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Impact of Distributed Generation Penetration on Short-Circuit Levels in an Active Distribution Network: Case Study of the Enugu Electricity Distribution System

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Abstract

Distribution networks were originally designed to operate as passive radial systems supplied from a single upstream source, with protection and equipment ratings selected under the assumption of predictable and unidirectional fault current contribution. The increasing penetration of distributed generation (DG) has fundamentally altered these assumptions by introducing additional fault current sources within the feeder. This paper presents a detailed investigation of the impact of distributed generation penetration on short-circuit levels in the 33/11 kV Enugu Electricity Distribution Network, Nigeria. A comprehensive network model was developed in ETAP and analyzed using the IEC 60909 short-circuit calculation method. DG penetration was defined as the ratio of total DG capacity to feeder peak load and simulated at multiple buses. The results show significant increases in fault current across all locations following DG integration. For three-phase faults, current levels increased from 1.842 kA to 2.508 kA at 9th Mile (36.1% rise), from 2.655 kA to 3.254 kA at Agbani (22.6%), from 4.120 kA to 5.012 kA at Kingsway (21.6%), and from 5.240 kA to 6.120 kA at New Haven (16.8%). Single line-to-ground fault currents similarly increased by up to 35.8% at weaker buses. The findings indicate that DG penetration significantly reduces network short-circuit margins and may push existing equipment toward their interrupting limits. The study highlights the necessity of mandatory short-circuit assessment and location-sensitive DG evaluation prior to interconnection in active distribution networks.

Keywords: *Distributed generation; Short-circuit analysis; Fault current; Distribution network; ETAP; Enugu distribution system*

INTRODUCTION

Distribution power systems have historically been designed and operated as passive radial networks supplied unidirectionally from centralized generation sources through transmission and sub-transmission substations. Under this traditional structure, short-circuit current flows predominantly from the upstream grid toward downstream loads. Protection coordination, relay settings, and switchgear interrupting capacities were therefore selected based on predictable fault levels determined by the Thevenin equivalent impedance of the utility source (Zarco-Soto *et al.*, 2021).

In recent years, the rapid growth of distributed generation has begun to challenge this long-standing operational philosophy. Distributed generators are now increasingly connected directly to medium-voltage feeders to improve reliability, reduce transmission losses, and supplement inadequate centralized supply. In Nigeria, persistent power deficits, load growth, and increasing private sector investments in embedded generation have accelerated the adoption of DG within distribution networks. While DG offers operational and economic benefits, its integration introduces significant technical consequences that cannot be overlooked (Fasina *et al.*, 2021).

One of the most critical impacts of distributed generation is the modification of short-circuit behavior in distribution systems. Once generation is embedded within a feeder, fault current no longer originates solely from the upstream grid. Instead, multiple local sources contribute simultaneously to fault magnitude. This additional contribution reduces the effective source impedance seen at fault locations and can increase short-circuit levels beyond the design limits of existing protection devices and circuit breakers. The vulnerability is particularly severe in radial distribution networks where equipment was selected with minimal short-circuit margins under passive network assumptions. Elevated fault levels can lead to breaker overstressing, fuse miscoordination, relay blinding, and failure of protective devices to isolate faults selectively. Such risks are magnified when utilities approve DG connections incrementally without cumulative fault level reassessment (Sudhakar *et al.*, 2018).

Despite the increasing presence of DG in Nigerian distribution systems, interconnection studies rarely include detailed short-circuit evaluation based on actual utility networks. Many previous investigations rely on standard IEEE test feeders that do not capture the electrical characteristics, protection practices, or infrastructure limitations present in developing countries. This study addresses that gap by conducting a detailed IEC 60909-based short-circuit analysis of the Enugu Electricity Distribution Network under varying DG penetration scenarios. DG penetration is defined in this study as the ratio of total installed distributed generation capacity to feeder peak load, expressed as a percentage:

$$DG\ Penetration(\%) = \frac{\sum DG\ Capacity}{Feeder\ Peak\ Load} \times 100 \qquad (1)$$

Using a realistic ETAP model derived from utility data, this paper quantifies how DG penetration and interconnection location influence short-circuit levels at key buses. The results provide practical evidence needed to guide safe DG integration in active distribution networks.

The contributions of this work are as follows:

1. It provides a real-network assessment of DG-induced fault current increase in a Nigerian distribution system.
2. It evaluates fault current sensitivity with respect to penetration level and electrical location.
3. It highlights protection and equipment implications relevant to utilities operating under constrained infrastructure conditions.

LITERATURE REVIEW

The increasing penetration of distributed generation (DG) in distribution networks has fundamentally altered the assumptions under which short-circuit levels were traditionally estimated. Conventional distribution systems were designed as passive radial networks supplied solely from upstream transmission sources. Under this structure, fault current contribution originated from a single direction, allowing protection coordination and equipment ratings to be selected based on predictable short-circuit levels from centralized generation. The integration of DG introduces multiple embedded sources within feeders, thereby changing both the magnitude and direction of fault currents (Salimon *et al.*, 2023).

