Journal of Electrical, Control and Telecommunication Research 2 (2020) 30 – 41

Journal of
Electrical, Control and Telecommunication Research

Journal homepage: www.sciengtexopen.org/index.php/jectr

Impact of faults on bus stability on an island 330kV mesh network on the Nigerian grid

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ARTICLE INFO

Article history:
Received 28 August 2020
Received 29 October 2020
Accepted 6 November 2020
Available online 9 November 2020

Keywords:
Bus
Fault
Island mesh network
Nigerian grid
Power stability

ABSTRACT

This study carried out an assessment on the impact of faults on bus stability along the Benin-IkejaWest-Aiyede-Oshogbo-Benin (BIAOB) 330kV island network. The sensitivity of BIAOB as a ring network on the Nigerian grid aroused the interest behind its choice for this study. The network parameters were collated from the National Control Centre, Oshogbo and the network was modeled on the MATLAB 2015 environment using the obtained data. A high reactive power flow was observed in all the buses while the lowest voltage profile was observed on the Line-Line-Line-Ground (L-L-L-G) simulated in bus 1. This is an indication that symmetrical faults have the greatest impact on the network. Further results showed that the BIAOB network has a better voltage profile when compared with other radial network from existing literature. The paper concluded by recommending the closure of more radial network on the grid in order to improve its performance.

https://doi.org/10.37121/jectr.vol2.121

1. Introduction

The impact of faults on transmission network is a function of its stability at any point in time. Weak transmission grid can therefore be a function of poor stability. Whereas, this may be a global issue; however, studies have shown that it is more pronounced in sub-Saharan Africa due to the increasing stressed condition to the grid is operated [1]-[3]. A major significance of faults along power network is its impact on the network as it often leads to interruption. If adequate measures are not taken to clear these faults in the shortest possible time, then, it could lead to a total collapse of the network [1]. In that wise, it becomes a keen responsibility for operators of the network to continually monitor and guarantee effective system stability around the clock [4]. As it were, the system is dynamic in nature and continues to change every second due to varying loads connected across it. Based on this, a round-the-clock assessment of the networks' dynamics remains essential.

One major problem that could lead to poor stability of a network is deficiencies in power generation. In this case, the system is forced to operate under an increasing stressed condition due to the large number of customers it is expected to feed. The results of this forceful operation most times are

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manifested in the form of frequency violations, voltage fluctuations, overcurrent etc. [5]. Fault analysis can either be clustered as either symmetrical or unsymmetrical [6]-[7]. The rate of occurrences of these faults is 5% for symmetrical fault, 15% for Line-Line (L-L) and Line-Line-Ground (L-L-G) faults and 80% for Line-Ground (L-G) fault [8]. Unexpected changes of load may be due to fast switching operations or sudden faults followed by tripping of load or circuit breaker [9]. A three phase AC power system operating under normal condition has magnitude of both current and voltage equally distributed across each phase. However, fault may occur to upset this situation [6].

The Nigerian transmission network is presently characterized by several constraints, which include ageing of transmission line, long transmission line lengths, and ineffective redundancy [10]-[12]. Due to the liberalization of the Nigerian Power Sector, the transmission network is expected to beef up its operation so that it can meet up with the speed of the generation sector concerning wheeling of power to customers at all times. This paper, therefore, presents the assessment and numerical impact of symmetrical, unsymmetrical faults and buses stability along BIOAB power network to determine the level of violations key parameters along the line.

2. Related Review on Genetic Algorithm Applications

The transmission network in Nigeria can presently wheel about 10000MW of power however, the available generated capacity is within 5000-6000MW. This results in short fall of supply to the consumers and customers of the product. As presented in Fig. 1, the network is characterized by more radial and fewer mesh structures. Additionally, the figure shows the level of sensitivity of the Benin bus being that it connects the Northern, Southern, Eastern and Western part of the country. Some form of redundancy is therefore envisaged across the network in order to relieve the Benin bus of its presently stressed conditions.

In [13] a review on power flow study on the Nigerian grid was carried out. The review results identified some factors as key parameters that must be given attention to enhanced service delivery. These parameters include but not limited to stability, maintenance, compensation etc. However, the effect of an island fault on the network was not discussed. In [14] a research on an Island network along the secondary transmission network in Nigeria was done. The study used the Kaduna 132/33kV network as a case study. Results presented in the study showed a violation of voltage profile etc., compensation of the network was therefore, proposed. An assessment of sectionalized network along the 330kV network in Nigeria was carried out by. The network was modeled using live transmission tools on the MATLAB environment. Available results from the study emphasized on the need for upgrading the network to a double circuit if an effective quality of service is to be achieved. Furthermore, the study submitted that if appropriate policies on right-of-way for transmission network are not well defined by the appropriate authority, then, upgrading any island network may be a daunting task. Losses determination on the 132/33kV Maryland transmission network, Nigeria was carried out in [15]. The network was modeled on the Electrical Transient Analyzer Program (ETAP) environment. The operating condition of the network was found to be abnormal; therefore, some level of compensation was carried out to improve the affected buses.

