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Assessing the Impact of Distributed Generation in Etekwuru 11/0.415 kV Distribution Sub-Station.

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ABSTRACT

In electrical distribution systems, it is crucial to employ methods of power flow optimisation due to the nature of connected loads (inductive), which create voltage dips and power losses. Thus, this research work focuses on evaluating the impact of Distributed Generation (DG) on the overall performance of the system, using the Etekwuru $11/0.415kV$ distribution network as a case study. In a bid to ascertain the state of the power system, a load flow analysis was conducted using the Newton-Raphson method of solution. The results showed that 6 of the 11 buses had a critical magnitude of under-voltage, and that the total active and reactive power loss was 42.5 kW and 51.8 $kVAr$, respectively. Thus, the DG was inserted at Bus 6, and a load flow analysis was carried out to verify its impact on the voltage profile of buses and power losses in the system. The results showed that all the buses were operating within the IEEE voltage range of +/- 5%. At the same time, the active and reactive power losses dropped significantly from $42.5\ kW\ to\ 12.3\ kW$ and from $51.8\ kVAr\ to\ -9.1\ kVAr$. Also, a short circuit analysis was done both with and without the DG. The results showed that the DG makes the fault current stronger in the system. The total magnitude of the maximum fault current at the buses increased from $52.739\ kA\ to\ 59.976\ kA$, while the total magnitude of the minimum fault current increased from $38.238\ kA\ to\ 46.356\ kA$, respectively. Finally, an over-current protection scheme was created using Siemens 7SJ61 relays along with current transformers and circuit breakers, but not the DG. A three-phase fault was added in several places to see how well the scheme worked, and the results were confirmed by the fact that the relays sent out trip signals when they needed to. It was tested with a three-phase fault after the DG was added to see what effect it had. The results showed that the DG caused the relays to trip too often because it caused a short-circuit, creating another research gap for future researchers.

1. Introduction

Electricity is essential for fuelling the economic development of nations, regardless of their developmental stage. With the advancement of technology and population growth, the electricity demand has soared, surpassing supply and causing strain on power networks (Stephen *et al*., 2019). Less than forty percent of Nigeria's population can dependably and reliably access top-notch electricity. Essentially, Nigeria's current power system operates by generating electricity in the traditional manner at remote facilities, transmitting it at high voltage through transmission stations to the distribution network, and then supplying it to consumers at a lower voltage level. This setup often leads to issues such as low voltages, significant losses in the network, and repeated instances of partial or total network collapse (Taiwo *et al*., 2021).

The power system loses approximately 13% of generated power, with the distribution network accounting for around 70% of this loss. These significant losses within the distribution system can be attributed to various factors, such as the structural configuration of distribution grids, often characterised by radial or loosely interconnected layouts; the prevalence of unbalanced loads with higher resistance to reactance (R/X) compared to transmission systems; and the abundance of system components. We have observed a distinct trend and significant expansion in distributed generation (DG) following the privatisation of the electricity sector. This approach involves the use of small-scale technologies to produce electricity closer to end users, signalling a significant advancement in the industry (Prahlad & Laxman 2019). In simple terms, Distributed Generation (DG) is typically not linked directly to the primary power generation or large-scale transmission systems. Instead, it's usually connected closer to the end user. DG comprises both traditional (non-renewable) and renewable energy sources. Traditional DG technologies, like internal combustion engines, gas turbines, and microturbines, rely on non-renewable energy sources. On the other hand, renewable DG technologies encompass solar PV, wind, fuel cells, small hydro, biomass, solar thermal, and geothermal systems. These technologies vary in size and are commonly integrated into the grid (Sunkanmi & Akmal, 2021).

In the past, power distribution typically followed a one-way path from higher to lower power levels in a radial network. However, with the integration of Distributed Generation (DG) into the existing system, the flow of power throughout the distribution network has been altered. As a result, the distribution network now comprises both centralised and distributed generation sources. This new setup offers consumers more flexibility in accessing power, as they can draw electricity from both centralised distribution systems and distributed generation sources (Adlan *et al*., 2019).

There are many benefits to adding distributed generators (DGs) to the distribution system. These include lower line losses, better voltage profile, better stability and power quality, higher network efficiency, higher reliability, higher security, less transmission and distribution congestion, delayed investments in facility upgrades, lower operational and maintenance costs, and no fuel costs related to DGs (Sunday *et al*., 2023).

Neglecting to assess the inclusion of distributed generators (DGs) in the distribution network can result in various problems, including overvoltage events and heightened system losses. Although integrating DG units into power grids presents evident benefits, their substantial impact on systems for protecting power networks introduces many challenges and uncertainties regarding fault detection and isolation in operational distribution networks.

Researchers have undertaken numerous endeavours to scrutinise the disadvantages of linking DG units and suggest strategies to mitigate their effects. This study assesses the impact of DGs on protection systems within distribution networks. Fang *et al.* (2021) conducted a study on a two-step distance protection method tailored for flexible HVDC transmission lines. In this study, different low-pass filters with different cutoff frequencies were used to process electrical parameters and make the protection system faster and more reliable. The results of the simulation showed that the suggested distance protection system can quickly and reliably find metallic pole-to-ground and pole-to-pole faults.

Ogboh *et al.* (2019) examined how distributed generation impacts the grid network in Nigeria's southeastern region. NEPLAN software was employed to simulate the integration of distributed generation capacity into the network. The results indicated reductions in network losses, transmission line power losses, and congestion, as well as improvements in voltage profiles at network nodes.

Sanaullah *et al.* (2016) carried out various reliability tests on Bus 2 of the RBTS, revealing the varying effects of Distributed Generation (DG) on the reliability of the distribution network. The assessments demonstrated that integrating DG into the distribution system enhances the reliability of the power system. Moreover, it also showed that placing DG units nearer to load points or farther from the feeder enhances reliability even more. However, installing multiple DG units at the same location has a detrimental effect on distribution network reliability. Additionally, it is possible to evaluate the reliability value using a range of renewable or non-renewable energy sources.