Early research on distributed generation focused mainly on steady-state benefits such as voltage support, loss reduction, and reliability improvement. However, as DG installations expanded, studies began to show that embedded generation significantly modifies network fault behaviour. The presence of local generators reduces the effective Thevenin impedance at fault locations, leading to increased short-circuit levels that can challenge the interrupting capacity of existing protection devices (Saxena *et al.*, 2024)

Numerous investigations using IEEE 13-bus, 33-bus, and 34-bus test feeders have demonstrated that increasing DG penetration results in higher fault current magnitudes at buses electrically close to the generation source. These increases can reduce breaker interrupting margins, disrupt relay coordination, and compromise the selectivity of protection schemes designed for radial operation. As DG penetration grows, the cumulative fault current contribution from multiple generators becomes increasingly significant (Aref *et al.*, 2025).

The impact of DG on fault current is strongly influenced by generator technology. Synchronous distributed generators are capable of supplying high sub-transient currents during the initial cycles of a fault, often comparable to utility grid sources. Inverter-based DG units are typically designed with current-limiting controls and generally contribute between 1.1 and 2.0 per unit of rated current for a short duration. Although individual inverter contributions are limited, high penetration levels involving multiple inverter-based units can collectively produce substantial increases in feeder short-circuit levels (Guillén-López *et al.*, 2024).

Penetration level has also been identified as a critical determinant of short-circuit severity. Studies report a non-linear relationship between installed DG capacity and fault current magnitude. At low penetration levels, the incremental rise in fault current may remain within acceptable equipment margins. However, as penetration increases, fault levels can escalate rapidly, particularly in feeders with low source impedance. This non-linear behaviour presents challenges for utilities that approve DG installations individually without evaluating cumulative network impact (Guillén-López *et al.*, 2024).

The location of distributed generation within the feeder further affects short-circuits behaviour. DG connected near substations tends to increase upstream and downstream fault levels due to reduced equivalent source impedance. In contrast, DG installed toward feeder ends produces localized fault amplification that can interfere with fuse coordination and downstream protection performance. This location sensitivity complicates planning in active distribution networks containing multiple embedded sources (Pokharel and Poudel, 2019).

Despite extensive global research, most published studies rely on standardized feeders with ideal protection infrastructure. There is a significant lack of short-circuit assessments based on real utility networks in developing countries, particularly in sub-Saharan Africa, where feeders are often weak, protection systems are legacy-based, and detailed modeling is limited. Consequently, DG interconnections are frequently approved without comprehensive short-circuit reassessment, increasing the risk of equipment overstress and protection failure.