In [17], the effect of loss of line along the Enugu 132/33 network using MATPOWER 5.0 was carried out. The buses with violated voltage profile were identified and suggestions were raised on how to go about concerning their improvement. The study recommended the use of more ring network other than radial network which characterizes the network. A research on the sizing and placement of Distribute Generator (DG) along the Nigerian grid was done by [18]. A reduction in losses and

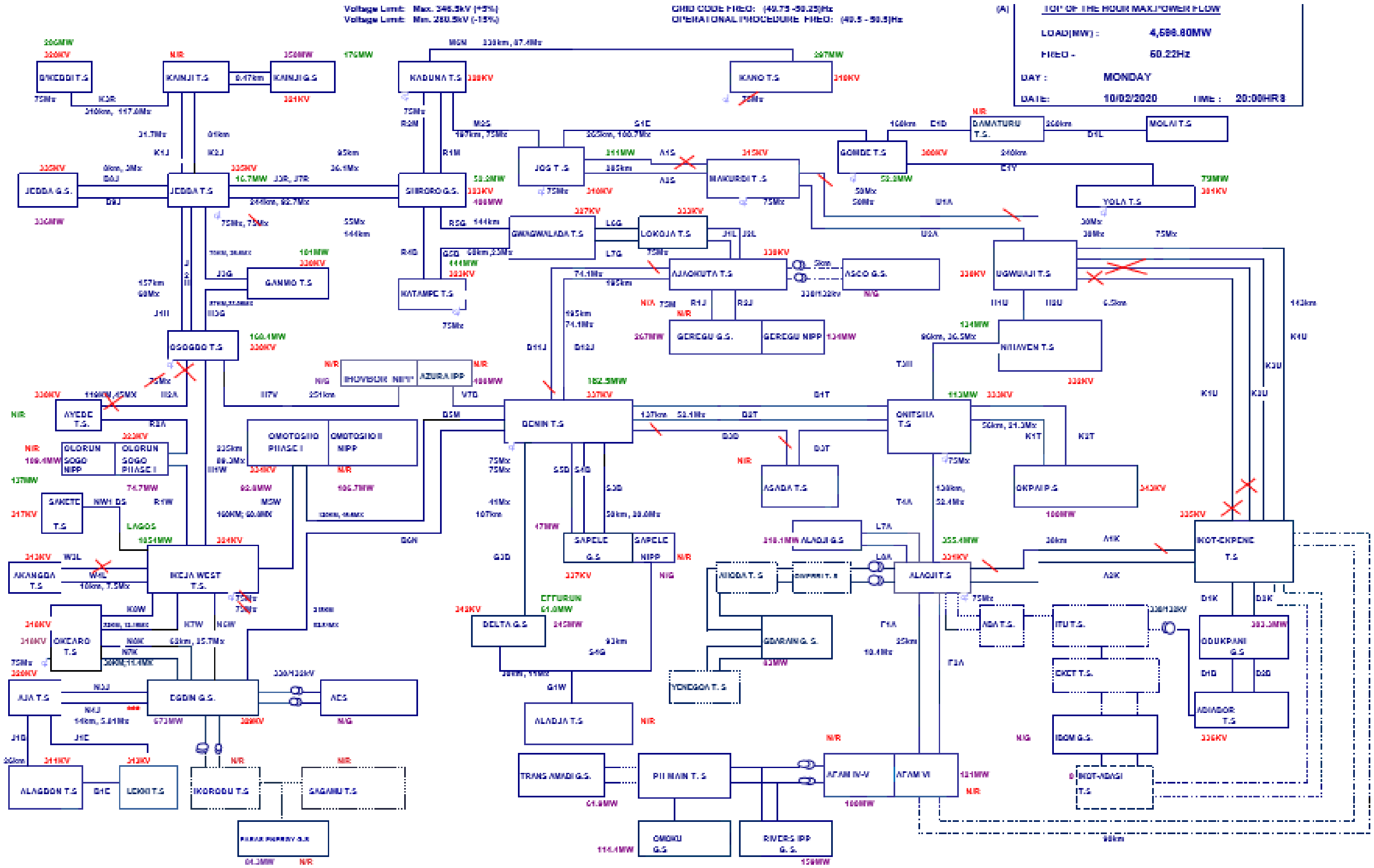

Fig. 1 One-line diagram of Nigerian 330-kV Transmission Network [16]

improvement on voltage was achieved. The result obtained is an indication of the effectiveness of the method used. According to [19], for the grid to function properly given its present state, then, the integration of FACTS devices across the network is necessary. In [20], the authors undertook a study on Power Flow study on the 220kV Maharashtra Power Network using Newton-Raphson (N-R) algorithm on MATLAB. The study suggested new ways of voltage profile improvement by replacing single circuit lines with double circuit, tap changing transformers, compensation of reactive power etc. It has therefore been established from literature that the Nigerian network needs compensation at all levels. Therefore, more studies on island network become pertinent in order to establish how their operations or mal-operations affect a local network or community [21].

