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# EFFECT OF DISTRIBUTED GENERATION PLACEMENT ON NIGERIAN 33-BUS ILORIN INDUSTRIAL DISTRIBUTION FEEDER PROTECTION SCHEME

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**Abstract:** Electric distribution system in Nigeria is faced with acute problems that undermine the regular power supply to many consumers in the country. These include incompetent personnel, insufficient investment and huge load demand which affect the operation, planning, technical and safety issues of distribution networks protection scheme. As a result, high penetration of Distributed Generation (DG) has been incorporated to improve the network operation and protection scheme. However, effect of the incorporation of the DG into the network need to be studied in order to provide necessary solution for the network during contingency. Therefore, this research paper analyzed the effect of incorporation of DG on Nigerian 33-bus Ilorin distribution feeder during contingency in order to assists power system engineer in effective selection of protective relays and their rating when installed in power system with DG.

**Keywords:** Distribution Network, Distributed Generation, 33-Bus Ilorin Distribution Feeder, Protection Scheme, Contingency, Energy Demand.
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## I. Introduction

Nigeria distribution system since its inception is designed to operate radially whereby electric power flows in one direction from large generating power plants to the customers load along the radial feeder [1, 2]. The distribution system is being operated by Electricity Distribution Companies (DISCOS). The DISCO provide the connection between customers and the electricity grid, and responsible for transforming or stepping down electricity from the high voltage of 132 kV at the transmission level, to the lower voltage levels of 33 kV/11 kV/0.415 kV depending on the category of customer [1, 3, 4].

In recent times, the distribution network is constantly being faced with a very rapid growing load demand which always result in high network loss and on the operation, planning, technical and safety issues of the distribution networks [4].

In order to improve the load supply in the distribution network, various types of small generation sources, known as DG are been integrated into the distribution system due to their advancement in technologies and concern about the environmental impacts [1].. However, such services must be designed in a manner that is computationally feasible and efficient, because DG systems utilized electronic power converters which may affect the coordination between protective devices [3, 5]. Thus, effect of DG on existing protection system on the distribution network must be effectively examined through detailed simulations of power system protection studies

### A. Nigerian 33-bus Ilorin Distribution Feeder

For the purpose of this research paper, data of practical Ilorin industrial 33 kV feeder distribution network of Ibadan Electric Distribution Company (IBEDC) Nigeria was used. The single-line diagram of 33kV 33-bus Ilorin industrial distribution feeder which spans a length of about 40 km proposed as a case study is shown in Figure 1. The distribution feeder has thirty three buses with seventy number of substations, four injection substation with a total real power loads and reactive power of 6.15 MW and 3.04 MVar respectively, where 4.27 MW of load is connected upstream of the recloser while 1.18 MW is downstream of the recloser [2, 6, 7].