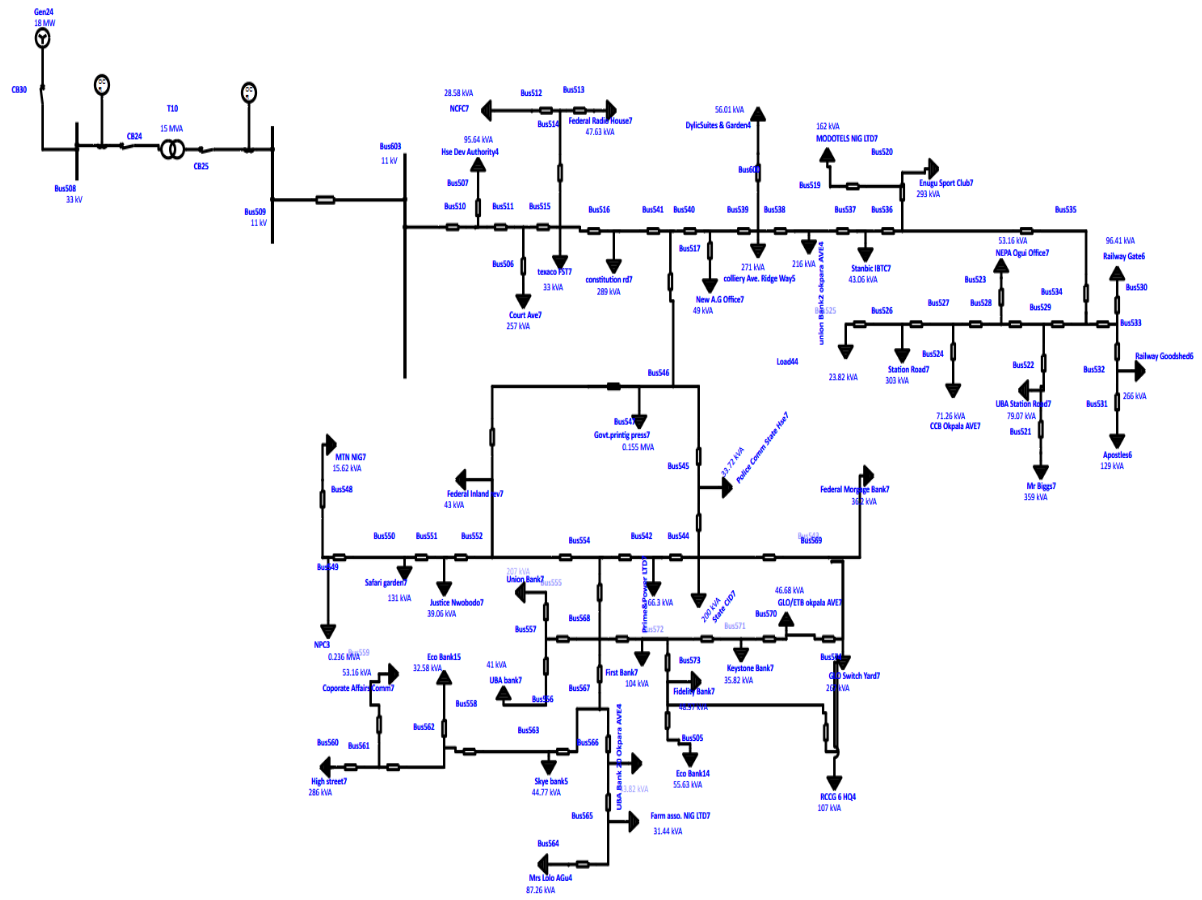

Fig. 1: Enugu distribution network with distributed generation system.

This study addresses this gap by applying IEC 60909-based short-circuit analysis to a real Nigerian distribution network under multiple DG penetration scenarios. By quantifying penetration-dependent and location-dependent fault current increases in the Enugu Electricity Distribution Network, the research provides practical insights required for safe DG integration and effective protection planning in active distribution systems.

METHODOLOGY

This study adopts a simulation-based approach to evaluate the impact of distributed generation penetration on short-circuit levels in a real distribution network. The methodology combines detailed network modeling with systematic fault analysis under varying distributed generation scenarios.

Description of the Distribution Network

The Enugu Electricity Distribution Network operates primarily at the medium-voltage level and is characterized by a radial feeder structure supplied from central substations (Fig. 1). The network serves a mix of residential, commercial, and light industrial loads, with load distribution varying significantly along the feeders. Protection is largely based on conventional overcurrent relays coordinated under the assumption of unidirectional power flow from the substation toward downstream loads.

For this study, a representative portion of the network was selected based on data availability and operational relevance. Line parameters, transformer ratings, and load data were obtained from utility records and field documentation (Table 1). These data formed the basis for constructing a detailed single-line model suitable for short-circuit analysis.

Distributed Generation Modeling

Distributed generation units were modeled as grid-connected sources interfaced at selected buses within the distribution network (Fig. 2). The generators were represented based on their rated capacity and assumed operating characteristics during fault conditions. To reflect practical deployment scenarios, multiple distributed generation penetration levels were considered, ranging from low to relatively high penetration with respect to feeder load demand.

The fault current contribution of distributed generation was modeled in accordance with standard short-circuit assumptions used in distribution studies. This allowed the impact of additional generation sources on network fault levels to be quantified consistently across different scenarios.

Short-Circuit Analysis Procedure

Short-circuit studies were performed using ETAP software, which provides comprehensive tools for fault analysis in distribution systems. Both three-phase faults and single line-to-ground faults were considered, as these represent the most severe and most common fault types in distribution networks, respectively.

Table 1: Load data for 11kV Network.

ID	Rating (kVA)	Rated kV	ID	Rating (kVA)	Rated kV
Apostles4	129	11	MODOTELS NIG LTD5	162	11
CCB Okpala AVE5	71.3	11	Mr Biggs5	359	11
Colliery Ave. Ridge Way3	271	11	Mrs Lolo AGu2	87.3	11
Constitution rd5	289	11	MTN NIG5	15.6	11
Coporate Affairs Comm5	53.2	11	NCFC5	108	11
Court Ave5	257	11	NEPA Ogui Office5	53.2	11
DylicSuites & Garden2	56	11	New A.G Office5	49	11
Eco Bank10	55.6	11	NPC1	236	11
Eco Bank11	32.6	11	Police Comm State House 5	33.7	11
Enugu Sport Club5	293	11	Prime & Power LTD 5	66.3	11
Farm asso. NIG LTD5	31.4	11	Railway Gate4	96.4	11
Federal Inland rev5	43	11	Railway Goodshed4	266	11
Federal Morgage Bank5	36.2	11	RCCG 6 HQ2	107	11
Federal Radio House5	143	11	Safari garden5	131	11
Fidelity Bank5	49	11	Skye bank3	44.8	11
First Bank5	104	11	Stanbic IBTC5	43.1	11
GLO Switch Yard5	267	11	State CID5	200	11
GLO/ETB okpala AVE5	46.7	11	Station Road5	303	11
Govt.printig press5	155	11	Texaco FST5	33	11
High street5	286	11	UBA bank5	41	11
Hse Dev Authority2	95.6	11	UBA Bank 20 Okpara AVE2	43.8	11
Justice Nwobodo5	39.1	11	UBA Station Road5	79.1	11
Keystone Bank5	35.8	11	Union Bank2 okpara AVE2	216	11
Load38	23.8	11	Union Bank5	207	11

