase, Line-line, 2-line-ground and single-line ground faults, were all considered during simulation in two different cases, before and after the integration of the PV system during the simulation in section 4.0. The flow chart for the realization of short circuit analysis is shown in Figure 6.0. The algorithm's output is used to identify, classify and locate transmission line faults. Simulation results have shown the effectiveness of the algorithm under various fault conditions.

5. Results and Discussion

The short circuit evaluation of the 33/11kV Nsukka Onuiyi electricity distribution network incorporated with a 12MW photovoltaic system was successfully performed with the Electrical Transient Analyzer Program (ETAP). The tool has features for assessing the impact and consequences of short circuits in the power system grid. The analysis was based on two different scenarios: before and after integration of the photovoltaic system, while the outcome of the simulation when faults of various types were applied to bus 3,20,33 and 34 are presented and discussed in the following subsections with figures and tables:-

5.1. Scenario I

The short circuit survey was initially performed without integration of the photovoltaic system. The simulated model of the 30-bus distribution network is shown in Figure 7.0. From the simulation, the initial symmetrical Current values (kA, rms) for 3-phase, double line–ground, line – line and line-ground faults were 5.808, 5.386, 5.030, and 4.430 respectively [17]. The result is shown in table 1.0.

5.2. Scenario II

The short circuit simulation was repeated when a 12 MW photovoltaic system was integrated into the network [18]. The simulated model and PV array editor are shown in Figures 8.0 and 9.0. The results of fault current values (kA, rms) for 3-phase, double line–ground, line – line and line-ground faults were 6.758, 6.198, 5.606, and 4.632. Table 2 contains a short circuit summary report after the PV system was added. From the table 2. The values fault currents obtained in scenario ii guaranteed an avenue for safe cut-off abnormal current flow in the system and minimize device breakdown.

Table 1. Short circuit summary report without PV integration

Bus	3-Phase				Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus3	11.000	5.809	14.116	2.906	4.431	10.767	4.431	4.431	5.030	12.225	5.030	5.030	5.386	13.089	5.386	5.386
Bus20	11.000	5.809	14.119	2.906	4.431	10.769	4.431	4.431	5.031	12.227	5.031	5.031	5.386	13.091	5.386	5.386
Bus33	11.000	5.808	14.100	2.905	4.430	10.755	4.430	4.430	5.030	12.211	5.030	5.030	5.386	13.075	5.386	5.386
Bus34	11.000	5.808	14.100	2.905	4.430	10.755	4.430	4.430	5.030	12.211	5.030	5.030	5.386	13.075	5.386	5.386

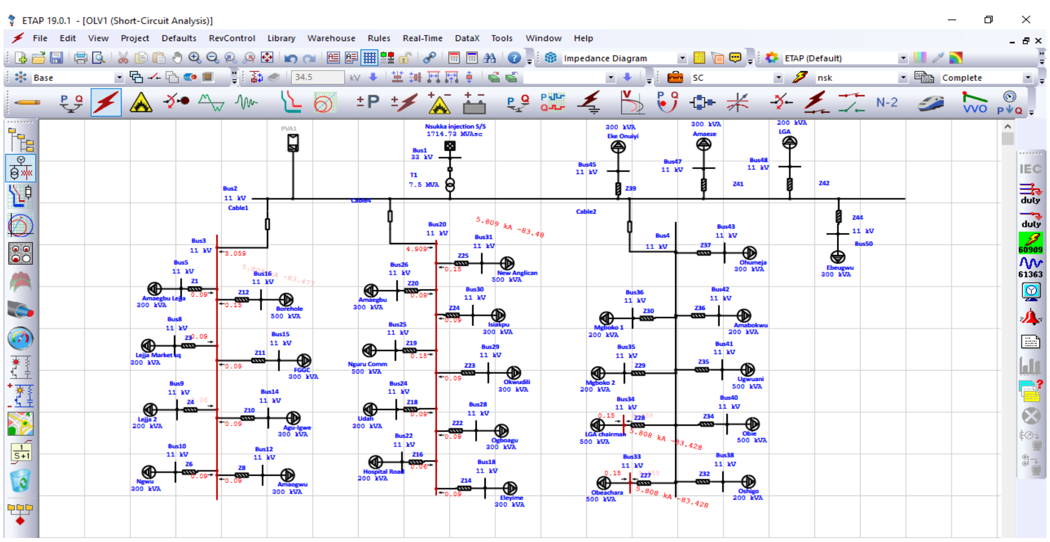

Fig. 7 Onleine diagram of 30 bus distribution network without PV integration

Table 2. Short circuit summary report with PV integration

Bus	3-Phase				Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus3	11.000	6.758	15.434	3.886	4.632	10.424	4.632	4.632	5.606	12.615	5.606	5.606	6.198	13.948	6.198	6.198
Bus20	11.000	6.759	15.436	3.886	4.632	10.579	4.632	4.632	5.606	12.803	5.606	5.606	6.198	14.156	6.198	6.198
Bus33	11.000	6.758	15.417	3.885	4.631	10.566	4.631	4.631	5.605	12.788	5.605	5.605	6.198	14.140	6.198	6.198
Bus34	11.000	6.758	15.417	3.885	4.631	10.566	4.631	4.631	5.605	12.788	5.605	5.605	6.198	14.140	6.198	6.198

