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Original Research Article

Transient Characteristic Behaviour of a Distributed Generation System

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ABSTRACT

The increase in penetration of distributed generation into power system has made the transient stability an integral aspect of power network analysis. This paper analyses the frequency and voltage responses of a natural gas distributed generation under transient conditions. This analysis involves line to ground, line to line, double line to ground and three phase to ground faults under different load conditions. The distributed generator is modelled and simulated under different loading and fault conditions. The results obtained indicated a deviation in the frequency and voltage of the system from the standard operating values when different loads were added to the system. The deviation increased as the load and fault time increased before it finally returned to its nominal values after the duration of the fault. The implication of these findings is that sensitive equipment needs effective protective mechanism put in place to guard against damaging effect of transient conditions.

1. INTRODUCTION

These days, the problem of excessive greenhouse gas emissions, transmission line losses and ever-increasing electrical power demand are some of the significant challenges associated with conventional power generation systems (Sun *et al*., 2018; El-ela *et al*., 2020; Ahmed *et al*., 2021). This has led to a push in the energy industry towards a more environmentally friendly and economically viable power generation systems. The use of distributed generation in recent times as an alternative source of power generation has been one of the ways through which issues related to conventional power generation are being address (Abujubbeh *et al*., 2021; Anuradha *et al*., 2021) .Distributed generation refers to the installation of small power generating units close to local areas where electrical power is needed (Ansari and Guo 2019; Razavi *et al*., 2019; Rigo *et al*., 2020).

Distributed generation can either be grid connected or operated independently off grid (Wu *et al*., 2022; Sahoo *et al*., 2021). Power generation technologies such as photovoltaic systems, micro-turbines, small hydro-plant, wind turbine, small gas generator, and fuel cells are used in distributed generation systems (Lakum and Mahajan 2018; Pesaran *et al*., 2020). The use distributed generation in power systems remains one of the major important alternatives for areas outside the conventional grid system (Shalukho *et al*., 2019; Domenech *et al*., 2021). The introduction of distributed generation into the power system is expected to affect the structure of the distribution system and have a significant impact on the power flow, voltage and stability of the system (El-Taweel *et al*., 2019; Abbaspour and Heydarian, 2019; Jenkins and Kochar, 2020). Furthermore, distributed generation penetration into the power system is expected to increase to a level where its impact will be felt on the overall system (Zhang *et al*., 2018; Bajaj *et al*., 2020). System stability, grid integration, and protection are some of the challenges which are associated with distributed generation (Manditereza and Bansal, 2016; Asharry and Nasir, 2021).

Research on distributed generation transients has attracted interest at different levels. The performance of wind turbine as a distributed generation was analysed by (Syahputra *et al*., 2014). The system was simulated under both normal and fault conditions using Matlab-Simulink. Results obtained showed that the distributed generation unit performed well under fault and steady state conditions. The transient stability of distributed generation connected with distribution network was equally analysed by (Huang *et al*., 2015). Different distributed generation technologies were interfaced with the distribution network with the system simulated on an infinite bus system. The transient process and corresponding critical fault clearing time during terminal fault condition was analysed. The methods for improving the transient stability of different distributed generation used in the analysis such as speed adjustment for improved mechanical power of the synchronous generator based distributed generation interface and the use of well-established control system in grid connection for inverter based distributed generation interface were put forward in the research work.

Analysis of the transient stability in distribution system with distributed generations was the subject of discussion reported by Madruga *et al*., (2018), where a global methodology for the evaluation of transient stability of distribution system connected with distributed generation system was presented. Distributed generation technologies such as wind and small hydro plants were connected to the system with different case studies of transient conditions. Results obtained when compared with acceptable limits showed that the system was stable in some cases and unstable in others during the transient conditions in the system. In Kou *et al*., (2020), fault characteristics of distributed solar generation was presented with fault events recorded from different solar distributed energy resource sites analysed, during transient periods and steady state conditions. The system during transient period had high phase and negative sequence fault currents while under steady state condition, the fault currents in the system were continually lower than the output rated current with negligible negative and zero sequence current in the system.

Judging from the above it is obvious that information about studies of transient characteristics of distributed generation system is scanty in the literature. This study analyses transient characteristics of gas fired distributed generation system operating in a standalone mode with focus on the voltage and frequency of the system during transient conditions

2. METHODOLOGY

The dynamics of distributed generation system under transient conditions can be studied using set of equations that model the power system. The equations are expressible in per unit as follows:

$$\frac{H}{\pi f}.\frac{d^2\delta}{dt^2} = (P_i - P_e) \tag{1}$$

$$\frac{d\omega}{dt} = \frac{1}{2H}(P_i - P_e) \tag{2}$$

$$P_e = \frac{|\mathrm{E}||\mathrm{V}|}{X_T'} \tag{3}$$

where H is the inertia constant, f is the frequency, t is time in seconds, δ indicates the power angle, P_i is the input power, P_e represents the electromagnetic power, while ω, E, V and X_T' stand for aangular speed, internal voltage, terminal voltage and transient reactance, respectively.