Eltamaly *et al.* (2019) examined how Distributed Generators (DGs) affect the performance of power systems to elevate their quality, with a specific emphasis on enhancing voltage profiles and minimising power losses. The study used the IEEE-12 bus power system as an example to show how adding wind generation DGs to the distribution network can help control voltage and lower both active and reactive power losses.

Suresh *et al.* (2019) used an efficient approach employing VSI and FA to address the DG allocation issue. The study identified optimal locations through VSI and determined suitable sizes for the DGs using FA. Subsequently, the method was evaluated on an 85-bus system across various scenarios to assess its impact on losses, voltage profile, and VSI.

Deploying three DGs achieved optimal outcomes, including significant loss reduction, a favourable voltage profile, and enhanced VSI. Ultimately, the study demonstrated that the proposed method effectively minimises losses while enhancing the VSI and voltage profile of the distribution system to the desired degree.

Zineb *et al.* (2021) presented a comprehensive examination of how distributed generators influence the coordination of protection systems in distribution networks. It dug into the various solutions proposed in the existing literature to address the challenges posed by DGs, scrutinising both their effectiveness and limitations. The main goal of the study was to bring together all the relevant research on protection coordination in distribution networks with DG integration. This would create a single resource that would help researchers find new areas to study in the future.

Basudev & Bimal (2013) conducted a study on the impact of distributed generation on the reliability of the distribution system. The study aims to examine the effect of DG on the reliability of the distribution system.

Seyed-Ehsan *et al.* (2019) examined the suitable approach for managing Distributed Generators (DGs) within a power flow software created with MATLAB. They specifically designed this software for real-world unbalanced distribution networks in Iran. It was part of their study to find out how the placement of DGs and the control modes they have (like PV and PQ modes) affect things like voltage profile, power loss reduction, and voltage unbalance factor (VUF). They validated their findings by analysing simulation results and utilising metrics like voltage deviation, an unbalanced voltage factor, and power loss to assess the effectiveness of DG placement.

Christian and Al Ameri Ahmed (2013) highlight the importance of integrating Distributed Generation (DG) into utility systems efficiently. Their research emphasizes: Mesh and radial distribution systems have different capabilities to support DG penetration due to their distinct structures.

The study reviews the impact of DG on these systems, focusing on power losses, voltage profile, protection, reconfiguration, load balance, reliability, planning, and cost. The research suggests that distribution topologies significantly influence DG integration, depending on DG size, type, and penetration level.

Their analysis aims to enhance DG utilisation while minimising associated problems, providing valuable insights for electricity companies and markets seeking to optimise DG integration.

Zineb *et al.* (2021) provided an overview of how distributed generators influence the coordination of protection in distribution networks. They thoroughly examined the solutions suggested in the existing literature to counteract the adverse effects of DGs and scrutinised the constraints associated with these proposed methods.

To achieve the goal of this study, the following objectives were addressed.

i. To model the electrical network from the data collected using ETAP software.

ii. To use the given parameters to perform load flow of the characterized Etekwuru 11/0.415 kV distribution network to ascertain the network's existing operating state before DG installation.

iii. To conduct a short circuit and design a protective scheme for the network.

iv. To determine the impact of distributed generation on power flow, short-circuit and coordination of switchgears at various locations in the power system.

2. Materials and Methods

2.1 Materials

The materials used in this research work are a single-line diagram of the Etekwuru 11/0.415 kV distribution network, ETAP software, and a computer system. ETAP was used to represent the electrical power system network under study, and the per-unit system for all calculations. The analysis presents the fundamental equations necessary for load flow analysis, while the procedure describes the artificial intelligence technique employed. Network design and simulation data were obtained from First Independent Power Limited (FIPL) as shown in Table 1. Table 1 contains route lengths, voltage and apparent power ratings of distribution lines and transformers.

Table 1: Equipment Data

S/N	Equipment ID	Voltage Rating (kV)	Capacity/Length
1.	Line 1	33	7.5km
2.	Line 2	11	4km
3.	Line 3	11	7.5km
4.	Line 4	11	6km
5.	Line 5	11	3km
6.	T1	33/11	15MVA
7.	T2	11/0.415	0.5MVA
8.	T3	11/0.415	0.3MVA
9.	T4	11/0.415	0.5MVA
10.	T5	11/0.415	0.5MVA
11.	Lump 1	0.415	0.219MVA
12.	Lump 2	0.415	0.219MVA
13.	Lump 3	0.415	0.219MVA
14.	Lump 4	0.415	0.219MVA

(Source: First Independent Power Limited)