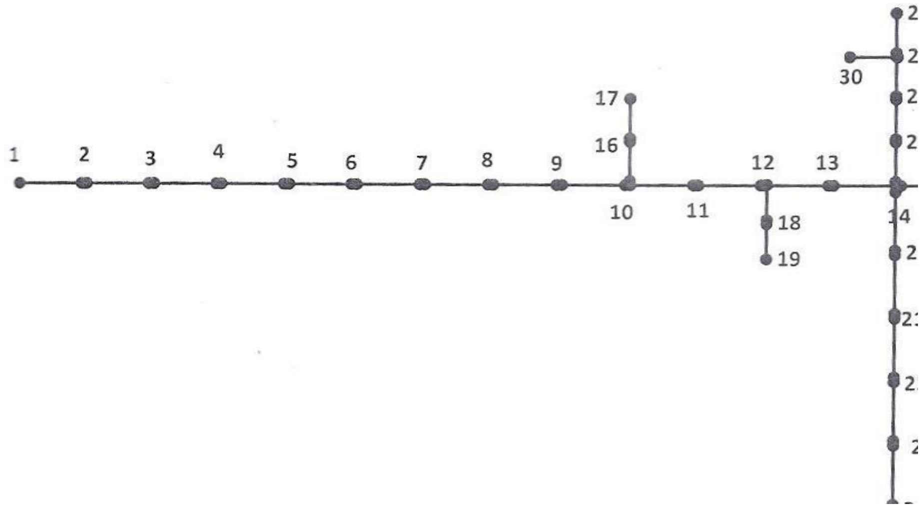

Figure 1: 33kV 33-Bus Ilorin Industrial Distribution Feeder

### B. Distributed Generation

Distributed Generation (DG) is electricity-generating plant connected to a distribution system rather than the transmission system. DG is a key element in a growing number of Distributed Energy Resources (DERs) that are being deployed across the distribution grid. They range from larger generation plants to small scale resources [2, 5, 8]. DG has been growing rapidly in deregulated power systems due to their potential solutions in meeting localized demands at distribution level and to mitigate limited transmission capacities from centralized power stations [9 – 11].

The DG resources include a variety of energy sources, such as turbines, photovoltaic's, fuel cells and storage devices, with capacities range between 1 kW to 10MW [12, 13]. Integration of DGs into the distribution systems alters the basic configuration from a passive system to an active one and this potentially increase the network reliability, reduces line losses, improves the voltage profile, reduces emissions of pollutants, increases overall energy efficiency, improves power quality and lowers the cost of power delivery by placing energy sources nearer to the demand centers [14 -18\.

The DG can be classified into two major groups namely: inverter based DG and rotating machine DG. The inverters are used in DG systems after the generation process as the generated voltage may be in DC or AC form. The primary purpose of the inverter is to enable an efficient interconnection and economical operation for inverter based DG installations to the utility grid [13, 19]. While rotating machine base DG generates and transforms electric power from one form to another such as a motor, generator, or synchronous generator, rotating machine based DG are highly capable of sustaining an island with fast response governors [11, 17, 20]

## II. Materials and Methods

The Bus Injection to Branch Current (BIBC) and the Branch Current to Bus Voltage (BCBV) distribution load flow analysis was performed for steady state and contingency with DG on 33-bus Ilorin industrial feeder shown in Figures 2. The placement of DG was considered at load buses and the control variables are generator bus voltage magnitude and Volt Ampere Reactive (VAR) outputs from DG. These control parameters were adjusted for loss reduction. For contingency with DG on protective relays, the coordination of protective settings was treated as a linear programming problem for minimizing the total functional relay operating time.

### A. BIBC-BCBV load flow without and with DG

A BIBC and BCBV of Forward and Backward Sweep (FBS) load flow calculation of distribution system was used in this research paper with the incorporation of study data of practical Ilorin industrial 33 kV feeder distribution network of Ibadan Electric Distribution Company (IBEDC) Nigeria. The single-line diagram of 33kV 33-bus was utilized to perform a load flow for steady state due to the radial nature and high resistance to reactance ratio of the distribution system, in order to obtain system conditions prior to the inclusion of DG. Critical buses were identified. After running the network at steady state, DG model was incorporated into the network to inject reactive power at defective buses where voltage magnitude falls outside the acceptable voltage range of ±5 % and to check the network performance on power loss.

The DG load flow model was utilized based on the following assumptions:

i. The distribution system is a balanced 3-phase system
ii. Distributed generators are classified as constant PQ or PV nodes.
iii. For PQ units, the model was identical with constant power load model, except that the current was injected into the bus.
iv. For PV units, the connected bus was modeled as a PV node. s

From a single line diagram of a distribution network shown in Figure 2 with generator arbitrarily connected, the load flow calculation for the distribution network without and with DG was computed according to Cohen *et al*. (2015) as illustrated in equations (1) to (3):