Mathematical manipulations of Equations (2) and (3), allow the determination of the voltage and frequency responses of the distributed generation system under transient conditions. In this paper, a test distributed generator is modelled in MATLAB-Simulink environment using parameters of a natural gas-fired distributed generator. Parameters of the synchronous generator and governor system employed in the modelling of the system in MATLAB are shown in Tables 1 and 2, respectively. The IEEE Excitation AC1A was adopted.

Table 1: Distributed generator parameters

Parameters	Values
Direct axis synchronous (x_d)	300
Quadrature axis synchronous (x_q)	170
Direct axis transient (x'_d)	27.5
Direct axis sub-transient (x''_d)	12.6
Quadrature axis sub-transient (x''_q)	14.2
Negative sequence (x_2)	13.4
Zero sequence (x_0)	3.4
Open circuit (T'_{d0})	3.70
Transient (T'_d)	0.34
Sub-transient (T''_d)	0.018
Armature (T_a)	0.048
Power factor	0.8
Rated power	2 MW
Rated output voltage	400 V
Operating frequency	50 Hz
Inertia (H)	3
Number of phases	3

Table 2: Distributed generator governor parameters

Parameters	Values
Regulator gain (k)	55
Regulator time constants [T1, T2, T3]	[0.01, 0.02, 0.20] s
Actuator time constants [T4, T5, T6]	[0.2500, 0.0090, 0.0384] s
Torque limits [T_{min} , T_{max}]	[0, 1.1] pu
Engine time delay T_d	0.024 s
Initial value of mechanical power P_{mo}	0 pu

The MATLAB Simulink environment is used to implement the 2 MW natural gas-based distributed generator model, shown in Figure 1. It comprises of a synchronous generator with an output of 400 V and operating at a frequency of 50 Hz. The governor and excitation system are put in place to regulate the frequency and voltage of the generating system, respectively. Other entities in the model are connected to electrical loads, circuit breakers, and fault components. The generator is configured to operate in a standalone operating mode.

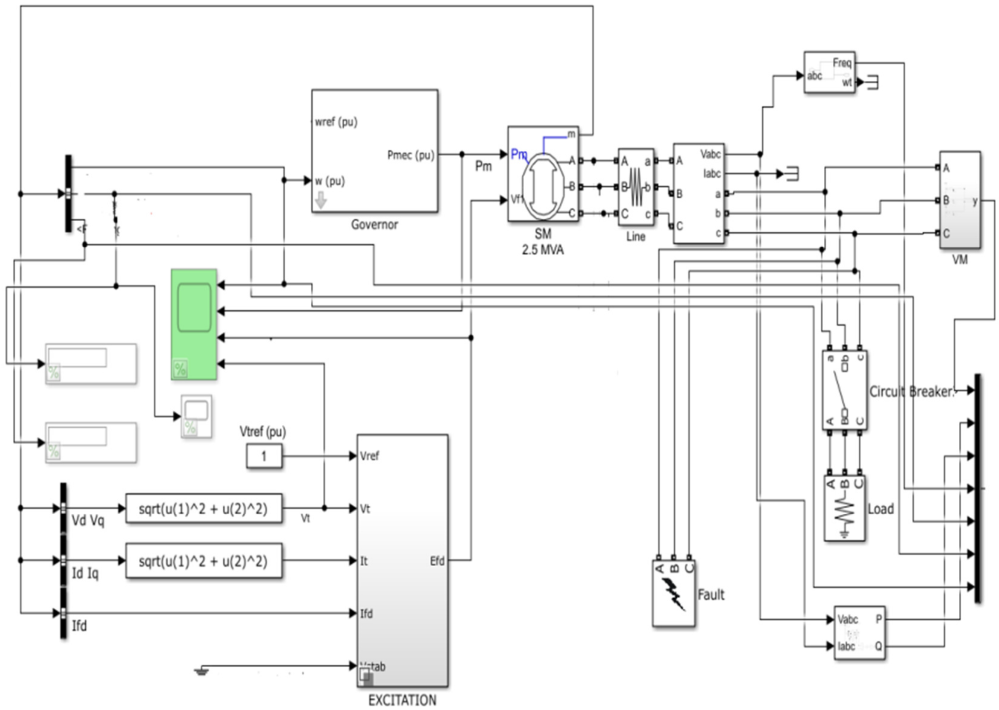


Figure 1: MATLAB-Simulink model of the 2 MW natural gas-fired distributed generator

3. RESULTS AND DISCUSSION

Simulation of the modelled natural gas-fired distributed generator was done under different fault scenarios. Results obtained from the analysis in terms of frequency response as well as voltage response are presented in what follows, beginning with those of line-to-ground fault.