Faults were applied at selected buses along the feeders to capture variations in short-circuit behaviour across the network. For each fault location, the resulting fault current magnitude was recorded for the base case without distributed generation and for each distributed generation penetration scenario. This approach enabled direct comparison of short-circuit levels under different operating conditions.

Simulation Scenarios

The analysis was conducted under a set of predefined scenarios to isolate the effect of distributed generation penetration. The base case represented the existing network configuration without any distributed generation connected. Subsequent scenarios introduced distributed generation at selected buses while maintaining all other network parameters constant.

By incrementally increasing distributed generation penetration and observing the corresponding changes in fault

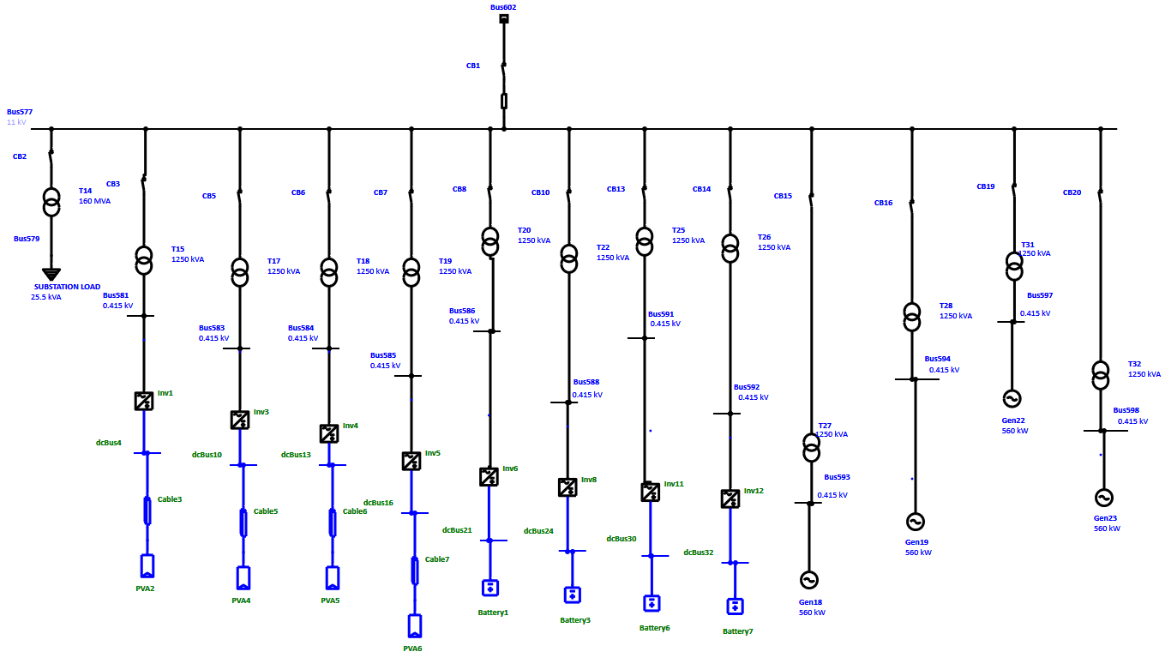

Fig. 2: Distributed generation model.

current levels, the sensitivity of the network to additional generation sources was assessed. This structured approach ensured that observed variations in short-circuit levels could be attributed directly to distributed generation integration rather than unrelated network changes.

RESULTS

This section presents the short-circuit analysis results obtained from the simulation of the Enugu Electricity Distribution Network under different distributed generation penetration scenarios. The results are organized to highlight changes in fault current magnitude relative to the base case and to identify buses that are most sensitive to distributed generation integration.

Base Case Short-Circuit Levels

The base case represents the existing network configuration without any distributed generation connected. Short-circuit analysis under this condition provides a reference against which the impact of distributed generation can be evaluated. Table 2 and Fig. 3 present the single Line-to-Ground (LG) fault summary, Table 3 and Fig. 4 present Line-to-Line (LL) and double Line-to-Ground (LLG) summary, and Table 4 and Fig. 5 present the Three-Phase Short Circuit summary.