In this study, an island radial network is presented in order to determine the key parameters and their level of violations if any using the BIOAB network which is a strategic one due to its criticality and sensitivity. Summarily, this paper attempts to solve the problem raised through the identification of grey areas in the network.

3. Methodology

The equivalent circuit of the network was modeled using the SIMPOWER tool on the MATLAB 2015 environment as presented in Fig. 2. The network parameters such as impedance, voltage, power and loads at the various buses of the network were fed into the model and simulation carried out. Four (4) generating plants; 1320 MVA, 1930MVA, 600MVA and 420MVA operating at a line-to-line rating voltage of 13.8 kV were also modeled. Plants 1 and 2 are connected to Benin Transmitting Station (BTS) while plants 3 and 4 are connected to Ikeja-West Transmitting Station (ITS) respectively. The reference power for the plants was modeled using Eq. (1), while the data for the plants and line parameters are presented in Table 1.

$$P_{ref} = \frac{EPA}{EPC} \quad (1)$$

Given that: EPA is the equivalent plant availability and EPC is the equivalent plant capacity

3.1. Steady-State Stability

The characteristics of the voltage, real power and reactive power will be determined in order to get the normal operating condition of the network under steady state condition. From the Simulink modeling presented in Fig. 1, it can be observed that the model was fed via the four generating plants with equivalent power capacity of 1320MW, 1930MW, 600MW and 420MW respectively. Because all the buses are connected in parallel each plant can be connected to any of the four buses. The model simulation attained its steady state in 5s, at which the best overview of the waveform and a realistic per unit data were obtained, as presented in Table 3. In Table 2, the line data from circuit under consideration was presented while Fig. 2 represents the Simulink model of the network.

3.2. Dynamic-State Stability

The dynamic state stability was carried out by setting the fault breaker into On-mode to simulate different fault conditions along BIAOB. The following faults L-L, L-G, L-L-G, L-L-L and L-L-L-G were simulated. The simulation time was set to 15s in order to get the best overview of the waveform. Based on the mathematical solver used (ode23mod stiff/trapezoidal), the 15s facilitated to obtain the best overview of the power system. This is because; anything less will not yield the anticipated result before the fault is cleared by the circuit breakers.