3.1. Line-to-ground Fault

The distributed generation frequency response during line to ground fault with systems loads of 0.25, 0.50, 0.75 and 1.00 MW with fault times of 100 – 200 ms for each of the loads are shown in Figures 2(a)-2(d). A cursory look at the figures shows that the frequency of the system deviated below the nominal value of 50 Hz for each of the test loads for the duration of the fault. When values of the load are 0.25 and 0.50 MW, the frequency output was constant for each of the loads all through the duration of fault at 49.79 Hz and 49.69 Hz, as can be observed in Figures 2(a) and 2(b), respectively. A similar trend was also obtained for the 0.75 and 1.00 MW load as depicted in Figures 2(c) and 2(d), respectively, with a frequency output of 49.65 Hz in each case which was constant all through the duration of fault.

In the case of voltage response, obtained results when line-to-ground fault is injected are illustrated in Figures 3(a0-3(d). It is obvious that values of the voltage during the duration of fault deviated from the nominal system voltage of 400 V. The affected lines have voltage deviations below the nominal value of 400 V to be constant at 17.68, 31.66, 42.37, and 52.01 V, when values of test loads are 0.25, 0.50, 0.75 and 1.00 MW, respectively. The unaffected lines have values of their voltage deviated above the nominal values with minimum and maximum values for all the test loads at 573.0 and 663.8 V, respectively.

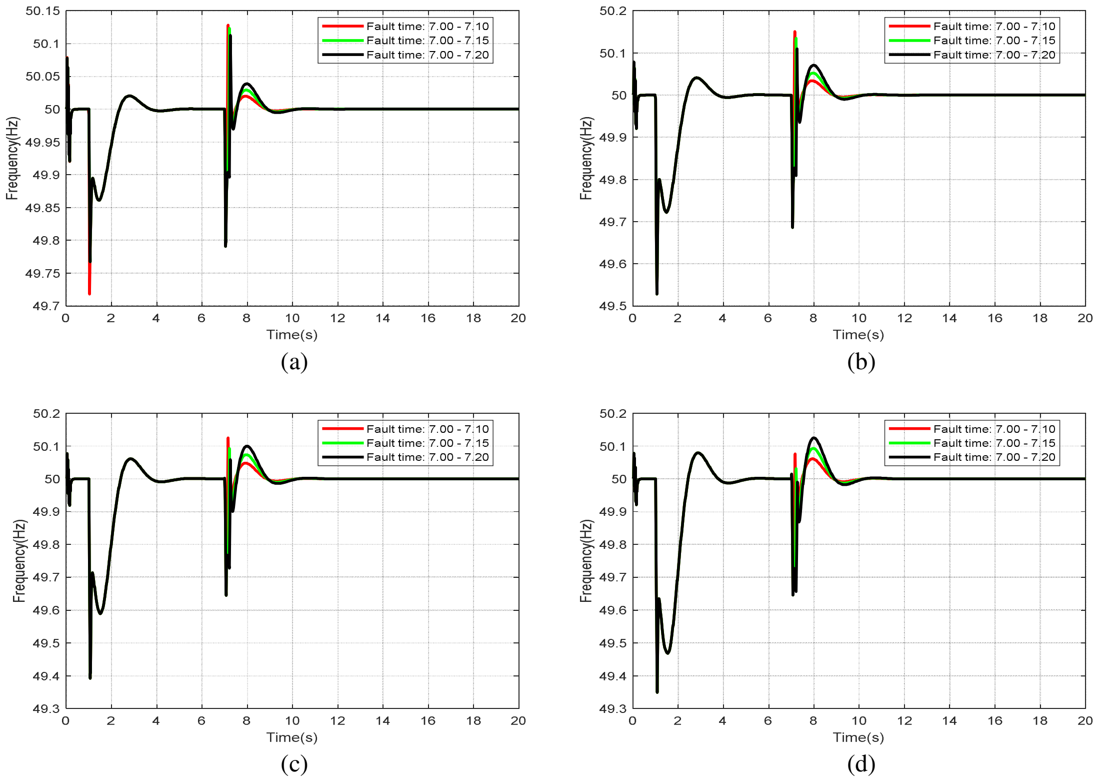
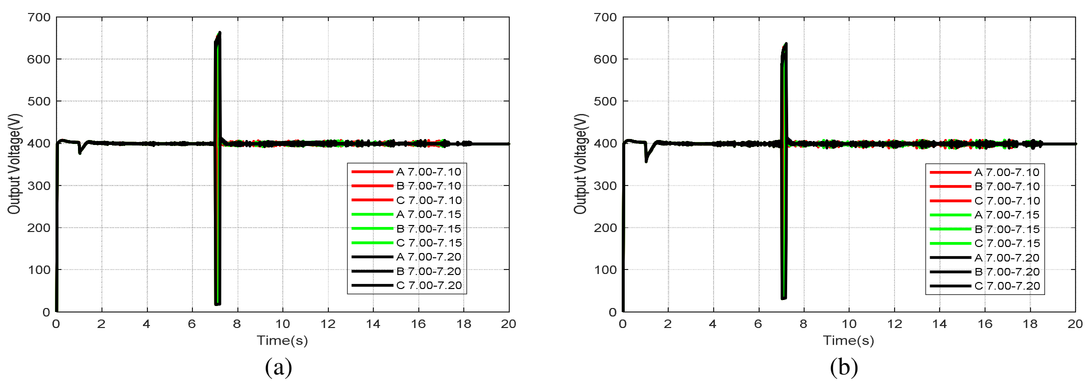
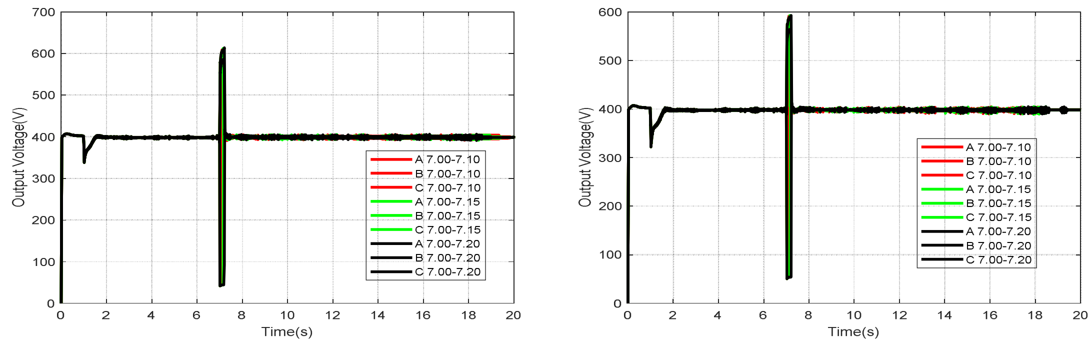


