

Exploring the Reduction of Power Losses Through Distributed Energy Resources

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Abstract: This study addresses the critical issue of power losses in Nigeria's electricity distribution networks, which contribute to energy poverty and high electricity costs. By modeling the Enugu distribution network and integrating distributed energy resources, specifically a hybrid system comprising solar PV, diesel generators, and battery storage, the research evaluates the impact on power losses. Load flow analysis reveals that the integration of distributed energy resources significantly reduces both active and reactive power losses, with a notable 36% decrease in reactive power loss for a key transformer. Notably, the reactive power loss in a key transformer (T10) decreased by 36%, from 201.4 kvar to 128.8 kvar, while active power loss in the same transformer dropped from 10.1 kW to 6.4 kW. Other branches, such as Line604, also showed reduced losses, with active power loss decreasing from 50.9 kW to 49.5 kW. These findings demonstrate the potential of distributed energy resources to improve the efficiency and reliability of power distribution networks, supporting Nigeria's objectives for universal energy access and sustainable development.

Keywords: Power Losses, Distributed Energy Resources, Distribution network

I. Introduction

Energy is one of the most critical infrastructures for economic growth and development worldwide. Though the world has continued to experience higher generation and consumption per capita, reverse has been the case for Africa. Nigeria currently has one of the highest rates of energy poverty in the world. The electricity access rate stands at 25% for rural populations for whom biomass and waste are the primary source of energy for cooking. Conversely, Nigeria has one of the highest costs of electricity in the world at an average of \$0.52/kWh. Development finance institutions and other donors, wealthier, high-emitting countries, and international NGOs are well-placed to support this agenda through financing and research, and by encouraging constructive engagement on subsidy reform and justice and social responsibility in energy transition more broadly. Nigeria's energy transition creates significant investment opportunities, including establishing and expanding industries for solar, hydrogen and electric vehicles, and using its vast natural gas resources for economic development. A Renewable Energy Roadmap was produced with the International Renewable Energy Agency and the Energy Commission of Nigeria in January 2023 that "encompasses all key sectors of the Nigerian energy system to provide additional context for energy policy discussions on how increased ambition in terms of renewable energy beyond current government policy and targets can be realized (Nwani, 2018). Nigeria is at a key juncture in time; with a growing population and a range of socio-economic challenges, it requires sustainable energy sources to meet the growing needs for all the sectors of its economy and achieve universal access to modern energy services.

Nigeria has a significant number of people in Africa without access to electricity. Achieving universal electricity access in Nigeria will have a significant impact on a large number of people's lives. Currently, Nigeria's main barriers to universal energy access is rural electrification and unreliable electricity from the grid. Both have significantly influenced the productivity of Nigeria's economy, which points to the potentially significant economic growth impact that reliable and universal electricity access will have in Nigeria. Universal provision of energy services for cooking and power are key objectives of national energy policies, in addition to priorities of energy affordability, energy security, and reduced air pollution and carbon dioxide emissions (Okoroafor et al., 2024b).

Distribution losses, or simply the difference between energy input into the network and energy invoiced to customers, are the total amount of energy lost throughout the transmission and distribution of electricity from power production to consumers. Technical and non-technical losses are the two categories into which these losses fall. Technical losses, such as those in transformers, transmission and distribution lines, power management equipment, and measurement systems, are intrinsically tied to the operating features of electrical systems. These losses include induction and radiation losses, dielectric losses in insulating materials, and copper losses resulting from conductor resistance (I^2R losses). Technical losses are also caused by things like harmonic distortion, poor grounding, unequal transformer loads, and the use of inferior materials like aluminum conductors. Non-technical losses, on the other hand, are caused by outside activities or administrative errors rather than being directly tied to the physical characteristics of the power system. These include metering mistakes, especially in industrial settings where current transformers may be of low quality, customer nonpayment, industrial usage of energy at low power factors resulting in underbilling, and electricity theft via unauthorized connections or meter manipulation. Non-technical losses are difficult to manage since system operators do not routinely record them, making them hard to measure. This calls for tactics that emphasize precise meter reading, proper customer billing, efficient revenue collection, and accountability. Both kinds of losses are important to the effectiveness and financial stability of the power distribution industry in Nigeria, where networks such as 33kV and 11kV are in place. As such, particular measures are required to reduce and manage these losses. (Adesina, 2016).