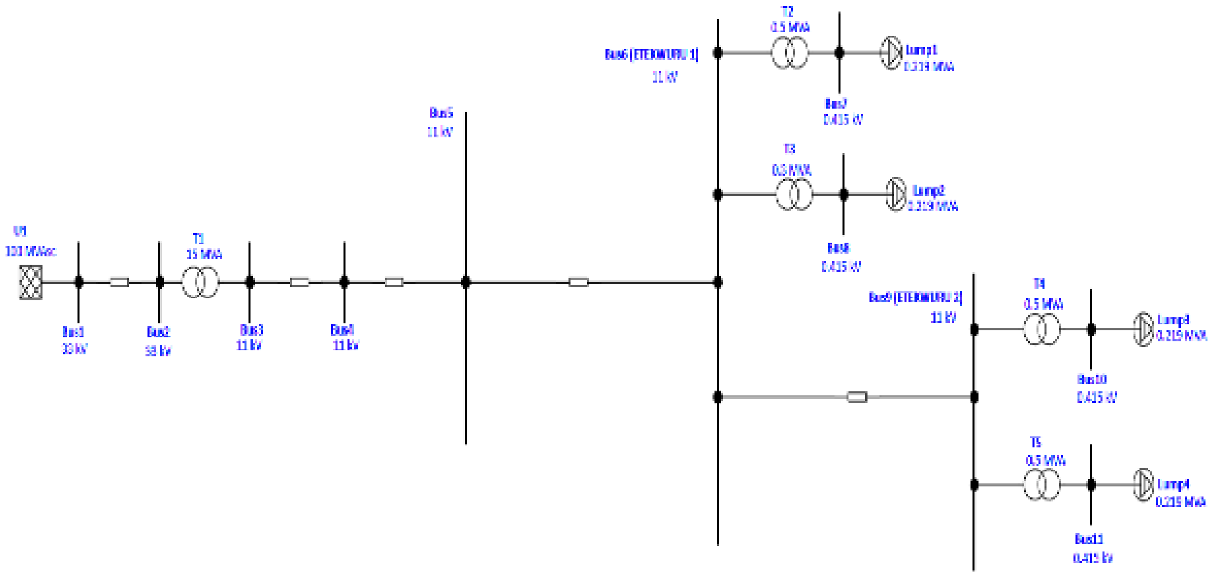

Figure 1: ETAP Representation of Etekwuru 11/0.415 kV Distribution Network

The network shown in Figure 1 contains 11 buses, 5 distribution transformers and line sections, 4 lumped loads and a grid representing the FIPL generating station.

2.2 Methods

The Newton-Raphson method was deployed for load flow studies, followed by a short-circuit analysis as per IEC 60909 standard, before designing an overcurrent protection scheme. Distributed generations (DGs) were inserted at weak buses to compare results obtained before and after installations. The network modelling, simulation and analysis were done in the ETAP environment.

2.2.1 Newton-Raphson Method

As usual, load flow analysis will be conducted on the network under investigation to ascertain the voltage level, power flow and loss magnitude under balanced steady operating conditions using the conventional Newton-Raphson (NR) solution algorithm. Thereafter, based on the findings, a novel capacitor allotment and sizing algorithm will be deployed for system parameter optimisation for an efficient and reliable power supply.

The Newton-Raphson method is valid for load flow analysis and deployed for solving the Jacobian matrix contained in equation 1(Ojuka & Ekwe, 2023).

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \quad (1)$$

Where ΔP and ΔQ are the actual bus power and the operating force do not exactly match the vectors between the stated value and the calculated value, respectively; ΔV and Δδ represent the maximum power of the bus and angles in the form of additions; and J_1 to J_4 are called Jacobean matrices.

2.2.2 Short-Circuit Analysis

Short-circuit analysis provides a systematic mathematical approach used in determining the magnitude of fault currents (symmetrical and asymmetrical) at various locations in the power system, protective device withstand and/or interrupting capability (device duty calculations), close and latch capability and determine appropriate ratings or settings for relay coordination by calculating the maximum and minimum fault current at the buses. As earlier stated, the method used in calculating short-circuit magnitude is the per unit impedance method, while the standard used is the IEC 60909, which accounts for symmetrical and asymmetrical faults respectively.

The procedure for short-circuit calculations includes:

i. Prepare the single line diagram with equipment ratings, voltage level and impedance.
ii. Convert the impedance value to a common base MVA.
iii. Combine impedances.
iv. Calculate short-circuit current at the fault location.

The per-unit method of fault current and MVA calculations are conducted using equations 2, 3 and 4, respectively (Gupta, 2008).

$$I_{sc} = \frac{Fault\ MVA}{\sqrt{3}\ X\ kV} \quad (2)$$

But,

$$Fault\ MVA = \frac{Base\ MVA}{Z_{pu}\ up\ to\ the\ point\ of\ fault} \quad (3)$$

where;

I_{sc} = Short-circuit current

MVA = Rated power

Z_{pu} = per unit impedance

$$Z_{pu} = \frac{Actual\ Impedance\ in\ Ohms\ x\ Base\ MVA}{(Base\ kV)^2} \quad (4)$$

2.2.3 Analysis of the Overcurrent Protection Scheme

The overcurrent protection scheme is one of the most widely used power system protection principles due to its simplicity and use of a transient change in current (an effect of a fault) as its actuating parameter (indicator) because current magnitude can indicate impedance source. The design of an overcurrent protection scheme requires a circuit breaker, a current transformer, and an overcurrent relay (50/51). The current transformer simply measures the magnitude of current flowing through a circuit and compares it with a pre-determined (set) value. If there are discrepancies between the measured and set values, it will give a signal to the overcurrent relay, which will in turn, issue a trip signal to the circuit breaker.

The current transformer ratio (CTR) is calculated using equation 5.

$$CTR = FLA + 25\% \, of \, FLA \quad (5)$$

where;

CTR = Current transformer ratio

FLA = Full load current in amperes

The full load current in amperes can be obtained using equation 6.

$$FLA = \frac{MVA}{\sqrt{3} \, X \, kV} \quad (6)$$

The relay setting calculation is achieved using equation 7.

$$t = \frac{\alpha \, .TDS}{(PSM)^{\beta} - 1} \quad (7)$$

The plug multiplier settings of the protective relay is calculated using equation 8.

$$PSM = \frac{I_{sc}}{CT_{sec}} \quad (8)$$

The pick-up current of the protective relay is calculated using equation 9.

$$Pick \; up = \frac{1.1 \, X \, FLA}{0.9 \, X \, CT_{sec}} \quad (9)$$

Where;

TDS = Time dial settings

PSM = Plug setting multiplier

α and β = Constant of relay curves

2.2.4 Distributed Generation (DG) Sizing Calculation

In this research work, we will adopt the analytical method for the sizing and placement of Distributed Generation (DG). Newton-Raphson's method will be used to do a load flow analysis of the power system network to find out how much active and reactive power loss there is. This will help figure out the best size of DG needed to make the network better.

The primary objective of installing DGs in a power system is to minimise losses, thereby contributing to the higher efficiency and reliability of the power supply. Thus, the analytical method operates on the principle of power injection at each bus bar to verify the impact on the power losses incurred. Furthermore, it employs a loss sensitivity factor (LSF) to rank the buses and determine the most sensitive location for the DG.