Figure 2: Frequency response of a 2 MW gas fired distributed generator when subjected to line –to-ground fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75 MW (d) 1.00 MW



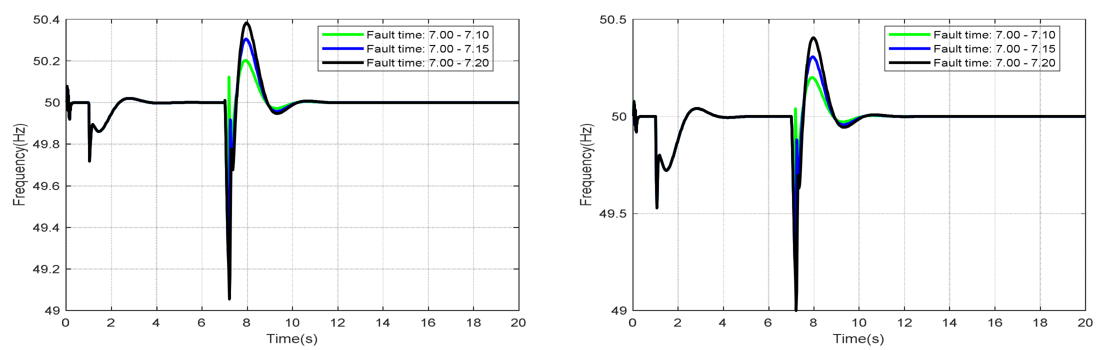


(c) (d)

Figure 3: Voltage response of a 2 MW gas fired distributed generator when subjected to line –to-ground fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75MW (d) 1.00 MW

3.2. Line-to-Line Fault

Next is the investigation of the behaviour of a standalone distributed generation unit when subjected to line-to-line fault. Figures 4(a)-4(d) depict obtained results for frequency response when values of applied loads are 0.25, 0.50, 0.75 and 1.00 MW with fault times ranging between 100 and 200 ms. It is observable from the results obtained from the simulation that the frequency of the system deviated below the nominal value of 50 Hz for each of the test loads and given fault times, with the associated frequency deviation due to each loads ranging between 48.69 and 49.52 Hz for line-to-line fault. The voltage of the system during the fault times deviated from the nominal system voltage of 400 V. The affected lines voltages deviation below the nominal value was observed to be constant irrespective of the value of the applied load as can be seen in Figures 5(a)-5(d). The values of voltage lie between 200.3 and 246.1 V for the test loads. The unaffected line voltage deviated above the nominal values and was observed to be constant with minimum and maximum values for all the test loads at 471.8 and 482.4 V, respectively, when the system is subjected to line-to-line faults.