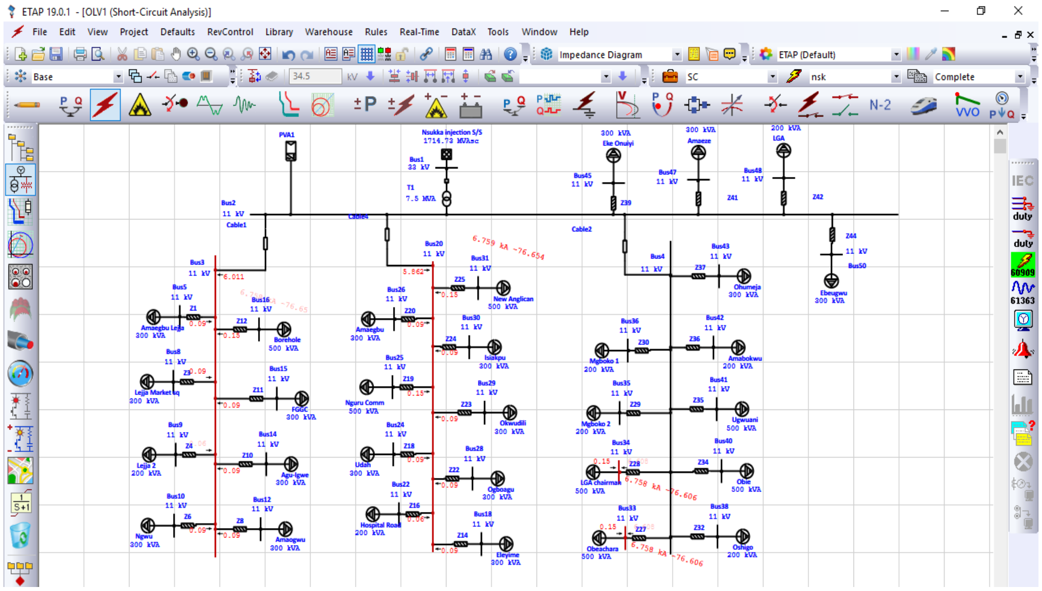

Fig. 8 Onleine diagram of 30 bus distribution network with PV

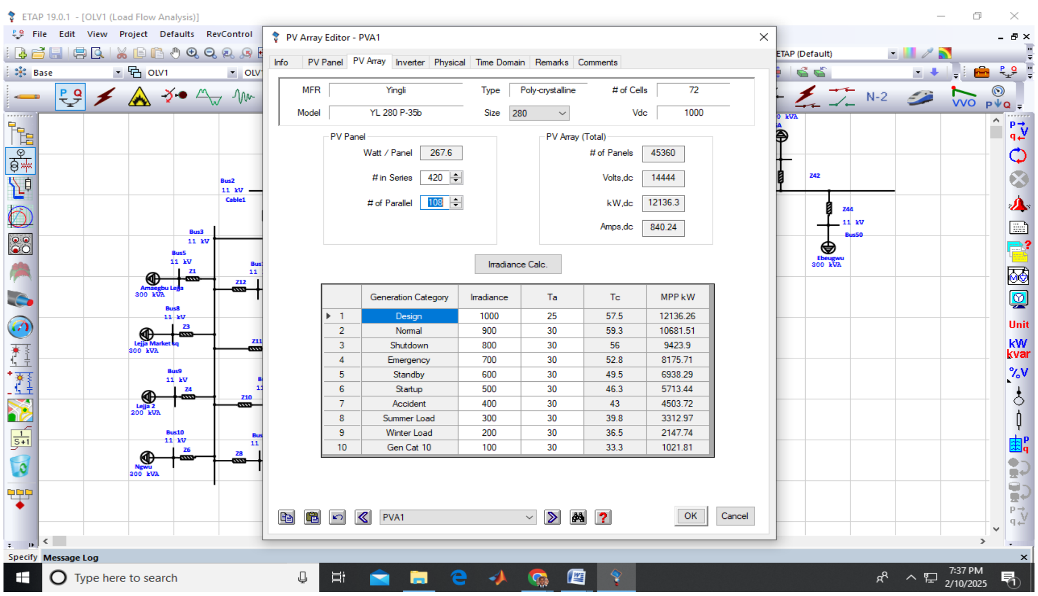

Fig. 9 Photovoltaic array editor

Comparing the results of the short analysis shown in Tables 1 and 2, it was observed that the fault current in Table 2, that is, after integration of the PV system, is slightly higher (6.758, 6.198, 5.606, 4.632.) than when PV system was not connected in the network (5.808, 5.386, 5.030, 4.430). This is because the network virtually creates a minimal impedance route for current to flow, enabling the PV system to deliver its maximum current during a fault condition, which is what short circuit current means.

6. Conclusion

Short circuit analysis of a 30-bus Nsukka 33/11 kV electricity distribution network incorporated with a 12MW photovoltaic system was successfully conducted. The system was designed and simulated using the Electrical Transient Analyzer Program (ETAP version 19.0 software). The outcome of the simulation before and after integration of the PV system produced fault current (kA, rms) in three phases, double Line-ground, Line-line, line–ground of 5.808, 5.386, 5.030, 4.430 and corresponding values of 6.758, 6.198, 5.606, 4.632kA when a fault is applied to bus 3,20,33 and 34 respectively. Integration of the PV system offered a faster control approach to mitigate the risk of device breakdown. The research findings aided in the appropriate selection and configuration of protective devices, such as fuses, breakers and relays, that can withstand or accommodate the impact of abnormal current flow in the event of a short circuit in line with the International Electrotechnical Commission's standards 60909.

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