Natural occurring technical losses in power networks are mostly related to the physical characteristics of the electrical network. Harmonic distortion where non-linear loads like computers and electronic gadgets produce harmonics that create extra heating and losses in transformers and lines is one major driver of these losses (Al-Shetwi et al., 2019). Inappropriate earthing at the consumer end may also result in higher losses by opening channels for inadvertent current flow, therefore aggravating energy waste and raising safety hazards. Long single-phase lines are particularly prone to larger losses owing to increasing resistance over distance, especially in rural locations where power distribution could be spread out. In three-phase systems, uneven loading of phases results in inefficiency as it allows current to flow via the neutral, hence increasing losses. Low voltage and overloading situations worsen losses when overloaded transformers and lines run less effectively at lower volts, hence increasing resistance losses. Furthermore, important is the inadequate quality of equipment; obsolete or subpar transformers or cables may greatly cause technical losses. Finally, particularly under high load situations, smaller conductor size causes greater resistance and therefore more losses. Conversely, non-technical losses which result from human and administrative mistakes or malpractices have none bearing on the operational or physical features of the power system. Errors in technical loss calculation may lead to misrepresentation of losses, influencing financial planning and system efficiency ratings. Illegal connections and theft of power directly bypasses revenue collection, resulting to severe financial losses for utilities. Faulty energy meters or un-metered supply circumstances imply that consumption is not precisely or at all recorded, resulting to billing disparities and unexplained energy usage. Finally, faults and delays in meter reading and billing lead to non-technical losses by producing inconsistencies in how much users are billed vs how much they really consume. This may result in underbilling or overbilling, both of which harm the utility's financial health and consumer confidence. Managing these non-technical losses needs sophisticated systems for metering, invoicing, and monitoring, plus regulatory frameworks to fight theft and fraud.

Distributed generation (DG) denotes the decentralized production of electricity, geographically dispersed within the serviced area and proximate to energy consumers, typically the facility owners, in contrast to the conventional model of large, centralized power plants. The principal attributes of distributed generation (DG) include its localized influence, less reliance on the central grid, adaptability to incorporate diverse energy sources, and the augmentation of energy security and environmental sustainability (Vera et al., 2018).

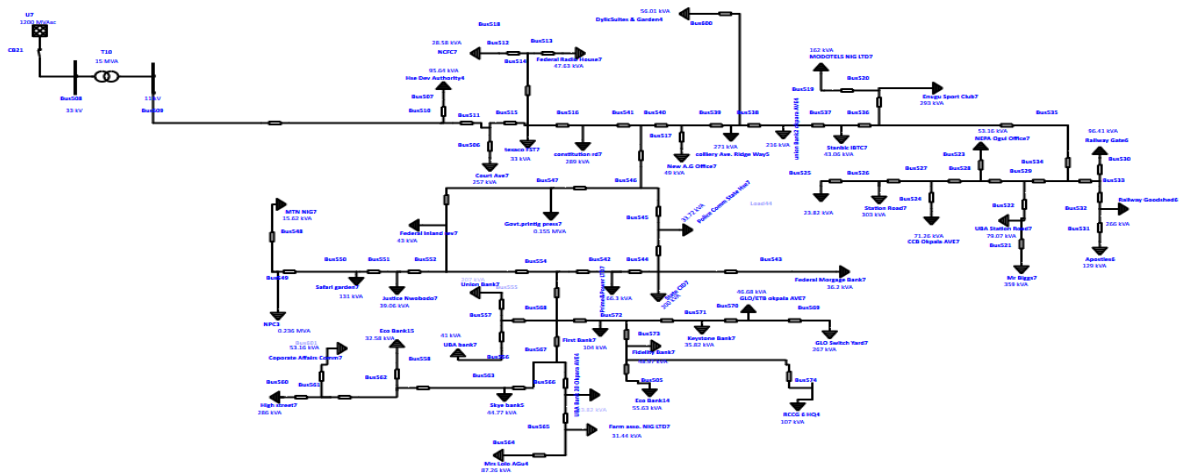
Due to global needs, particularly in developed and emerging nations, more sustainable energy solutions are now needed to replace traditional power generating resources like fossil fuels. Climate change and global warming are two harmful environmental problems brought on by fossil fuel-based energy sources. Over the last several decades, electricity production has drastically expanded its emissions of greenhouse gases into the atmosphere. In order to tackle the present environmental issue, renewable energy technologies such as solar, wind, hydro, biomass, geothermal, and hydrogen energies have been developed to create power. As society's awareness of a clean environment grows, renewable energy is gaining more and more attention because of its environmentally favorable qualities and capacity to produce electricity with almost no emissions of air pollutants. Renewable energy has economic significance in addition to its environmental benefits. Because it uses natural, renewable resources to create energy, it lowers the cost of generating power, which helps the economy. Because users may sell the energy they create back to the power grid, it can also serve as an additional source of income. The bulk of power production is still done using fossil fuels because of the high initial cost and intermittent nature of renewable energy sources, even if their use is growing. For instance, a hydro turbine can only run when there is potential energy generated by water flow, a solar system can only run during the day, and a wind turbine can only run when there is enough air movement. As a result, scientists worldwide are doing thorough study to increase renewable energy's effectiveness and get over its drawbacks (Ang et al., 2022).

Distributed generation can improve system efficiency because distributed generation helps reduce system losses when connected to the network. Distributed generation is environmentally friendly in producing electrical energy. Emissions generated from the production of electrical energy by distributed generation are low, even close to zero. Losses in the distribution network can be significantly reduced using distributed generation. Because of the nearness of the distributed generations to load centers, power lost due to transmission of electricity over a long distance is minimized. This nearness reduced the burden of load on the transmission/distribution network, which will lead to a good voltage profile with a reliable grid network. The management of peak loads is better with distributed generation because the efficiency of the system is enhanced by pairing generation with load demand. The challenges faced by the power system in Nigeria due to poor or weak infrastructure, it is profitable to adopt distributed generation, which can address the various issues of reliability and the access to energy. This study will utilize distributed generation interconnected with the distribution network to minimize losses on the power system network.