(a) (b)

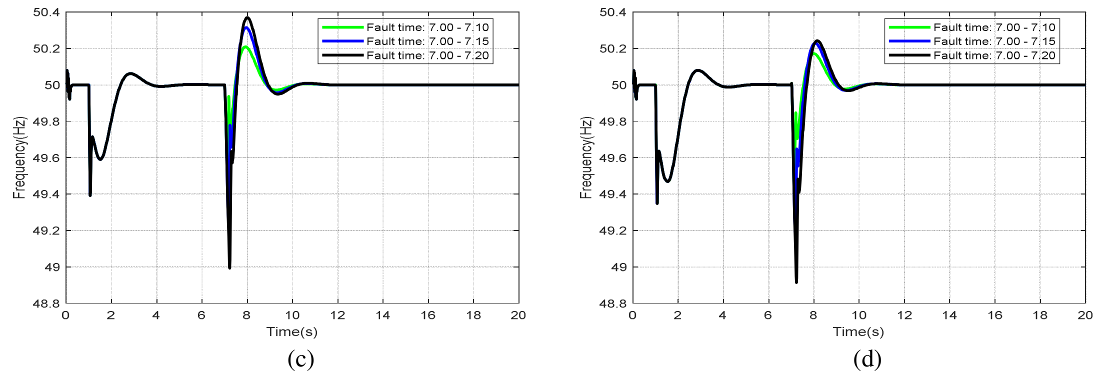


Figure 4: Frequency response of a 2 MW gas fired distributed generator when subjected to line –to-line fault under different loading (a) 0.25 MW (b) 0.5 MW (c) 0.75 MW (d) 1.00 MW

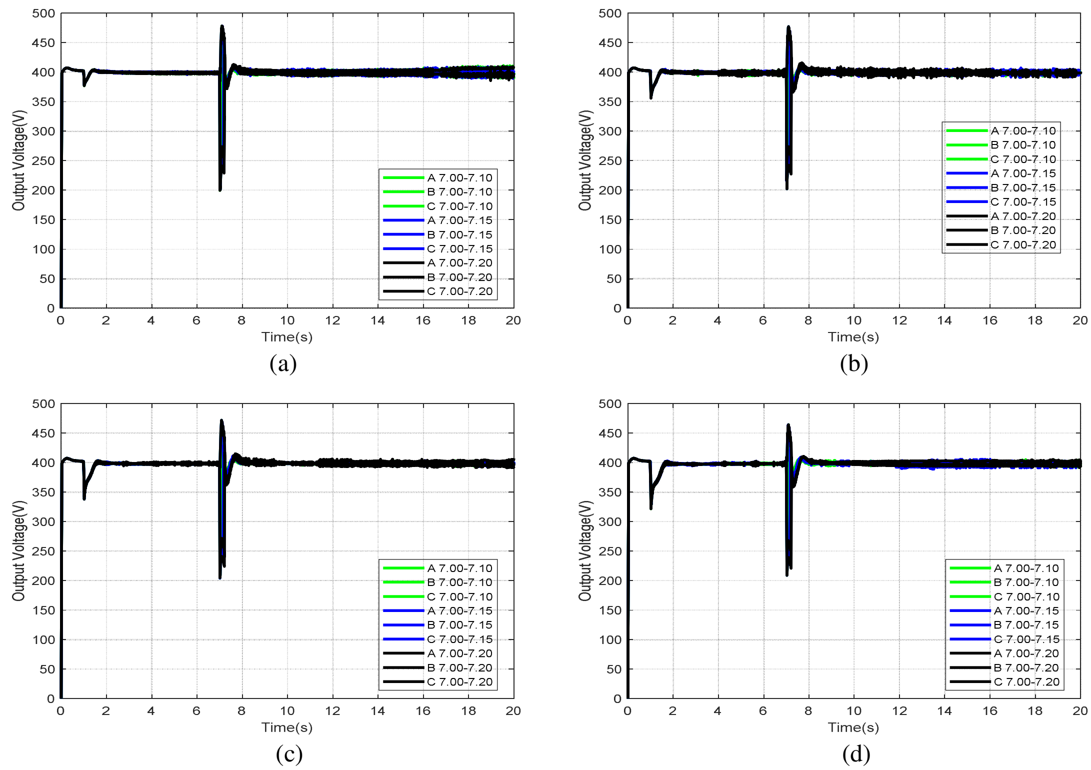
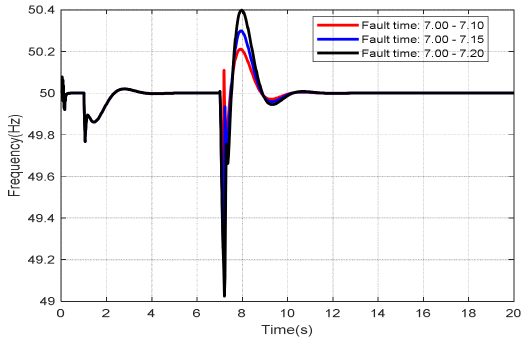