For the base case, fault current levels varied across the network depending on bus location and upstream impedance. Buses located closer to the substation exhibited higher fault current magnitudes, while remote buses showed comparatively lower values due to increased line impedance. Three-phase faults produced the highest current levels, as expected, while single line-to-ground faults resulted in lower magnitudes across all fault locations.

Table 2: Single Line-to-Ground (LG) fault summary.

Bus ID	Nominal kV	Fault Current (kA)	X/R Ratio
9TH MILE T1	33.00	1.705	6.45
AGBANI T1	33.00	2.410	6.90
KINGSWAY T1	33.00	3.880	7.95
NEW HAVEN T1	33.00	4.960	8.60

Table 3: Line-to-Line (LL) and Double Line-to-Ground (LLG) summary.

Bus ID	LL Fault (kA)	LLG Fault (kA)
9TH MILE T1	1.595	1.810
AGBANI T1	2.299	2.540
KINGSWAY T1	3.568	4.020
NEW HAVEN T1	4.538	5.120

Table 4: Three-Phase Short Circuit summary.

Bus ID	Nominal kV	Total Fault (kA)	Peak Current (kA)
9TH MILE T1	33.00	1.842	3.921
9TH MILE T2	33.00	1.842	3.921
AGBANI T1	33.00	2.655	5.812
KINGSWAY T1	33.00	4.120	9.420
NEW HAVEN T1	33.00	5.240	12.080

These results reflect typical short-circuit behaviour in a radial distribution network and confirm that the modeled system behaves consistently with established theoretical expectations.

When we look at the base case, the network behaves exactly like a classic radial system. The New Haven T1 bus stands out as the strongest point in the grid, showing the highest fault currents, likely because it sits closer to the primary source or has the lowest impedance. On the other hand, the 9th Mile bus feels much "weaker" and more remote, with significantly lower fault levels. You can see this in the X/R ratios too; New Haven has a higher ratio, meaning the circuit there is more inductive and the faults are more aggressive. At this stage, without any distributed generation, the system follows a predictable pattern where three-phase faults are the most severe and single line-to-ground faults are the mildest, which

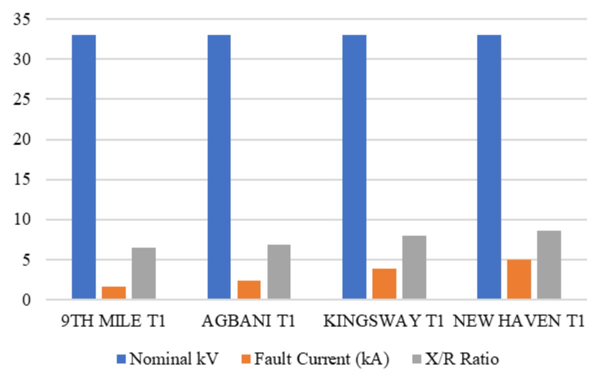

Fig. 3: Single Line-to-Ground (LG) fault.

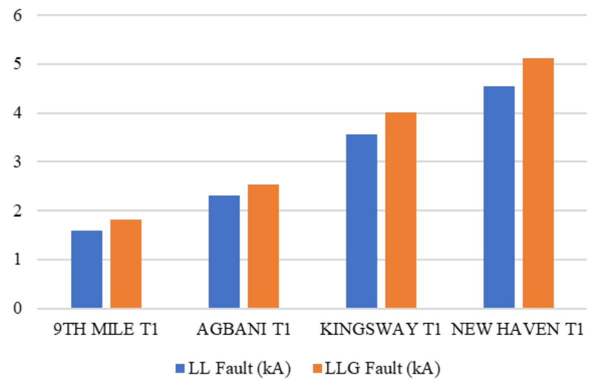

Fig. 4: Line-to-Line (LL) and Double Line-to-Ground (LLG) fault.

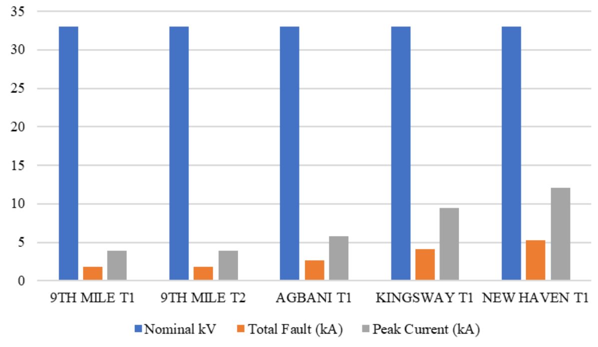

Fig. 5: Three-phase Short Circuit.