To properly incorporate DGs into a power system network (in this case, a distribution network), the following steps are to be followed meticulously:

- A proper load flow analysis should be performed to determine the existing operating state of the power system network under investigation.
- The results of active and reactive power losses at various buses should be obtained from the load flow result.
- Determine the optimal size of DG required for each bus bar.
- Place the DG with the optimal size obtained at each bus, one at a time and perform a load flow analysis to determine the power losses in each case.
- Locate the optimal bus at which the loss is minimum, corresponding with the optimal size at that bus.

Transformer ratings are converted from $MW \; to \; MVA$ using equation 10.

$$\frac{MW}{PF} = kVA \quad (10)$$

Where;

MW = Active power in megawatts

PF = Power factor

kVA = kilovolts-ampere

Furthermore, the power factor of the loads = 0.85. Thus,

$$\frac{0.744}{0.85} = 0.875MVA$$

In order to install the DGs at bus 6, the total capacity of the transformers should be taken into account. Thus, the total MVA required by the generator = 1.8 + 0.75 = 2.675.

The running requirement of the DGs should be clearly defined (standby measure or primary source). In this case study, it is expected that the DGs will operate in conjunction with the grid supply. Thus, for the DGs to supply 50% of the load, we will utilise 50% of the total MVA required by the generator, which is equivalent to 1.34 MVA.

3. Results and Discussion

As earlier stated, a load flow analysis was carried out on the power system network under investigation, and Figure 2 displays a pictorial view of the results obtained. Figure 2 displays the operating bus voltage of each busbar as a percentage. Also captured in Figure 2 are the active and reactive power flows through the different branches in kW and kVAr, respectively.

A critical examination of the results obtained reveals a total of 6 out of 11 buses flagged red by ETAP software, while 1 bus is flagged pink. The buses flagged red indicate that they are operating in a critical state of under-voltage; thus, there is a crucial need for voltage regulation. However, the bus with a pink flag indicates a slight under-voltage, making it manageable. Currently, the system is experiencing total active and reactive power losses of $42.5\ kW\ and\ 51.8\ kVAr$, respectively. The results align with the literature review's findings on DG's ability to improve voltage profiles (Ogboh *et al.*, 2019; Eltamaly *et al.*, 2019).

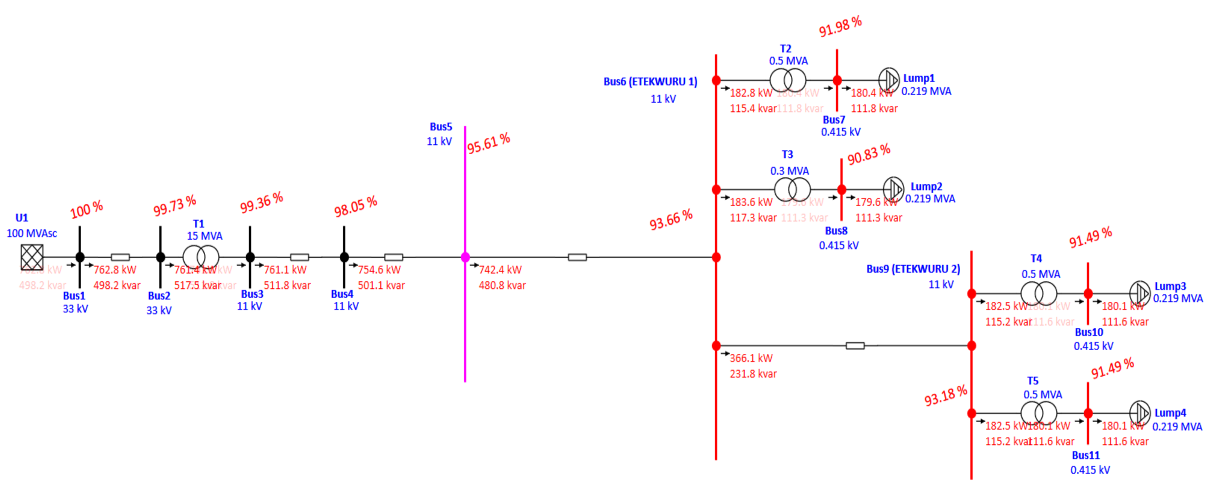

Figure 2: Existing Load Flow Analysis of Etekwuru 11/0.415 kV Distribution Network

2.1 Load Flow Analysis after Insertion of DG

The study's focus on fault analysis and short-circuit currents aligns with the literature review's discussion on protection coordination challenges in distribution networks with DG integration (Zineb et al., 2021).

DG was inserted at bus 6 with a total capacity of $1.34MVA$, which is equivalent to $1.273MW$ using a power factor of 95%. Thus, a load flow analysis was carried out after the insertion of the DG to verify its impact on the voltage profile of the buses as well as the active and reactive power losses.

The results obtained are displayed and explained in this section.

Results in Figure 3 clearly show the effect of DG on the various busbars, as all critical buses reported in Figure 2 were successfully eliminated. This means that after the DG was added, all buses operated within the IEEE voltage limit of +/- 5%. The total active and reactive power losses existing in the system after DG insertion are $12.3\ kW\ and\ -9.1\ kVAr$, respectively.

The results demonstrate the effect of DG on fault currents, which is consistent with the literature review's emphasis on considering DG's impact on protection systems (Zineb *et al.*, 2021).

The study's findings on short-circuit currents and fault analysis contribute to the understanding of DG's impact on distribution networks, supporting the literature review's discussion on protection coordination and DG integration.