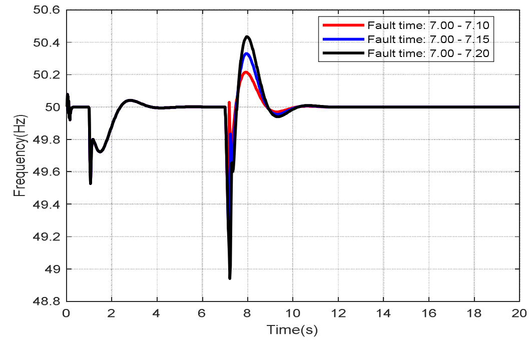
Figure 5: Voltage response of a 2 MW gas fired distributed generator when subjected to line –to-line fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75 MW (d) 1.00 MW

3.3. Double – Line-to-Ground Fault

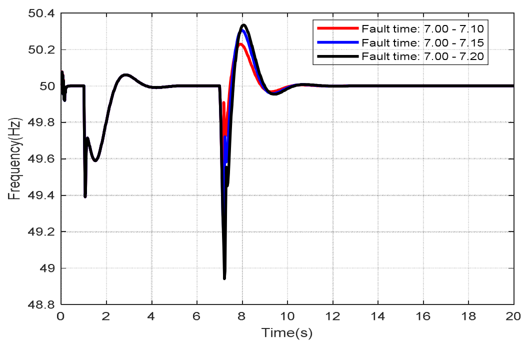
The frequency response of a distributed generator during double line to ground fault with system loads of 0.25, 0.50, 0.75 and 1.00 MW when the fault time ranges between 100 and 200 ms, are shown in Figures 6(a) – 6(d). Simulation results indicate that the frequency of the system deviated below the nominal value of 50 Hz for each of the test loads and given fault times with the frequency deviation of each loads ranging between 48.82 Hz and 49.46 Hz during the fault.



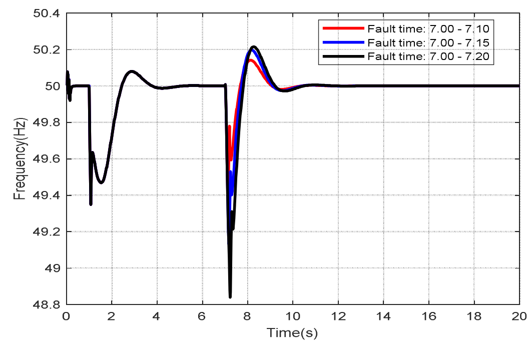
(a)



(b)



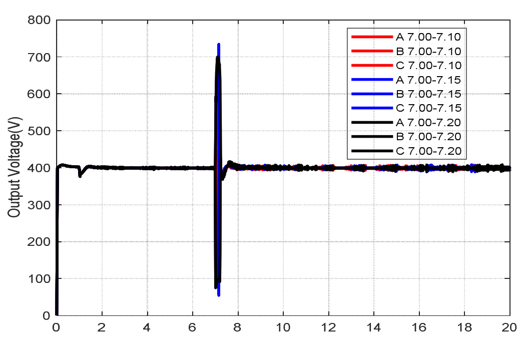
(c)



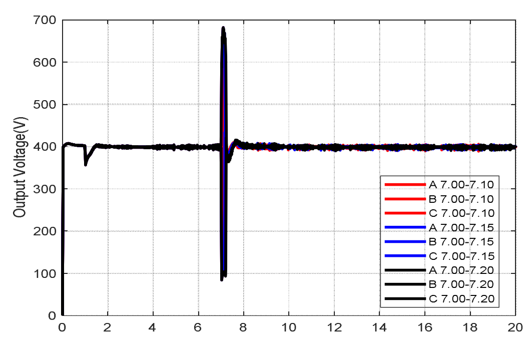
(d)

Figure 6: Frequency response of a 2 MW gas fired distributed generator when subjected to double-line –to-ground fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75 MW (d) 1.00 MW