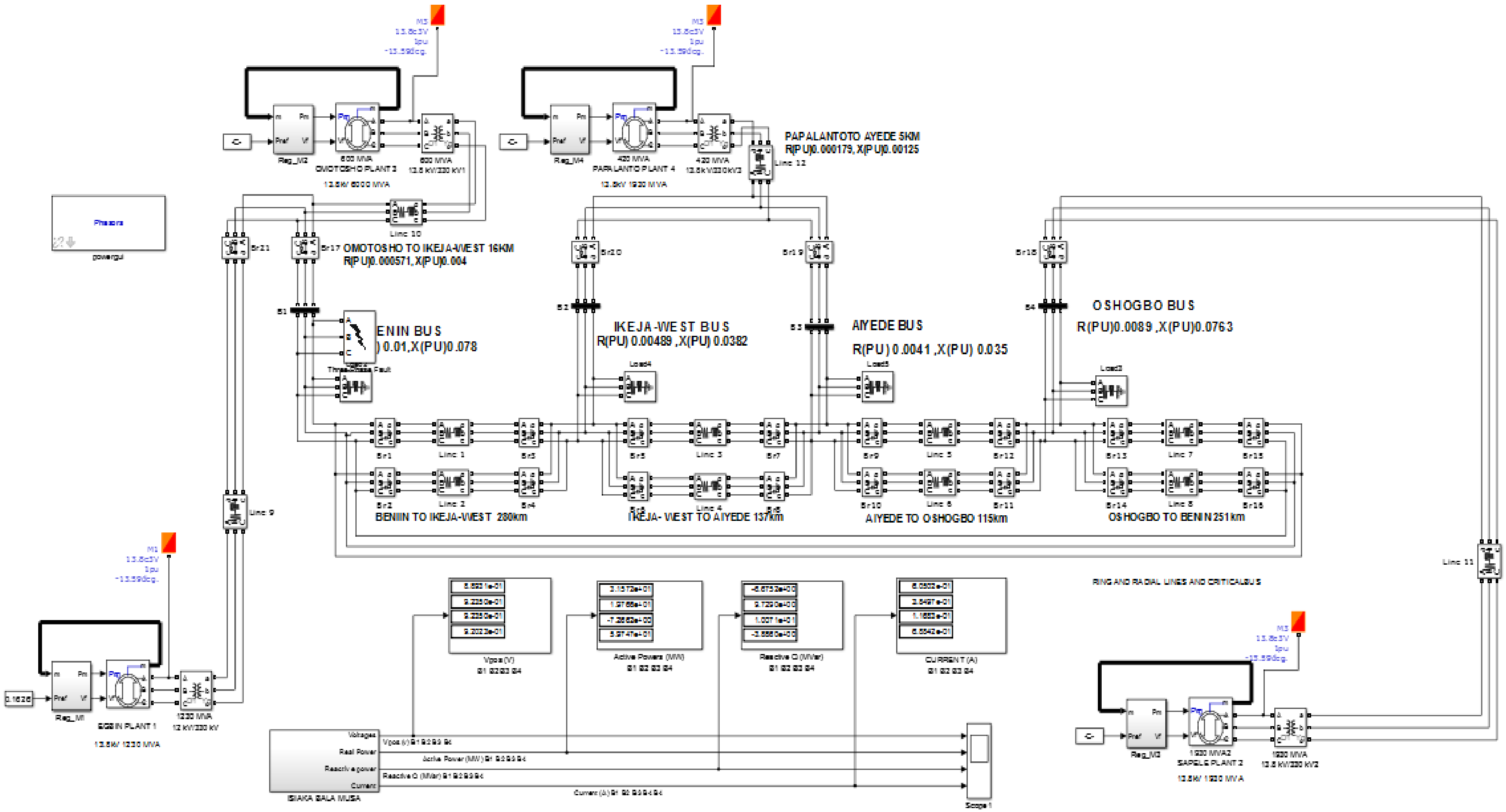

Fig. 2 MATLAB/Simulink model of Benin, Ikeja-West, Aiyede-Oshogbo and Benin

Table 1 Plants data

Identity	Power Plant	EPC (MW)	Terminal Voltage (kV)	EPA (MW)	(Pref.), Initial mechanical power (p.u.)
Plant 1	Egbin Plant	1320	13.8	200	0.1515
Plant 2	Sapele Plant	1930	13.8	455	0.23573
Plant 3	Omotosho Plant	600	13.8	100	0.66667
Plant 4	Papalanto Plant	420	13.8	80	0.190476

Table 2 Line data from circuit under consideration

From Bus	To Bus	Length (km)	R (p.u)	X (p.u)
Benin	Ikeja-west	280	0.01000	0.07800
Ikeja-west	Aiyede	137	0.00489	0.03820
Aiyede	Oshogbo	115	0.00410	0.03500
Oshogbo	Benin	251	0.00890	0.07630
Omotosho plant	Ikeja-west	16	0.000571	0.004
Papalanto plant	Aiyede	5	0.000179	0.00125

4. Results and Discussion

The result achieved from the steady state simulation is presented in Table 3. Fig. 3 shows the steady state waveform for the positive sequence, voltages, active power as well as the reactive power from bus 1 to bus 5.

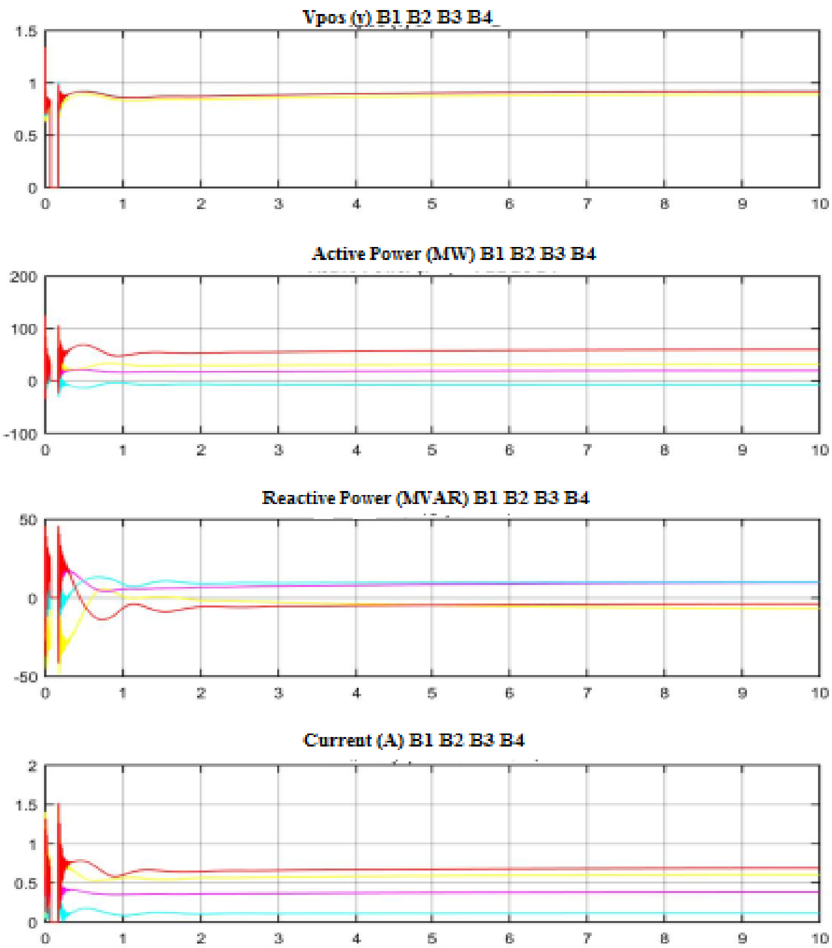

Fig. 3 Steady state waveforms for PVQ simulated along BIAOB

Table 3 Simulation result for steady state

Bus No	V (p.u.)	P (MW)	Q (MVAR)	I (p.u.)
1	0.92350	31.5720	-6.6800	0.60520
2	0.92350	19.7662	9.7300	0.38497
3	0.92350	-7.2662	10.071	0.11683
4	0.92023	57.7470	-3.8860	0.68842