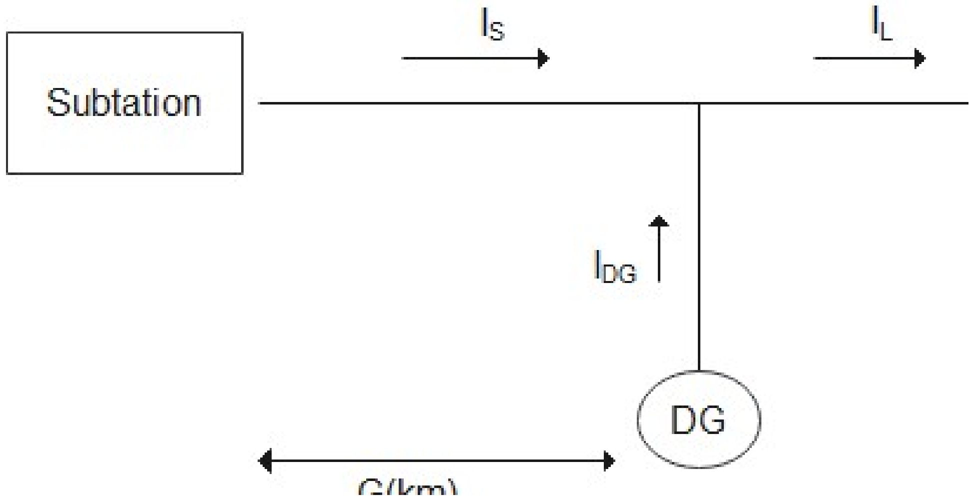

Figure 2: Distribution Network with incorporation of DG

The current in the network is given as:

$$I_{DG} = \left(\frac{S}{3V}\right)^* \tag{1}$$

The amount of power loss in the absence of DG is given as:

$$P_{Loss}^{withoutDG} = 3R_L \times (I_L)^2 \tag{2}$$

The amount of power loss in the presence of DG is given as:

$$P_{Loss}^{withDG} = 3R_G[(L_S)^2 + (I_L)^2] \tag{3}$$

where; $I_S$ and $I_L$ are the branch current, $R$ is the resistance of the network.

The simulation of BIBC-BCBV load flow of FBS algorithm without and with DG was done using MATLAB R2021a. The simulation was carried out according to the following steps:

Step 1: The system data such as distribution line, generation, and load data and the values of DG parameters were input;

Step 2: The node current or node current injection matrix was calculated without and with the integration of DG. The relationship was expressed as shown in equations (4) and (5):

$$I_i^k = \left(\frac{P_i+jQ_i}{V_i^k}\right)^* \tag{4}$$

$$I_{Di}^{DG} = \left(\frac{S_{Di}-S_{DGij}}{V_i}\right)^* \tag{5}$$

$$\text{for} \quad i = 1, \dots \dots \dots N$$

Step 3: Iteration count was set as $i = 0$

Step 4: BIBC matrix was formed

Step 5: The branch current was evaluated by using BIBC matrix and current injection matrix. The relationship was expressed as equation (6):

$$[I_B] = [BIBC] \cdot [I_n] \tag{6}$$

Step 6: BCBV matrix was formed. The relationship was therefore expressed as equation (7):

$$[\Delta V] = [BCBV] \cdot [I_B] \tag{7}$$

Step 7: The DLF matrix was calculated. The DLF matrix is the product of (6) and (7) which is expressed as shown in equations (8) and (9):

$$[DLF] = [BIBC] \cdot [BCBV] \tag{8}$$

$$[\Delta V] = [DLF] \cdot [I_n] \tag{9}$$

Step 8: Iteration count was set as $i = 1$ and updated voltage magnitudes were computed according to equations (10) and (11):

$$[\Delta V^{k+1}] = [DLF] \cdot [I^k] \tag{10}$$

$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}] \tag{11}$$

Step 9: The process was repeated until the voltage difference reached the specified accuracy as show in Equation (12), if not, simulation went back to step 5.

$$\left(\left|V^{(k+1)}\right| - \left|V^{(k)}\right|\right) \leq \varepsilon \tag{12}$$

Step 10: The node voltage magnitudes and angle, branch currents and losses are display and then the simulation was stopped.

### A. BIBC-BCBV load flow for Contingency with DG

The BIBC and BCBV of FBS load flow calculation of distribution system was performed for stability of the distribution system with DG to obtain system conditions prior to the contingencies. After running the network with DG at steady state, contingency was introduced by increasing the load bus of the selected case study by 70 % loading [16, 18, 20] to check the stability of the system during failure of the components and to verify the DG effect on system protection coordination. The protection coordination and sequence of relay operation for faults in different buses were checked. The critical buses were identified and ranked based on network power loss.