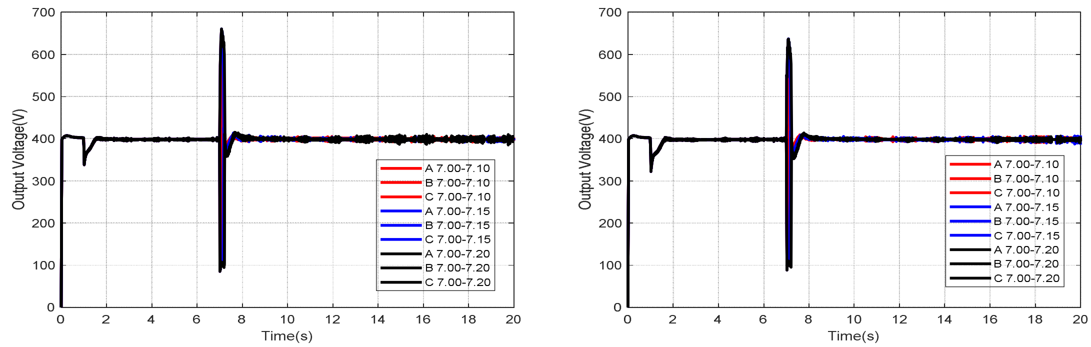
The output voltage of the system during the fault as shown in Figures 7(a)-7(d) deviated from the nominal system voltage of 400 V. The affected lines voltages deviation below the nominal value are observed to be constant with minimum and maximum voltage values at 75.5 V and 109.8 V, respectively, for each of the test loads. The unaffected line voltage deviated above the nominal values and was observed to be constant with minimum and maximum values for all the test loads ranging between 644.5 V and 708.5 V, respectively.



(a)



(b)

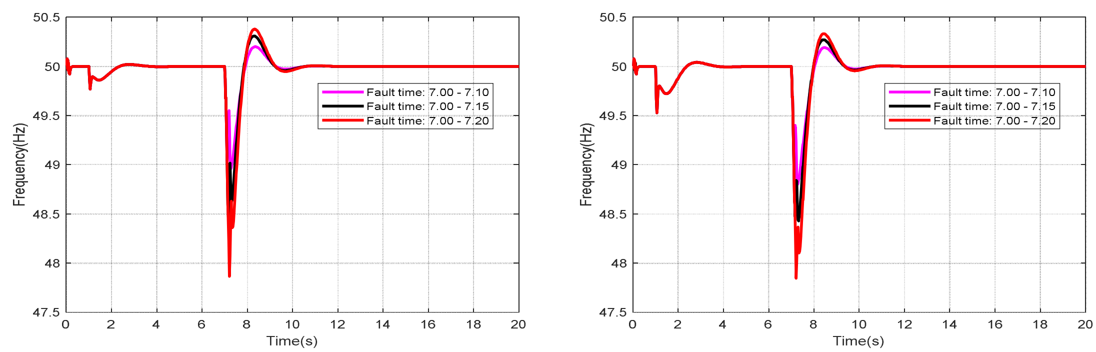


(c) (d)

Figure 7: Voltage response of a 2 MW gas fired distributed generator when subjected to double-line –to-ground fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75 MW (d) 1.00 MW

3.4. Three-Phase-to-Ground Fault

The distributed generator frequency response the three phase to ground fault with system loads of 0.25, 0.50, 0.75 and 1.00 MW with fault times of 100 ms – 200 ms for each load are shown in Figures 8(a)-8(d). Analysis of results showed that the frequency of the system deviated below the nominal value of 50 Hz for each of the test loads and given fault times with the frequency deviation of each loads ranging between 47.85 Hz and 49.04 Hz during the fault. Analysis of results obtained from the simulation for voltage response displayed in Figures 9(a)-9(d) reveal that the voltage of the lines during the fault times deviated from the nominal system voltage of 400 V. The affected lines voltage deviation below the nominal value was observed to be constant at 93.7 V, 94.3 V, 98.6 V, and 109.4 V when values of the test loads are 0.25, 0.50, 0.75 and 1.00 MW, respectively, for the duration of the fault condition.



(a) (b)