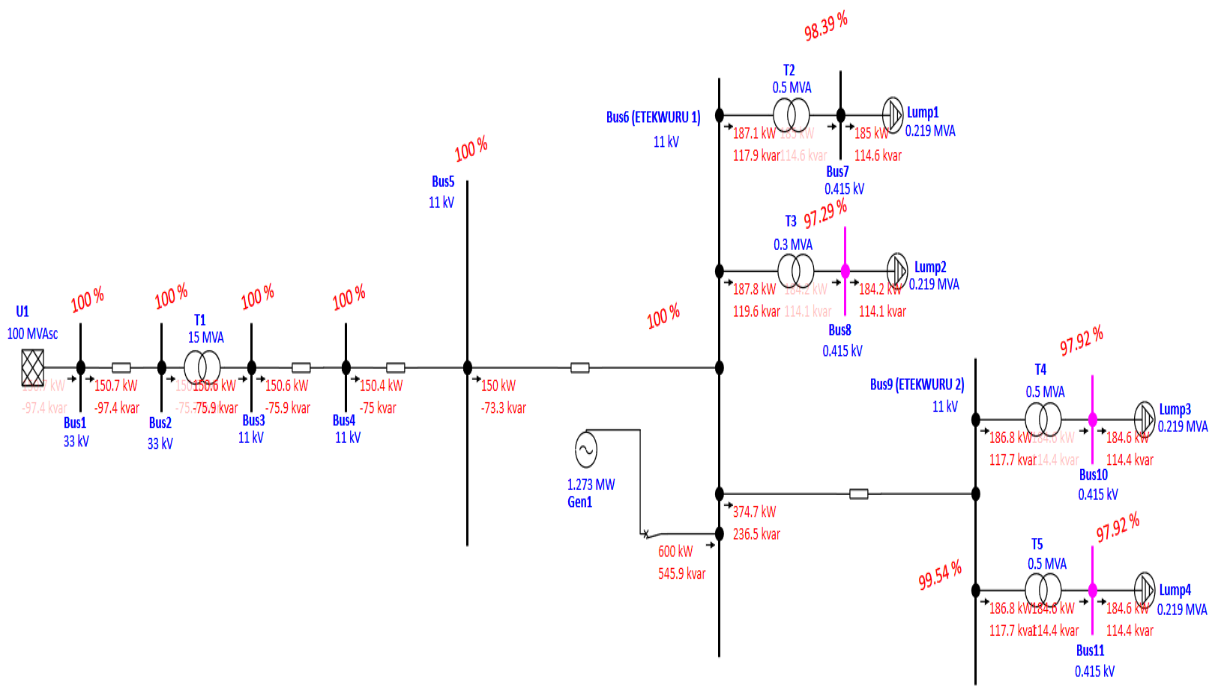

Figure 3: Load Flow Analysis after Insertion of DG

Figure 4 displays the short-circuit result obtained when the DG is isolated through a circuit breaker. The magnitudes of fault current at various locations are displayed in kA, the voltage magnitudes are displayed in kV, and the phase angles are displayed in degrees, respectively. Furthermore, it is observed that the voltage magnitudes at all buses are equivalent to zero, and this is because of faulting all buses with a maximum three-phase fault. Three-phase maximum and minimum fault current magnitudes at various buses before DG insertion are 52.739 kA and 38.238 kA respectively.

The results show the impact of a three-phase fault on the voltage profile, with voltage magnitudes equivalent to zero at all buses. The study's findings on fault current magnitudes align with the literature review's discussion on fault analysis in distribution networks (Zineb *et al.*, 2021).

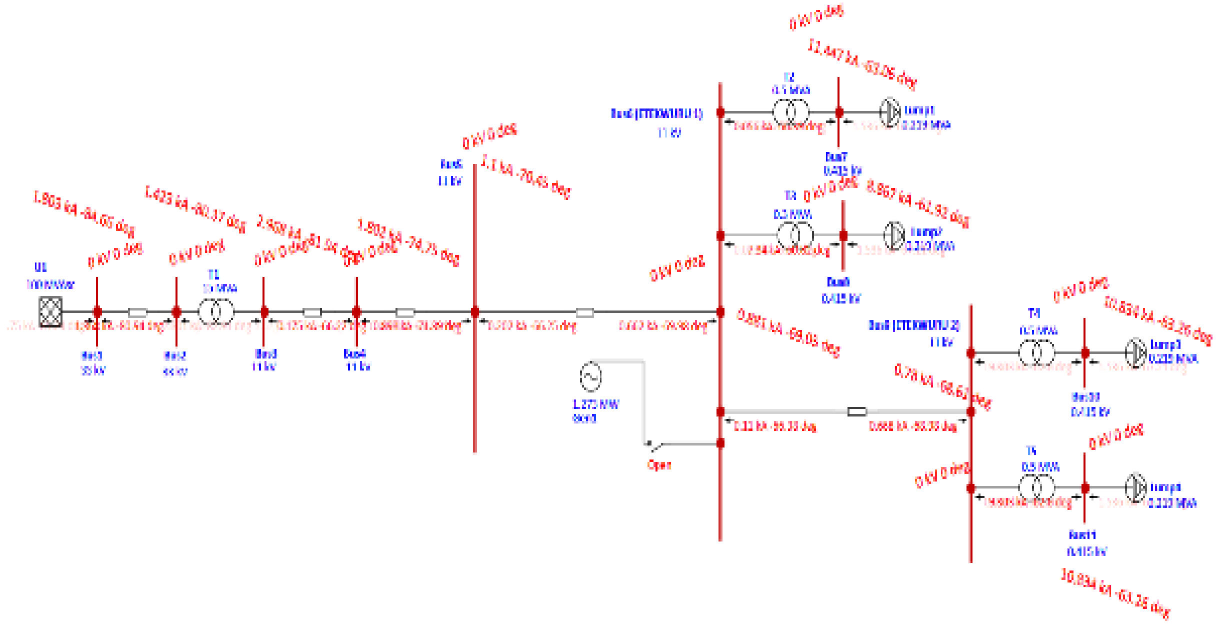

Figure 4: Short-Circuit Analysis of Etekwuru 11/0.415kv Distribution Network without DG

Figure 5 presents the short-circuit result obtained when the DG is activated through the closing of the circuit breaker. The results obtained after performing the analysis reveal a significant increase in the magnitude of fault current at various locations due to the DG contribution. Moreover, three-phase maximum and minimum fault current magnitudes with and without DG are $59.976\ kA$ and $46.356\ kA$ respectively.