The simulation for BIBC and BCBV load flow with DG for contingency was carried out in MATLAB R2021a according to the following steps:

Step 1: The initial values of the particles, sizes of the DG and the bus voltage limits were randomly generated;

Step 2: Load flow at steady state operation without and with DG was performed;

Step 3: BIBC and BCBV load flow for contingency with DG was performed;

Step 4: The performance of DG on system protection was monitored;

Step 5: The system was checked for any increment in the system fault current through the protection after DG incorporation;

Step 6: The updated voltage magnitudes were computed according to equations (10) and (11):

Step 7: The convergence was checked and if the voltage mismatch was not verified, power equations were mismatched until convergence was achieved. Else, the power flow results were displayed.

## III. Results and Discussion

In this section, distribution load flow analysis using Bus Injection to Branch Current (BIBC) and the Branch Current to Bus Voltage (BCBV) with voltage permissible working range values of 0.95 to 1.05 p.u, (±5%) and relay settings time-stepped of 0.3 to 0.5 sec. for steady state and contingency (70% loading) on 33-bus Ilorin industrial feeder with Distributed Generation (DG) incorporated was presented. The simulation was carried out in MATLAB R2021a. The system voltage magnitudes, current, relay operating time and power losses were presented.

Table 1 showed the simulation results of load flow of 33-bus Ilorin industrial feeder at steady state. From the Table, it was revealed that buses 5, 14, 19 and 31 with voltage magnitude of 1.0558, 0.9237, 0.9312 and 1.0542 p.u, and corresponding voltage angles of 0.9320, 2.8534, 8.7729 and -4.2724 degree, respectively, were buses whose voltage fell short of the ±5 % tolerance margin of the voltage criterion and therefore are potential buses for the integration of DG. These busses have pre fault system current and primary relay operating time of 16.367, 14.308, 17.674 and 13.931p.u; 0.2, 0.6, 0.2 and 0.1 seconds. Furthermore, the active line losses in these buses are 57.79, 0.02, 0.35 and 0.68 MW, while the total active and reactive line losses in the industrial feeder were 247.29 MW and 393.04 MVAR respectively.

Table 1: Load Flow Result of Selected load buses of 33-Bus Ilorin feeder at Steady State

| Bus No | Bus Type | Voltage Profile (p.u) | Voltage Angle (deg) | Current (p.u) | Relay Operating Time (s) |
|---|---|---|---|---|---|
| 5 | PQ | 1.0558 | 0.932 | 16.367 | 0.2 |
| 14 | PQ | 0.9237 | 2.8534 | 14.308 | 0.6 |
| 19 | PQ | 0.9312 | 8.7729 | 17.674 | 0.2 |
| 31 | PQ | 1.0542 | -4.2724 | 13.931 | 0.1 |
| Total Power Loss | | | | 247.29 MW | 393.04 MVAR |

Table 2 presented the simulation results of load flow of 33-bus Ilorin industrial feeder with DG incorporated, with DG size of 10, 12.5, 15 and 12.5 MW and primary relay power rating of 30, 45, 35 and 50 MVar incorporated on buses 5, 14, 19 and 31, respectively. The voltage magnitude of the selected buses 5, 14, 19 and 31 whose voltage magnitude fall short of the ±5 % tolerance margin of the voltage criterion at steady state were improved to 1.0094, 0.9793, 0.9594 and 0.9804 p.u, respectively. However, It was observed that with incorporation of the DG unit, the current in these buses were increased to 17.967, 17.568, 10.228 and 16.458 p.u, compared with steady state value of 16.367, 14.308, 17.674 and 13.931p.u; respectively. The increment caused the primary operating time setting to exceed its interrupting current ratings. The primary relay operating times in these buses were 0.1, 0.2, 0.1 and 0.2 seconds, respectively. In addition, the total active and reactive line losses in the feeder were reduced to 234.51 MW (5.2%) and 376.50 MVar (4.2%), respectively compared with steady state value of 247.29 MW and 393.04 MVAR.