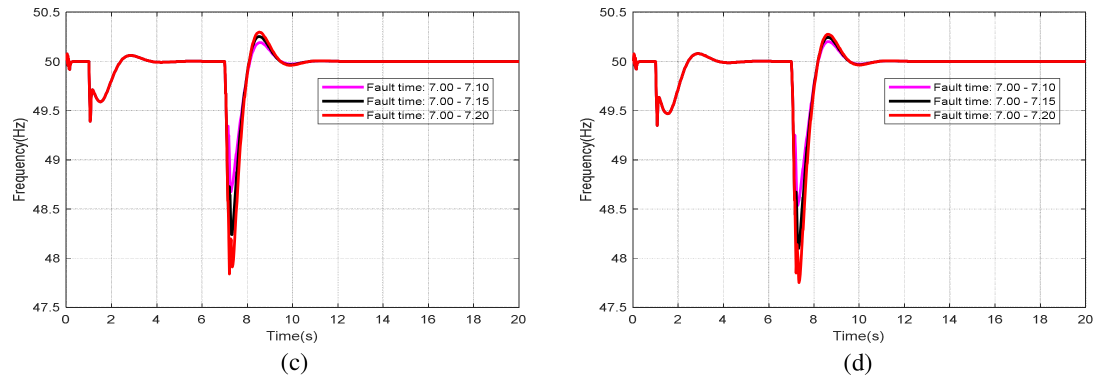


Figure 8: Frequency response of a 2 MW gas fired distributed generator when subjected to three-phase -to-ground fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75 MW (d) 1.00 MW

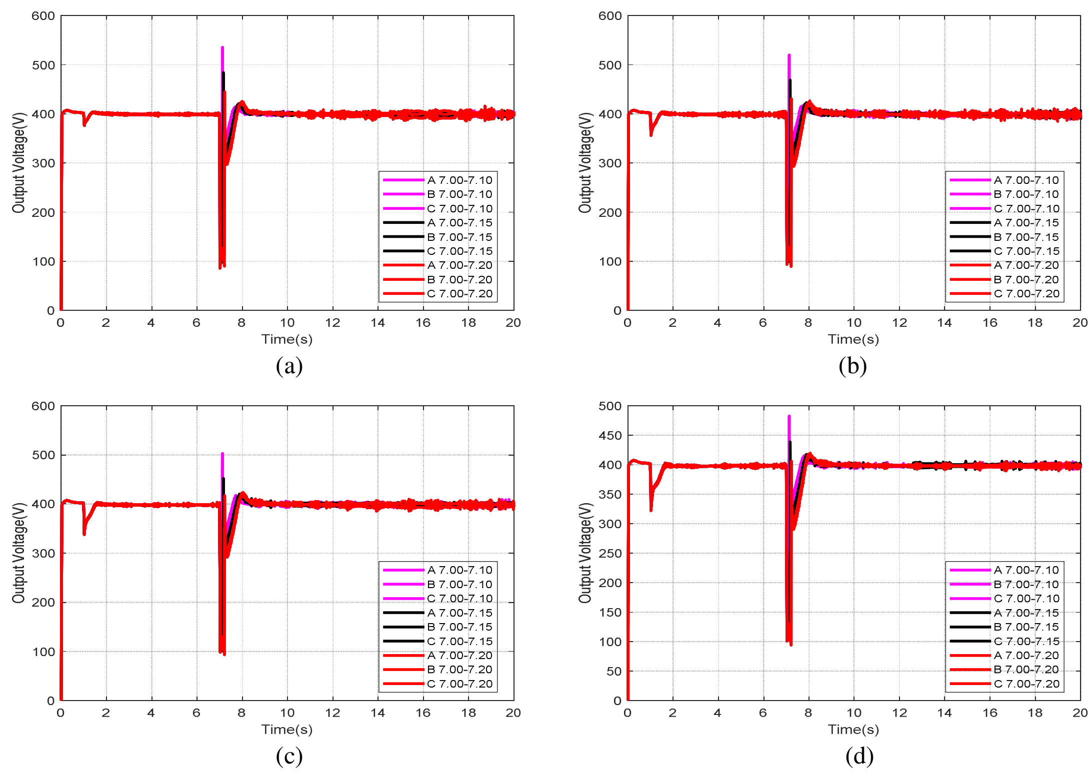


Figure 9: Voltage response of a 2 MW gas fired distributed generator when subjected to three –phase- to-ground fault under different loading (a) 0.25 MW (b) 0.50 MW (c) 0.75 MW (d) 1.00 MW

4. CONCLUSION

The importance of transient stability analysis of distributed generation systems cannot be overemphasized as its penetration continues to be on the rise in today's modern power system. In this research, the distributed generation system components were modelled in MATLAB-Simulink environment. The model was simulated to analyse the frequency and voltage responses of the distributed generation system, under transient conditions for a standalone operation. Results showed that the distributed generation frequency varied below its nominal value of 50 Hz for each of the test loads for the duration of the fault conditions when the load was varied between 0.25 and 1.00 MW in step of 0.25 MW. Also, the distributed generation system voltage also experienced deviations with the affected line voltages falling below the nominal system voltage of 400 V while the unaffected line voltages deviated above the nominal value. Considering the findings from this paper, it is obvious that the distributed generator will impact the power system network greatly when connected to the grid, going by what obtains in transient analysis of a typical standalone distributed generator. Thus, measures need to be put in place to mitigate the effect on the power system network to avoid attendant damages that may follow.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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