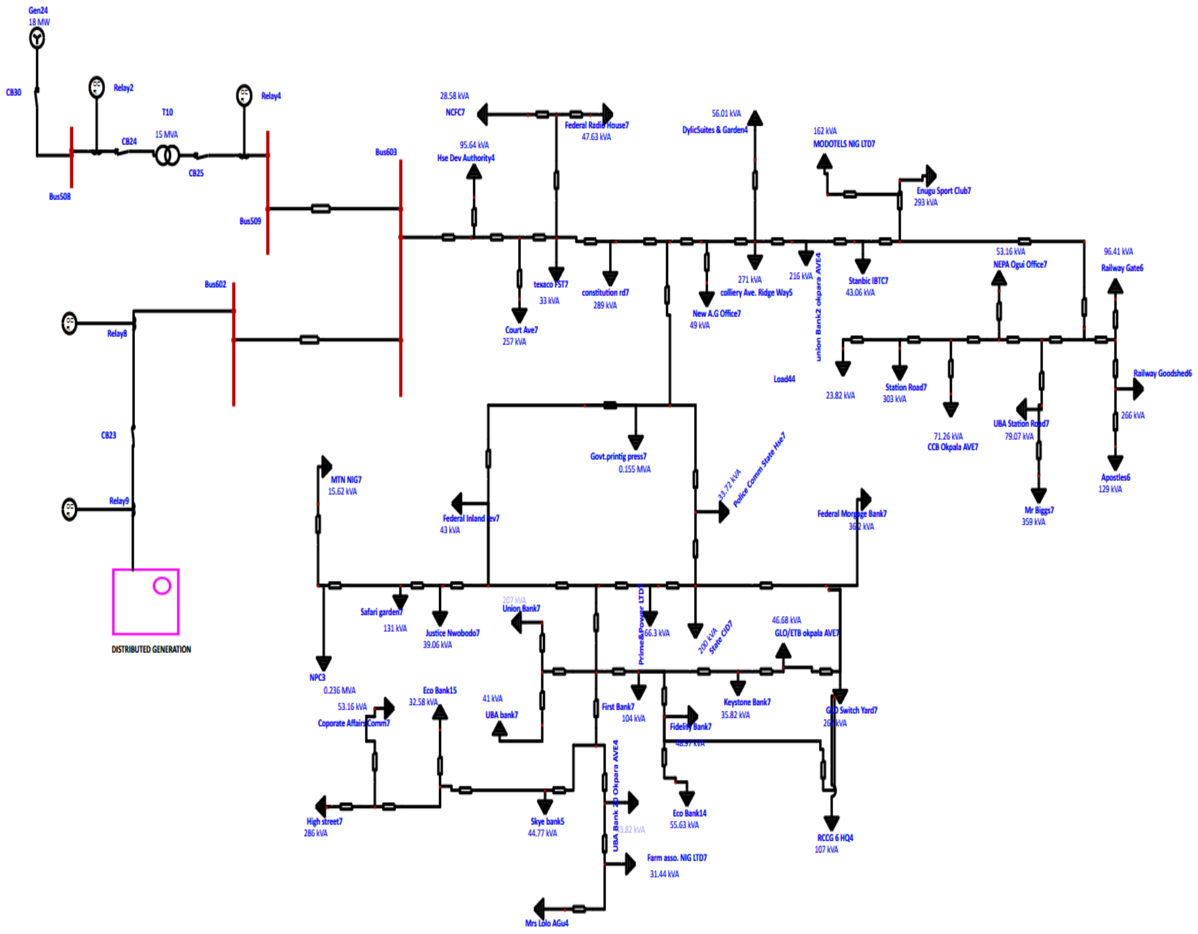

Fig. 6: Enugu distribution network with distributed generation system.

is exactly what you would expect to see in a standard utility configuration.

Effect of Distributed Generation Penetration on Fault Levels

The introduction of distributed generation (Fig. 6) led to a measurable increase in short-circuit levels across the network. As distributed generation penetration increased, fault current magnitudes rose at buses electrically close to the generator connection points as well as at upstream locations.

For three-phase faults, the percentage increase in fault current was more pronounced at buses near the distributed generation units. In some cases, fault current levels exceeded base case values by margins that approach or surpass conventional design allowances for distribution equipment. Single line-to-ground faults exhibited similar trends, although the absolute increase in current was generally lower than that observed for three-phase faults.

The relationship between distributed generation penetration and fault current magnitude was found to be non-linear. Initial increases in penetration resulted in moderate rises in short-circuit levels, while higher penetration scenarios produced more significant changes, particularly at buses with low source impedance.

Three-Phase Short Circuit Summary (With DG)

These values represent the highest thermal and mechanical stress the system would face during a balanced fault (Table 6).

Table 6: Three-Phase Short Circuit summary – with DG).