The study's findings on the increase in fault current magnitude due to DG contribution align with the literature review's discussion on the impact of DGs on fault currents (Zineb *et al.*, 2021).

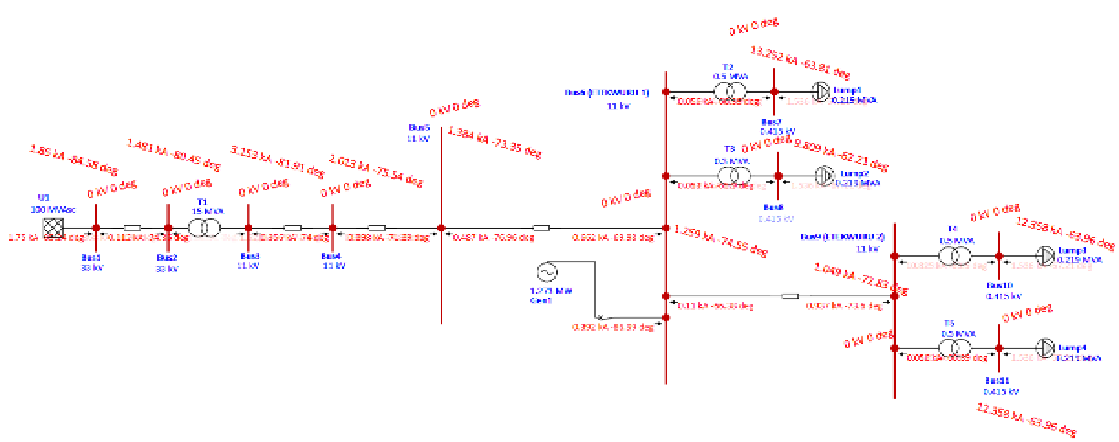

Figure 5: Short Circuit Analysis with DG Inserted

The results presented in Figure 6 clearly show how the protection scheme separates the fault that started at Lump 1 by sending a trip command to CB2 at $113\ mS$ from Relay 2. Furthermore, the sequence viewer on the right side of Figure 6 shows the tripping sequence of other relays along with their corresponding circuit breakers. For example, Relay 4 and CB4 trip at 123ms when Relay 2 fails to isolate the fault. This sequence goes on as displayed in Figure 6 until the fault is completely isolated. The study's findings, as shown in Figures 6 and 7 on the protection scheme's operation, align with the literature review's discussion on protection coordination in distribution networks (Zineb *et al.*, 2021).

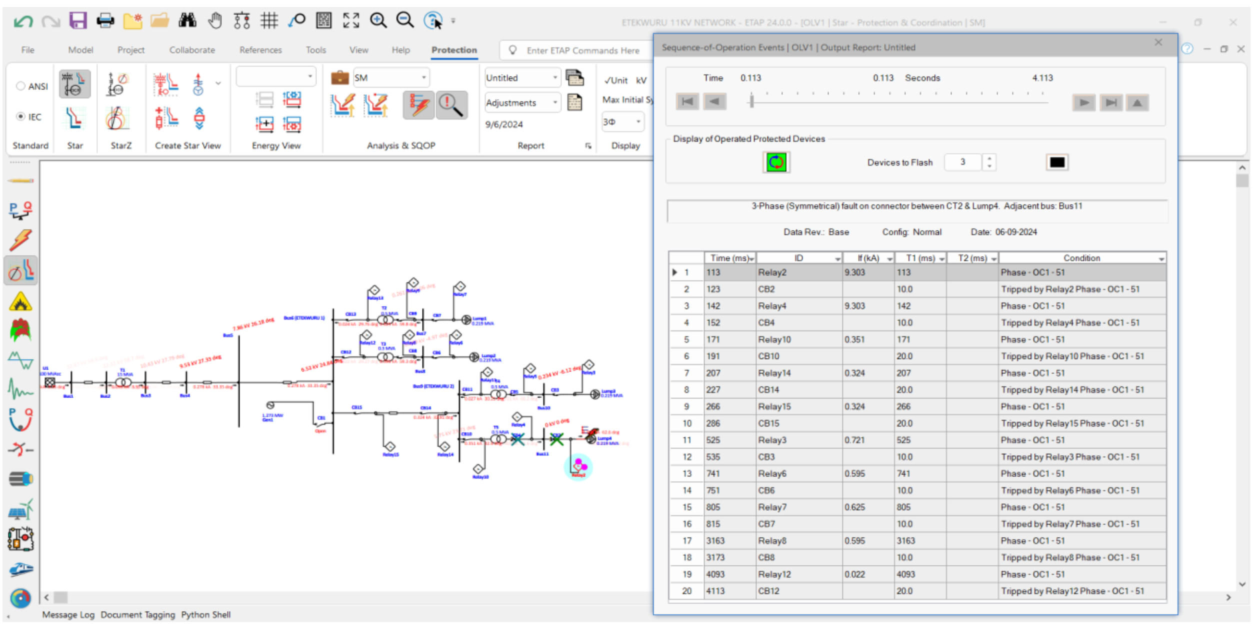

Figure 6: Fault Insertion at Lump 4 without DG

Figure 7 presents the results obtained when a fault is inserted at lump load 3 in the absence of the DG effect. Critical examination of the results obtained reveals Relay 3 in conjunction with CB3 being the nearest to the point of fault inception, thus being the first to trip at 113 ms. Furthermore, if the fault is not cleared, then Relay 5 in conjunction with CB5 operates at 123 ms, and the cycle continues as displayed in the sequence viewer.