The steady state data obtained for positive sequence voltages as well as the real and the reactive power showed that the simulated ring network was at its best steady state settings at 5s based on the model. The negatives real powers in per unit (-19) were obtained from bus 1,4 and 5 in Fig. 1 and Table 3 are not a problem because the oscillatory characterization of waveform ends at the negative x-axis at any sampling time. For bus 1, 4 and 5, the real powers in per unit are (-19) and at bus 2 and 3 real powers in per unit are (19) respectively, as the oscillatory characterization of the waveforms for bus 2, 3 ends at their positive x-axis at any sampling time.

The dynamic simulation at bus 1 showed a high reactive power flow of approximately 34.05 MVAR on the L-L fault simulated along bus 1. Consequently, the lowest voltage profile of 0.207 p.u. was observed in the L-L-L-G fault simulated in bus 4 as shown in Table 4. In Table 5, the dynamic simulation at bus 2 is presented. A high reactive power flow of 26.84 MVAR was observed on the L-L fault simulated along bus 1, while the lowest voltage profile of 0.4206 p.u. was recorded on the L-L-L-G fault along bus 2. Furthermore, the dynamic simulation at Bus 3 showed a maximum voltage profile of 0.7826PU on the L-L fault simulated in Bus 2, the highest reactive power flow of 26.886 MVAR on the L-G fault simulated in bus 1 and the lowest active power flow of 0.018 MW on the L-L-L fault simulated along bus 3 as presented in Table 6.

Table 4 Dynamic simulation at bus 1

Bus No	V (p.u.)	P (MW)	Q (MVAR)	I (p.u.)
Single line to line short circuit fault at bus 1				
1	0.70446	36.869	34.047	0.515
2	0.77835	17.662	1.11E+00	0.72759
3	0.77835	-7.5752	19.683	0.20715
4	0.77191	57.049	-26.169	0.91603
Single line to ground short circuit fault at bus 1				
1	0.75005	36.416	2.31E+01	0.26648
2	0.81503	17.431	3.8448	0.63897
3	0.81153	-6.9125	1.63E+01	0.16229
4	0.81013	55.902	-18.647	0.83347
Three lines short circuit fault at bus 1				
1	1.18E-05	4.78E-03	2.80E-03	2.86
2	0.208	0.89207	3.85E+01	1.8492
3	0.208	-10.731	1.10E+00	0.5186
4	0.20724	12.554	3.95E+01	1.9992
Three lines to ground short circuit fault at bus 1				
1	1.18E-05	4.75E-03	2.81E-03	2.86
2	0.20859	0.89722	3.87E+01	1.8545
3	2.09E-01	-10.47	1.05E+00	5.0442
4	0.20788	12.304	3.97E+01	1.9995

Table 5 Dynamic simulation at bus 2

Bus No	V (p.u.)	P (MW)	Q (MVAR)	I (p.u.)
Single line to line short circuit fault at bus 2				
1	0.73478	38.331	26.863	0.34193
2	0.70392	16.746	-7.32E+00	1.6753
3	0.70393	-7.4084	24.848	0.67746
4	0.73335	57.659	-34.822	1.0072
Single line to ground short circuit fault at bus 2				
1	0.77602	36.384	1.90E+01	0.18089
2	0.76095	16.811	-3.2315	1.3516
3	0.76096	-6.9888	1.94E+01	0.51086
4	0.78375	56.53	-24.449	0.90506
Three lines short circuit fault at bus 2				
1	7.35E-01	3.84E+01	2.69E+01	3.41E-01
2	0.7043	16.765	-7.30E+00	1.6622
3	0.79431	-73882	2.48E+01	0.65216
4	0.73382	57.667	-3.51E+00	0.95417
Three lines to ground short circuit fault at bus 2				
1	5.38E-01	1.83E+01	6.59E+01	1.42E+00
2	0.4206	9.4006	-6.48E+00	3.381
3	4.27E-01	-8.3566	9.17E+00	1.5685
4	0.49664	39.811	-2.27E+00	1.4096

Table 6 Dynamic simulation at bus 3

Bus No	V (p.u.)	P (MW)	Q (MVAR)	I (p.u.)
Single line to line short circuit fault at bus 3				
1	0.73576	38.346	26.886	0.34452
2	0.70397	16.731	-7.31E+00	0.30166
3	0.70397	-7.3664	24.826	1.3021
4	0.73477	57.658	-34.449	1.0047
Single line to ground short circuit fault at bus 3				
1	0.77508	37.484	1.92E+01	0.18058
2	0.76058	16.735	-3.331	0.19755
3	0.76099	-6.9087	1.95E+01	0.97317
4	0.78266	56.521	-24.983	0.89382
Three lines short circuit fault at bus 3				
1	2.03E-01	-5.20E+00	8.11E+01	2.52E+00
2	9.56E-05	-2.08E-02	-7.55E-03	1.7994
3	5.25E-05	1.87E-02	-2.26E-03	3.1452
4	1.33E-01	8.433	2.76E+01	2.1957
Three lines to ground short circuit fault at bus 3				
1	2.03E-01	-5.19E+00	8.11E+01	2.52E+00
2	9.57E-05	-2.08E-02	-7.55E-03	1.7995
3	5.25E-05	1.88E-02	-2.26E-03	3.1469
4	1.33E-01	8.433	2.76E+01	2.1958