Table 2: Load Flow Result of 33-Bus Ilorin feeder with DG

| Bus No | Bus Type | Voltage Profile (p.u) | Voltage Angle (deg) | Current (p.u) | Relay Operating Time (s) |
|---|---|---|---|---|---|
| 5 | PQ | 1.0094 | 2.9408 | 17.967 | **0.1** |
| 14 | PQ | 0.9793 | 2.8612 | 17.568 | **0.2** |
| 19 | PQ | 0.9594 | 8.7997 | 18.870 | **0.1** |
| 31 | PQ | 0.9804 | -4.2168 | 16.458 | **0.2** |
| Total Power Loss | | | | 234.51 MW | 376.50 MVar |

Figure 3 showed the comparison of voltage magnitude with the bus number of the 33-bus Ilorin industrial feeder with inclusion of DG at contingency (post fault), with 70% increase in load bus of the 33-bus Ilorin industrial feeder to check the stability of the feeder during failure of the components and to verify the DG effect on system protection coordination. Buses 5, 14, 19 and 31 whose voltage magnitude, fell short of the ±5 % tolerance margin of the voltage criterion at steady state were also examined. It was observed that the voltage magnitude of the selected buses reduced tremendously to 0.9660, 0.9570, 0.9520 and 0.9500 p.u with corresponding voltage angles of 9.6320, -1.3770, -11.4740 and 2.4450 degree, respectively.

In addition, the comparison of system current with the bus number of the 33-bus Ilorin industrial feeder with inclusion of DG at contingency (post) is presented in Figure 4. From the Figure, the system current in the selected buses 5, 14, 19 and 31 whose voltage magnitude fell short of the ±5 % tolerance margin of the voltage criterion at steady state were increased tremendously to 33.612, 19.815, 20.812 and 26.495 p.u compared with system current value of 17.967, 17.568, 10.228 and 16.458 p.u,, respectively with DG only.

Figure 5 illustrated the comparison of relay operating time of the 33-bus Ilorin industrial feeder with inclusion of DG at contingency (post). The primary relay operating time of the selected buses 5, 14, 19 and 31 at steady state were increased to 0.13, 0.10, 0.11 and 0.12 seconds compared with relay operating time value of 0.1, 0.2, 0.1 and 0.2 seconds, respectively with DG only. It was also observed that the primary relay operating time were out of delay time settings range.

Figure 6 showed the variation of system active line losses of the 33-bus Ilorin industrial feeder with inclusion of DG at contingency (post). The total active and reactive line losses in the feeder at contingency were 247.02 MW (0.1 % increased) and 392.05 MVar (0.3 %), respectively compared with steady state value of 247.29 MW and 393.04 MVAR.