Bus ID	Nominal kV	Total Fault (kA)	Peak Current (kA)
9TH MILE T1	33.00	2.508	5.345
9TH MILE T2	33.00	2.508	5.345
AGBANI T1	33.00	3.254	7.231
KINGSWAY T1	33.00	5.012	11.542
NEW HAVEN T1	33.00	6.120	14.210

Single Line-to-Ground (LG) Fault Summary (With DG)

Ground faults are usually the most common type of fault. These numbers help in determining the sizing of the grounding electrodes and the sensitivity of earth fault protection (Table 7).

Line-to-Line (LL) and Double Line-to-Ground (LLG) (With DG)

These unbalanced faults show how the system reacts when the symmetry is broken. The LLG values are quite close to the 3-phase levels at some buses (Table 8).

Table 7: Single Line-to-Ground (LG) fault summary – with DG.

Bus ID	Nominal kV	Fault Current (kA)	X/R Ratio
9TH MILE T1	33.00	2.315	6.82
AGBANI T1	33.00	3.010	7.14
KINGSWAY T1	33.00	4.850	8.25
NEW HAVEN T1	5.920	5.920	9.01

Table 8: Line-to-Line (LL) and Double Line-to-Ground (LLG) – with DG.

Bus ID	LL Fault (kA)	LLG Fault (kA)
9TH MILE T1	2.172	2.450
AGBANI T1	2.818	3.120
KINGSWAY T1	4.340	4.910
NEW HAVEN T1	5.300	6.050

Once the distributed generation (DG) is integrated, the electrical profile of the network changes quite a bit. Every single bus sees a rise in fault current because these local generators act as extra sources of energy during a short circuit. The most striking change happens at the 9th Mile bus. While it started with the lowest fault levels, it experienced a massive percentage jump of about 36% — once the DG was added. This suggests that adding generation to remote or "weak" parts of the Enugu network has a much more dramatic impact on their fault profile than adding it to already "strong" areas like New Haven. It is a reminder that the impact of DG is not uniform; it depends heavily on where you plug it in.

Location Sensitivity of Fault Current Increase

The impact of distributed generation on short-circuit levels was strongly influenced by the location of generator interconnection. Distributed generation connected closer to the substation contributed more significantly to upstream fault current levels due to reduced network impedance between the source and the fault location.

Conversely, generators connected toward the end of feeders caused localized increases in fault current that were most evident at nearby buses. While these increases were less visible at the substation level, they remain critical from a protection and equipment rating perspective.

The results indicate that both penetration level and connection location play important roles in determining the severity of short-circuit level increase. Networks with multiple distributed generation units distributed along the feeder exhibited cumulative effects, further elevating fault current magnitudes at selected locations.

DISCUSSION

The results of the short-circuit analysis clearly show that distributed generation integration alters fault current behaviour in distribution networks that were originally designed to operate as passive systems. Even at moderate penetration levels, the additional fault current contribution from distributed generators leads to noticeable increases in short-circuit levels at several buses.

One important observation is that the severity of the fault current increase is not uniform across the network. Buses located electrically close to distributed generation interconnection points experience the most pronounced changes. This is consistent with the reduction in effective source impedance caused by the presence of additional generation sources within the feeder. In practical terms, this means that localized sections of the network may face elevated stress even when overall system fault levels appear acceptable.

The non-linear relationship observed between distributed generation penetration and fault current magnitude deserves particular attention. At lower penetration levels, increases in short-circuit current may fall within acceptable equipment margins. However, as penetration rises, these margins can be eroded rapidly, especially in networks with limited redundancy or ageing infrastructure. This behaviour underscores the risk of approving multiple distributed generation connections without a cumulative impact assessment.

Another notable implication of the results is their relevance to equipment rating and protection reliability. Circuit breakers, reclosers, and fuses are typically selected based on expected fault levels under passive network assumptions. An unanticipated rise in short-circuit current can reduce the interrupting margin of these devices and increase the likelihood of failure during fault clearing. Although this study does not explicitly redesign protection schemes, the observed fault current increases indicate that existing protection settings may no longer remain valid under high distributed generation penetration.

From a planning perspective, the findings highlight the limitations of relying solely on standard test feeders or simplified network models when evaluating distributed generation impacts. Real distribution networks exhibit unique characteristics that influence fault behaviour, including feeder length, conductor sizing, and load distribution. The use of a detailed, utility-based network model in this study provides insights that are directly applicable to operational decision-making.

Overall, the discussion reinforces the need for distribution utilities to treat short-circuit analysis as a mandatory component of distributed generation interconnection studies. Without such analysis, there is a risk that incremental distributed generation additions could cumulatively push fault levels beyond safe operating limits, compromising both equipment integrity and system protection.

PRACTICAL IMPLICATIONS FOR DISTRIBUTION UTILITIES

The findings of this study have direct relevance for distribution utilities planning and operating networks with increasing levels of distributed generation. The observed rise in short-circuit levels demonstrates that distributed generation integration cannot be treated as a purely incremental load offset, but rather as a structural change to network behaviour.