In addition, the dynamic simulation in bus 4 yielded the highest voltage profile of 0.7857 p.u., on the L-G fault simulated along buses 2 and 3 and a high reactive power flow of 28.612 MVAR on the L-L fault simulated along bus 1 as presented in Table 7. The results obtained have been represented graphically in Figs 4-7. Similarly, the highest fault current of 5.0442 p.u. at Aiyede bus, 3.381 p.u. at Ikeja-West bus, 3.1469pu and 2.5635 at Aiyede bus respect was observed in the L-L-L-G fault simulated into buses 1, 2, 3 and 4 respectively.

Table 7 Dynamic simulation at Bus 4

Bus No	V (p.u.)	P (MW)	Q (MVAR)	I (p.u.)
Single line to line short circuit fault at bus 4				
1	0.73293	37.93	28.612	0.36278
2	0.73777	17.24	-7.89E+00	0.18808
3	0.73777	-7.4354	27.396	0.87767
4	0.69354	57.092	-40.267	1.0916
Single line to ground short circuit fault at bus 4				
1	0.77303	37.073	2.02E+01	0.18323
2	0.78573	17.108	-3.6309	0.22838
3	0.78573	-6.9544	2.21E+01	0.65611
4	0.75278	55.966	-29.09	0.94995
Three lines short circuit fault at bus 4				
1	2.01E-01	6.46E+00	8.03E+01	2.49E+00
2	1.29E-01	-3.39E+00	-1.17E+01	0.66681
3	1.29E-01	3.79E-01	3.67E+01	2.5633
4	6.09E-05	0.014227	-5.05E-03	2.4781
Three lines to ground short circuit fault at bus 4				
1	2.01E-01	6.47E+00	8.03E+01	2.49E+00
2	1.29E-01	-3.40E+00	-1.17E+01	0.66701
3	1.29E-01	3.79E-01	3.67E+01	2.5635
4	6.10E-05	0.0014296	-4.94E-03	2.4781