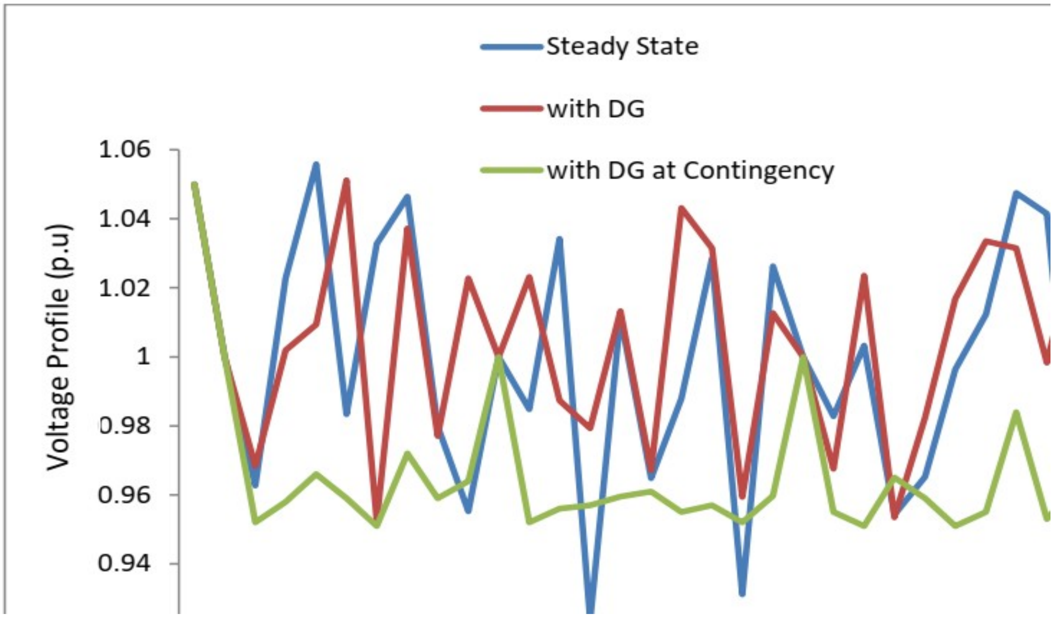

Figure 3: Voltage Magnitude of 33-Bus Ilorin Feeder with DG at contingency

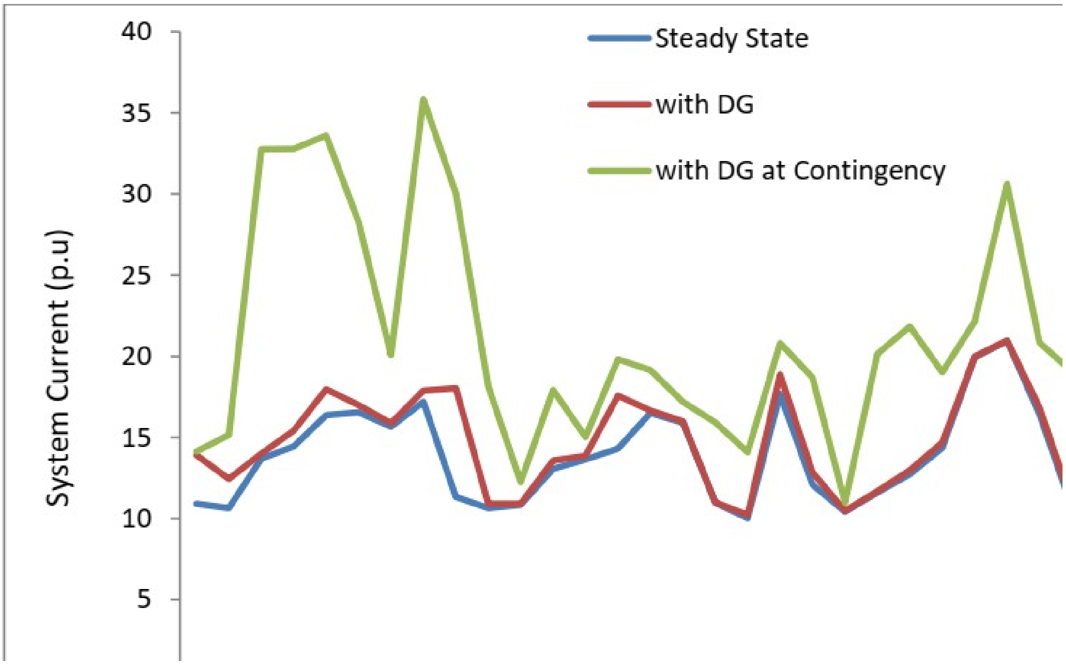

Figure 4: System Current of 33-Bus Ilorin Feeder with DG at contingency

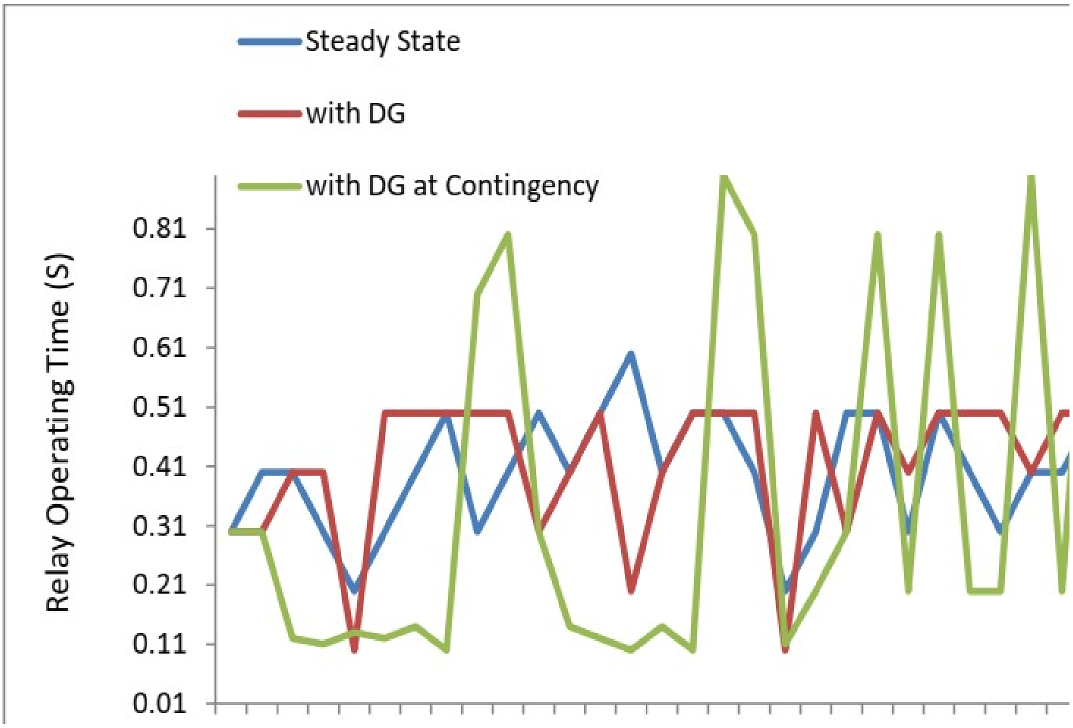

Figure 5: Relay Operating Time of 33-Bus Ilorin Feeder with DG at contingency

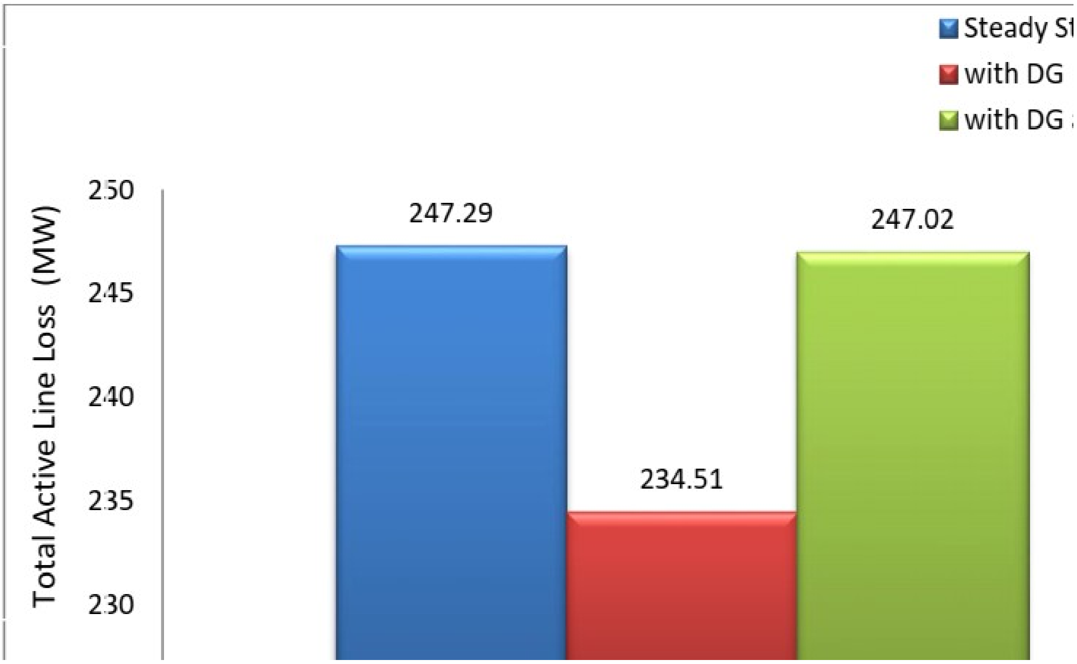

Figure 6: Total Active Line Loss of 33-Bus Ilorin Feeder with DG at contingency

## IV. Conclusion

This research paper has successfully presented the effect of DG incorporation on Nigerian 33-bus Ilorin distribution feeder protection scheme coordination during contingency (70% loading). This was done to improve the distribution network protection scheme with inclusion of DG during high load demand. The results of the analysis revealed that, the load flow results of the industrial feeder at steady state and contingency showed that the power station was unstable and this verified the radial nature of the power system which makes it to experience voltage instability. However, with application of DG, the system current increased abnormally and relay operating time setting was reduced due to changes in the relay sensing path Thus, the results provide effective information on the distribution feeder protection problems associated with incorporation of DG in the distribution system.

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