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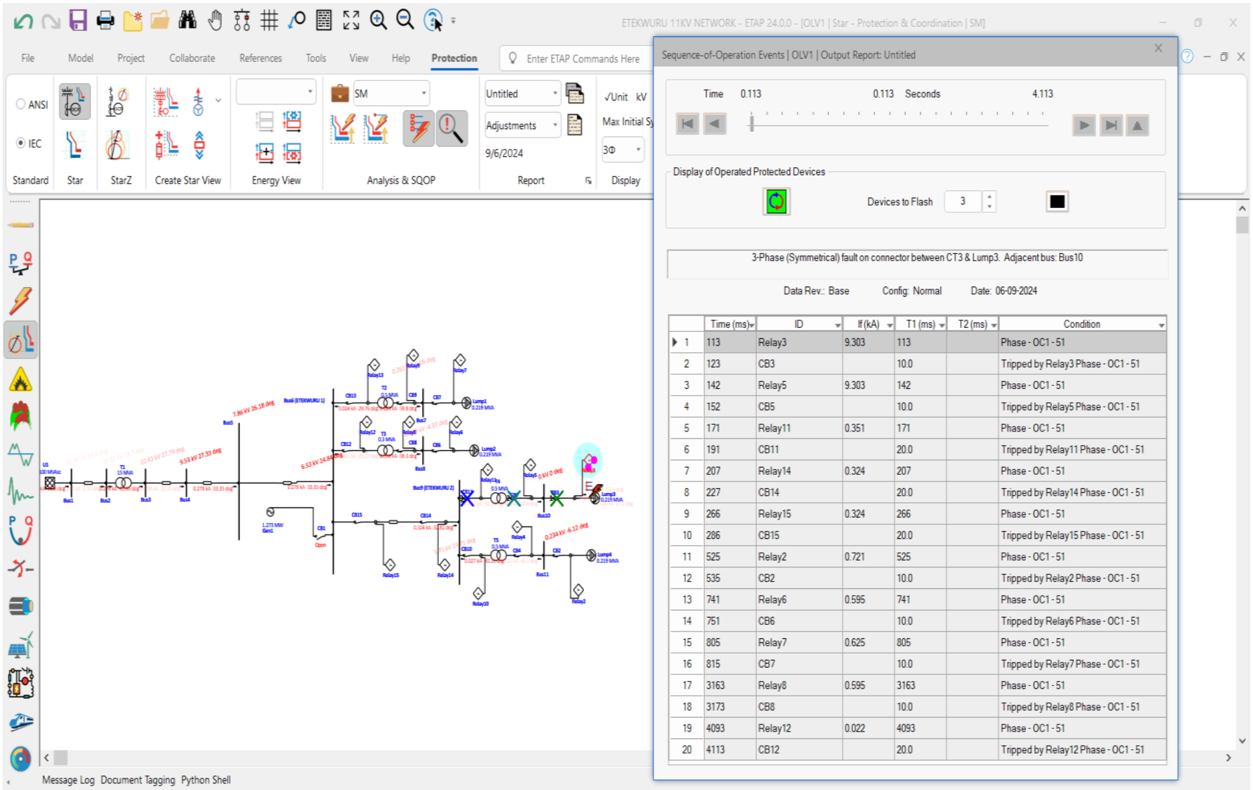

Figure 7: Fault Insertion at Lump 3 without DG

Figure 8 presents the results arising from the insertion of a three-phase fault in the presence of an active DG. In this scenario, the DG is no longer isolated, and a three-phase fault was inserted at Lump 4 to compare the results shown in Figure 6. A critical examination of the results shown in the sequence viewer reveals nuisance tripping at Relays 6 and 7, such that Relay 7 operates and does not give enough clearance for CB7 to operate before Relay 6 operates. Thus, the presence of the DG impacts the protection scheme, and the protection scheme requires re-coordination.

The study's findings on nuisance tripping and the need for relay coordination align with the literature review's discussion on the challenges posed by DGs on protection coordination (Zineb *et al*., 2021).

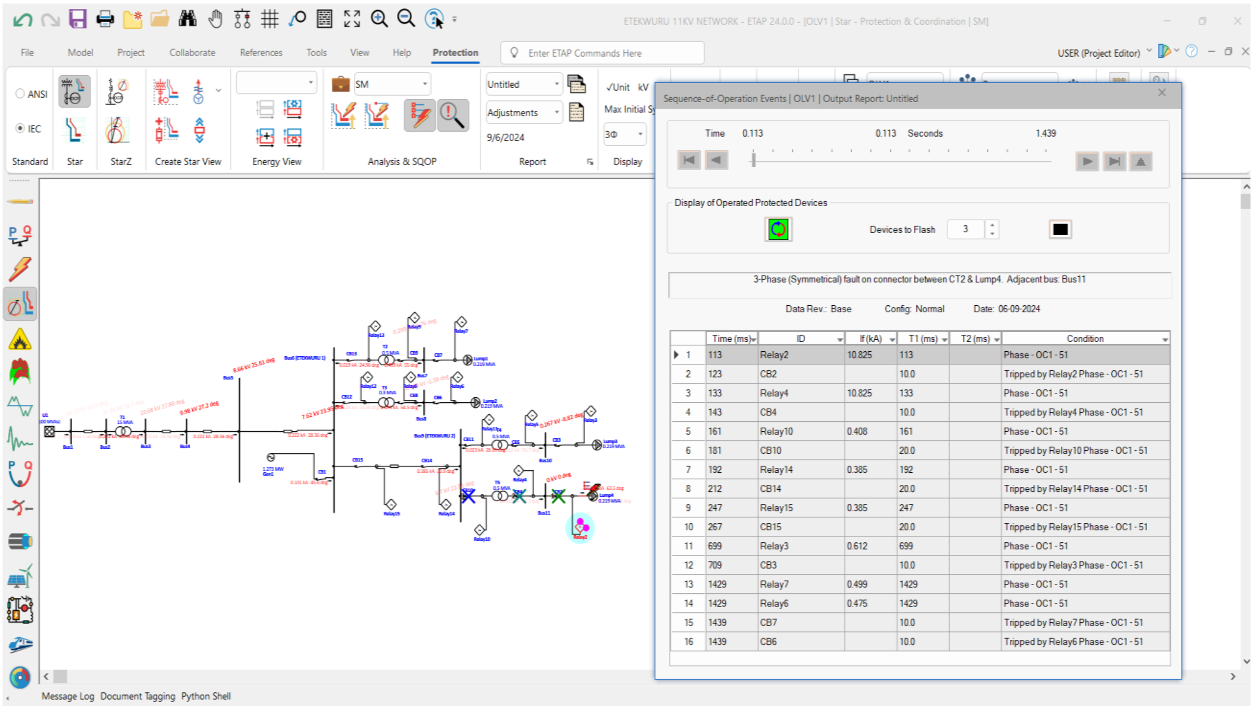

Figure 8: Fault Insertion at Lump 4 with DG.