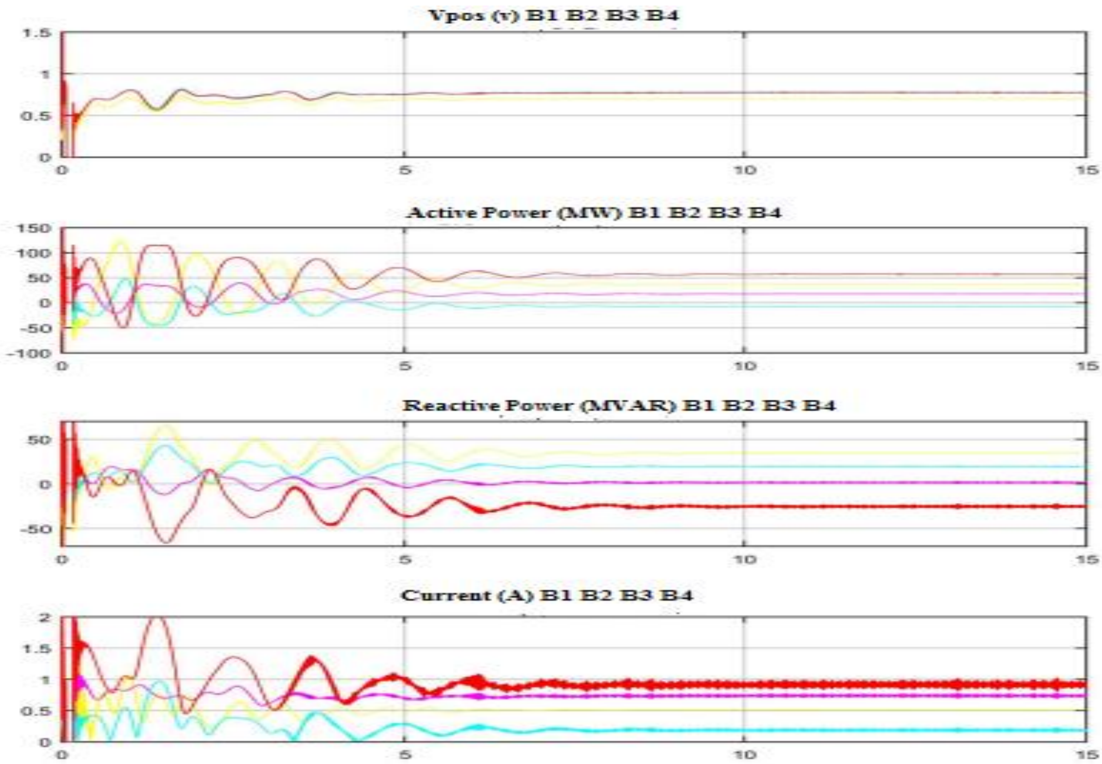

Fig. 4 L-G waveforms for PVQ simulated at bus 1

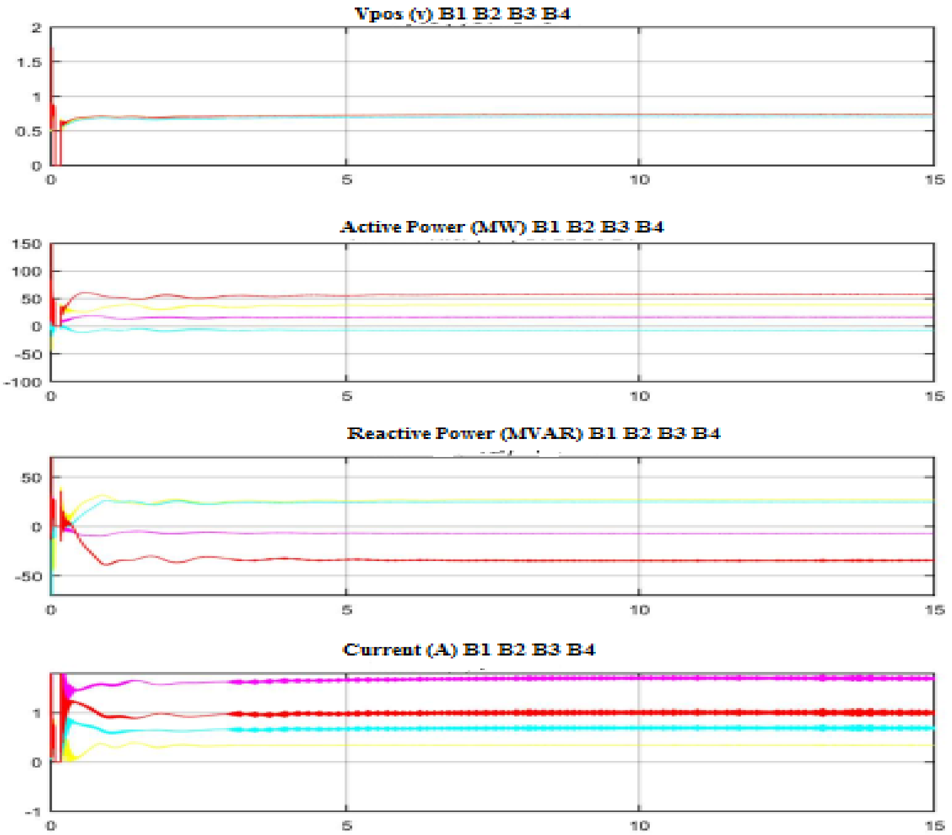

Fig. 5 L-L-G waveforms for PVQ simulated along BIAOB buses at bus 2

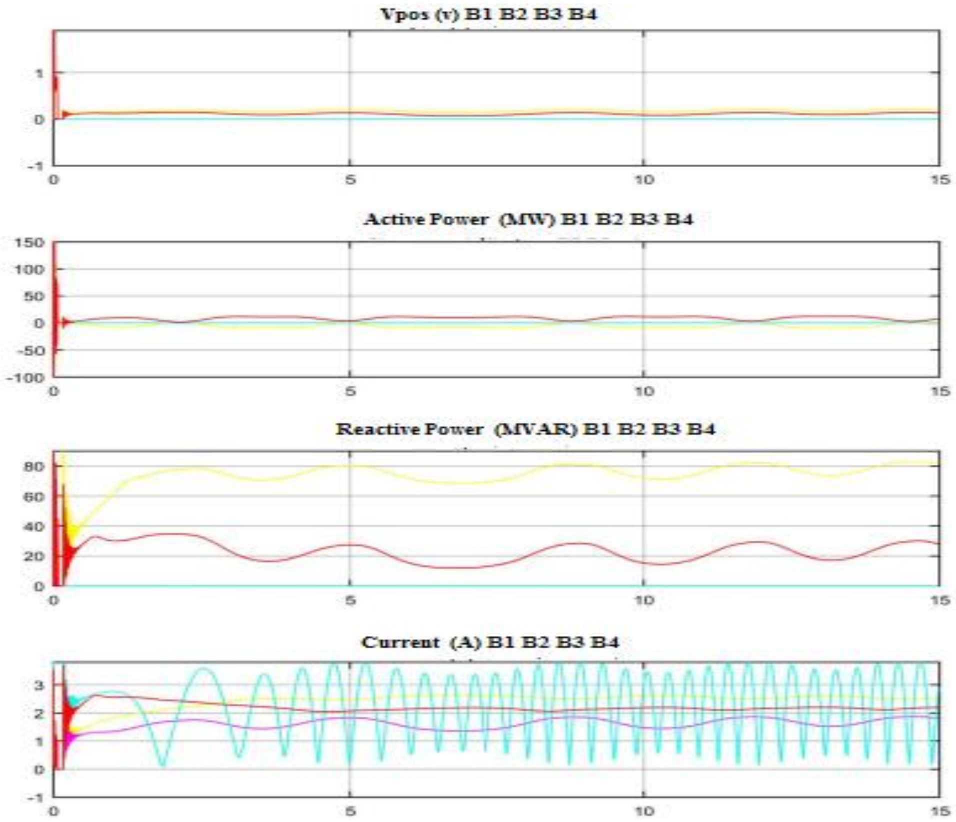

Fig. 6 L-L-L waveforms for PVQ simulated along BIAOB buses at bus 3

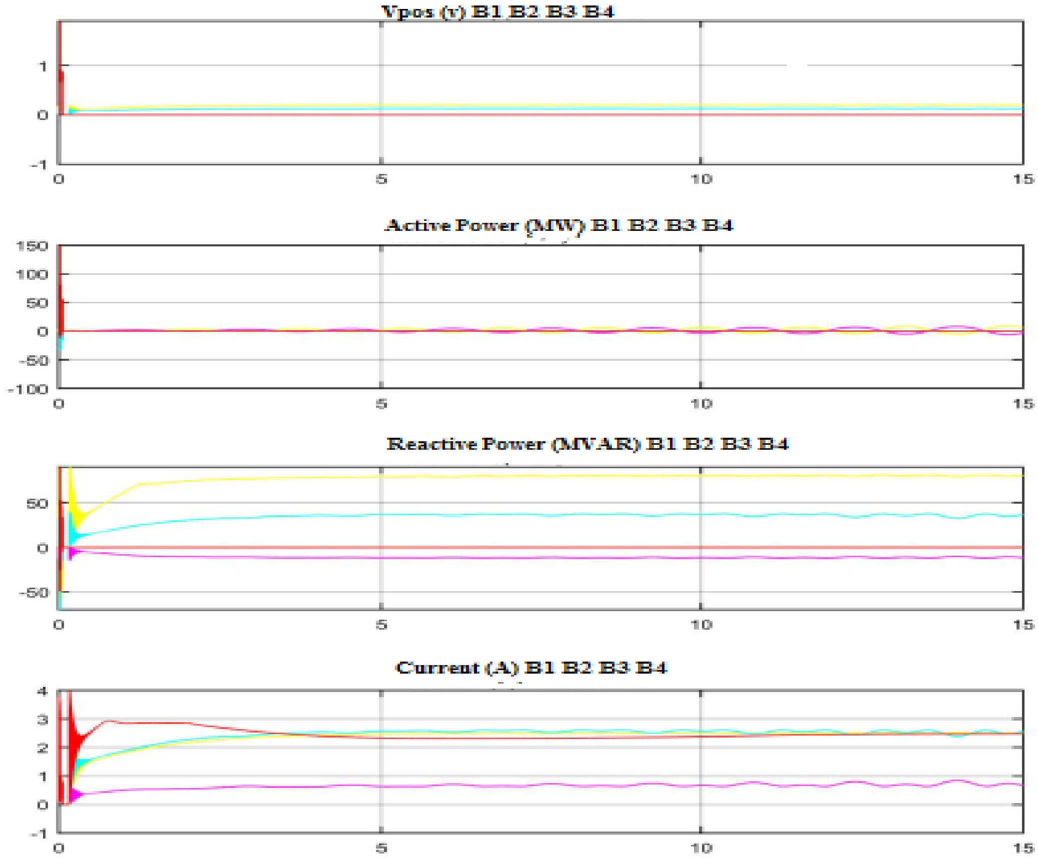

Fig. 7 L-L-L-G waveforms for PVQ simulated along BIAOB buses at bus 4

Generally, the impact of (unsymmetrical) single line-to-ground fault simulated into all the buses had voltage values that deviated from normal operating condition while the lowest voltage profile was observed in the (symmetrical fault) three-phase-to-ground fault in all the buses. On a comparative analysis with results obtained in [12], it was observed that at steady state, the voltage profile of BIAOB was 0.9235pu as against 0.96 in the literature. The lower voltage profile recorded may not be unconnected to the radial characteristics of the network. Furthermore, the L-L-L-G faults simulated along BIAOB and [12] yielded low voltage profile in both cases.

5. Conclusion

The impact of symmetrical and asymmetrical fault has been studied and analyzed along Benin, Ikeja-West, Aiyede-Oshogbo and Benin 330kV (Ring) Double Circuits power network of the Nigerian Transmission Power Grid. The results show that there is a great impact of symmetrical fault along the network that may lead to a partial or total black-out in the presence of fault. Therefore, the concerned authority managing the planning and operations of the network is expected to add more mesh networks to the grid as well as upgrading the single circuit to double circuit network across the entire country.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Citation: A. E. Airoboman, A. P. Oriaifo, and S. T. Wara, “Impact of faults on bus stability on an island 330kV mesh network on the Nigerian grid,” *Journal of Electrical, Control & Telecommunication Research,* vol. 2, pp. 30 – 41, 2020.