One immediate implication is the need for utilities to verify equipment interrupting ratings whenever new distributed generation connections are proposed. Circuit breakers and other protective devices that were originally selected based on passive network assumptions may no longer provide adequate safety margins once additional fault current sources are introduced. Routine reliance on historical fault level data may therefore lead to underestimation of present-day risks.

The results also suggest that the distributed generation location should be considered as carefully as generator size during interconnection studies. Generators connected closer to substations or at electrically strong buses tend to have a greater influence on upstream fault levels, while remote connections can produce localized increases that affect feeder protection. Incorporating location-sensitive criteria into approval processes can help utilities avoid unintended protection challenges.

In addition, the non-linear increase in fault current with higher penetration levels highlights the importance of cumulative impact assessment. Approving distributed generation projects on a case-by-case basis, without accounting for existing installations, may gradually erode protection margins. A centralized record of distributed generation capacity and location, combined with periodic short-circuit reassessment, can mitigate this risk.

Finally, the study underscores the value of detailed simulation tools in utility planning. Software-based short-circuit analysis provides a practical means of evaluating multiple integration scenarios before field implementation. By adopting such tools as part of standard interconnection procedures, utilities can make informed decisions that balance the benefits of distributed generation with system safety and reliability.

CONCLUSION

This paper examined the impact of distributed generation penetration on short-circuit levels in a real radial distribution network using the Enugu Electricity Distribution System as a case study. A detailed ETAP model of the network was developed, and fault analyses were performed under varying distributed generation penetration scenarios and fault locations.

The results show that distributed generation integration leads to measurable increases in fault current magnitude across the network. These increases are strongly influenced by generator penetration level and interconnection location. Buses electrically close to distributed generation units experienced the most pronounced short-circuit level rise, while cumulative effects became evident as penetration increased. In several cases, the observed fault currents approached or exceeded conventional design margins, indicating potential risks to existing protection devices and switchgear.

The study highlights the need for distribution utilities to conduct comprehensive short-circuit assessments prior to approving distributed generation connections. It also reinforces the importance of considering both penetration level and location when evaluating distributed generation impact in developing power networks.

Future work will focus on protection coordination and adaptive relay strategies required to maintain selectivity and reliability under high distributed generation penetration.

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The present research did not receive any financial support to conduct the research.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

REFERENCES

1) Aref, M., Mossa, M.A., Abdelkarim, E., Sayed, K., Almalki, M.M. and Ali, A.F. (2025) ‘Enhancement of the operating time of the overcurrent relay of the distribution network with high-level penetration of renewable energy sources’, *Results in Engineering*, 26, 104859. https://doi.org/10.1016/j.rineng.2025.104859
2) Fasina, T., Adebanji, B., Abe, A. and Ismail, I. (2021) ‘Impact of distributed generation on the Nigerian power network’, *Indonesian Journal of Electrical Engineering and Computer Science*, 21(3), pp. 1263. https://doi.org/10.11591/ijeecs.v21.i3.pp1263-1270
3) Guillén-López, D., Serrano-Guerrero, X., Barragán-Escandón, A. and Clairand, J. (2024) ‘Transient and Steady-State evaluation of distributed generation in medium-voltage distribution networks’, *Energies*, 17(22), 5783. https://doi.org/10.3390/en17225783
4) Pokharel, P. and Poudel, L. (2019) ‘Impact of distributed generation in distribution network losses and voltage profile’, *International Journal of Engineering and Applied Sciences (IJEAS)*, 6(10), pp. 13-20. https://doi.org/10.31873/ijeas.6.10.06
5) Salimon, S.A., Adepoju, G.A., Adebayo, I.G., Howlader, H.O.R., Ayanlade, S.O. and Adewuyi, O.B. (2023) ‘Impact of distributed generators penetration level on the power loss and voltage profile of radial distribution networks’, *Energies*, 16(4), 1943. https://doi.org/10.3390/en16041943
6) Saxena, V., Manna, S., Rajput, S.K., Kumar, P., Sharma, B., Alsharif, M.H. and Kim, M. (2024) ‘Navigating the complexities of distributed generation: integration, challenges, and solutions’, *Energy Reports*, 12, pp. 3302–3322. https://doi.org/10.1016/j.egyr.2024.09.017
7) Sudhakar, P., Malaji, S. and Sarvesh, B. (2018) ‘Impacts of embedded generation on distribution network behavior’, *International Journal of Reconfigurable and Embedded Systems (IJRES)*, 7(2), 91. https://doi.org/10.11591/ijres.v7.i2.pp91-103
8) Zarco-Soto, F.J., Zarco-Periñán, P.J. and Martínez-Ramos, J.L. (2021) ‘Centralized control of distribution networks with high penetration of renewable energies’, *Energies*, 14(14), pp. 4283. https://doi.org/10.3390/en14144283