Figure 9 presents the results arising from the insertion of a three-phase fault at lump load 3 with the DG connected to compare the results with Figure 7, and the results obtained revealed some discrepancies. Relays 6 and 7 still experience nuisance tripping due to the presence of the DG; thus, relay coordination is crucial after the insertion of the DG. The sequence viewer displays the tripping time of switchgears as well as the fault magnitudes inserted at various locations. The study's findings on nuisance tripping and the need for relay coordination align with the literature review's discussion on the challenges posed by DGs on protection coordination (Zineb *et al.*, 2021).

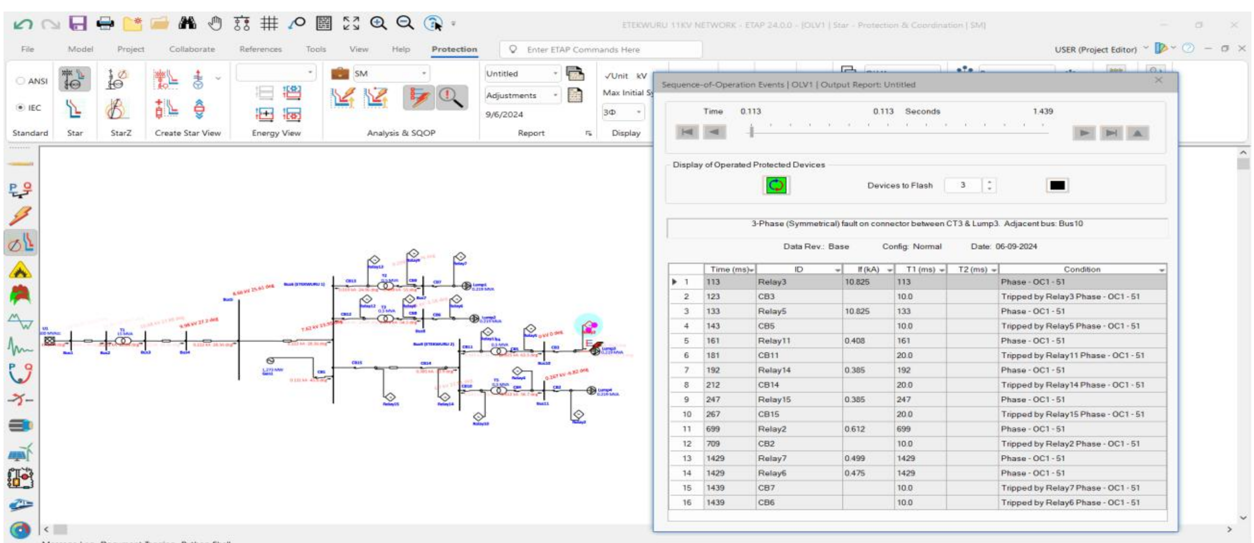

Figure 9: Fault Insertion at Lump 3 with DG

4. Conclusions

In electrical distribution systems, the connected loads are inductive, thus resulting in a high magnitude of voltage drop and power losses. However, distribution networks can optimise power flow using distributed generation (DG). This research work presents an approach for ascertaining the impact of DGs in an existing distribution network; thus, load flow, short circuit and protection studies were carried out with and without the presence of the DG to verify its impact on the system. The power system network used as a case study is known as the Etekwuru $11/0.415kV$ distribution network, which was modelled and analysed using the Electrical Transient Analyser Program (ETAP) software.

A load flow analysis was performed to determine the existing state of the power system, and the results obtained revealed 6 out of 11 buses flagged red while 1 bus was flagged pink by the software. The buses were flagged red due to the high magnitude of under-voltage they experienced (not within the IEEE permissible voltage limit of +/- 5%), while the bus flagged pink experienced a marginal magnitude of undervoltage. The total active and reactive power losses in the system were $42.5\ kW\ and\ 51.8\ kVAr$, respectively.

Thus, there was a crucial need for voltage regulation and power loss mitigation.

We inserted the DG and conducted the load flow analysis again, but the results showed a significant improvement in the power system. All buses stayed within the IEEE permissible voltage limit, and the power losses in the system dropped drastically from 42.5 kW to 12.3 kW and from 51.8 kVAr to -9.1 kVAr, respectively. Thus, the DG improved the voltage at all buses and reduced both active and reactive power losses, thereby enhancing the overall performance of the power system under study.

Additionally, a short-circuit analysis was done both with and without the DG. The results showed that the DG affected the amount of fault current at different points in the power system network that was being studied. We conducted a maximum and minimum short circuit analysis, and a critical examination of the results revealed a significant increase in both scenarios.

Finally, an overcurrent protection scheme was designed without the presence of the DG, and a three-phase fault was inserted at various locations to verify the effectiveness of the protection scheme.

The results obtained validated the relays in conjunction with circuit breakers responding accurately whenever a fault is inserted at any location. However, the insertion of DG tested the effectiveness of relay coordination and resulted in nuisance tripping. Protection schemes are thus negatively impacted by the introduction of DGs.

5. Recommendations

During this research work, some observations were made which led to the following recommendations:

- The electricity distribution company should perform periodic load flow analysis at various intervals to verify the network's operating state.
- Methods of voltage regulation and power loss minimisation should be employed at the load end to enhance the power system's overall performance.
- An alternative source of power supply should be introduced to the power system at the end to prevent total isolation of the power supply in the case of grid collapse.

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