II. Method

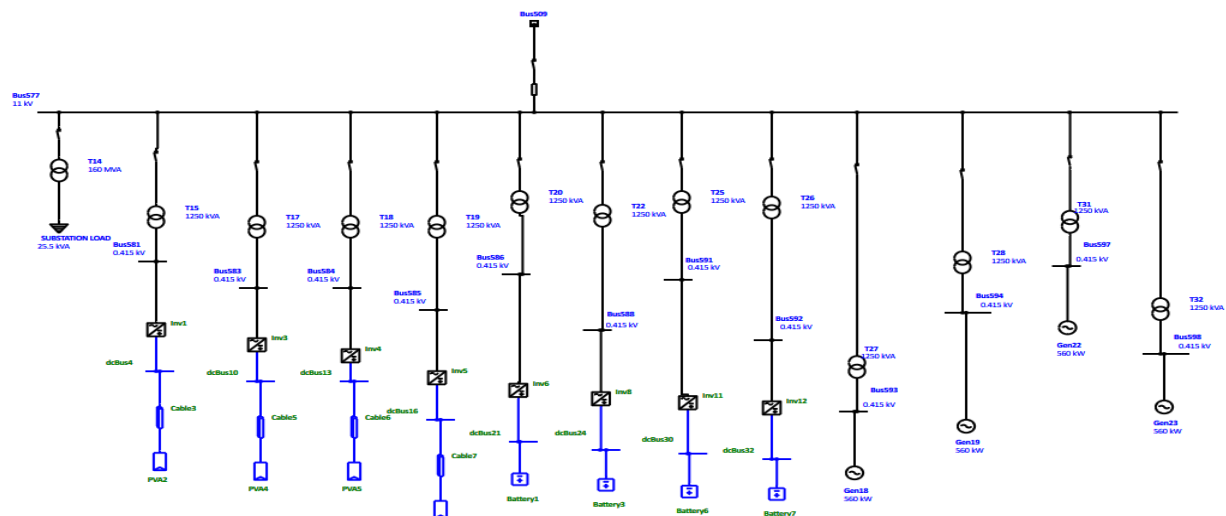
Modeling of The Distribution Network

The Enugu distribution network model, the model data used is from Kingsway substation. The voltage is stepped down from 33KV to 11kV for distribution through other feeders that delivers power to both urban and rural areas the state. The nominal voltage used for this study is 11KV and the model is simulated in ETAP to analyze power flow, losses, for assessing distribution network integration with distributed generation benefits in reducing losses.

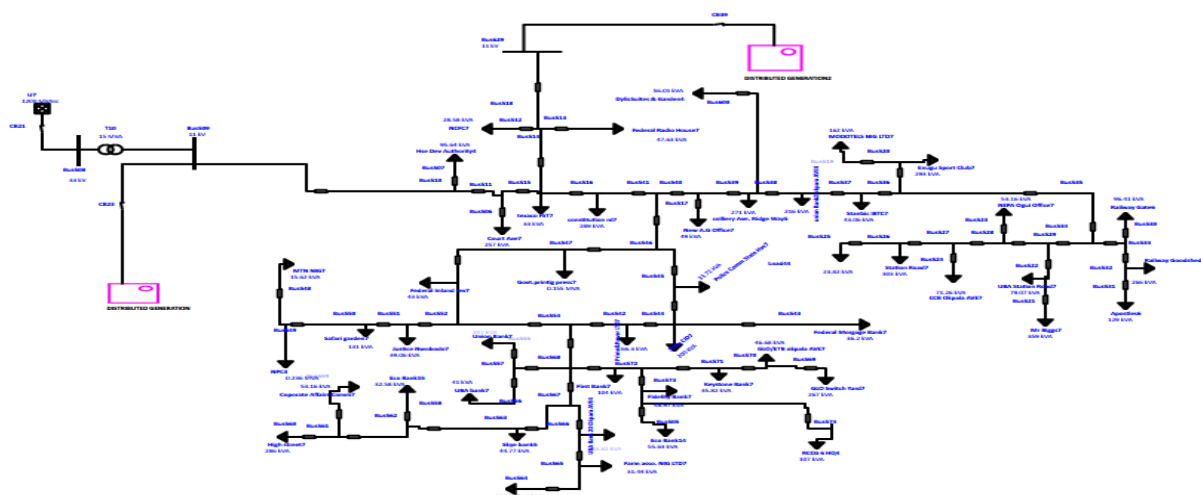


Modeling of The Distributed Generation Station

The distributed generation used is a hybrid distributed generating station, which has PV as its primary source of voltage and other sources like diesel generators, batteries. The model comprises of 4 strings of solar panels of 267.6Watt per panel, and 291 panels were connected in series and 13 in parallel. The batter comprises of 4 battery containers of about 486 cells in a string and it comprises of 4 strings in total, a total capacity of 200 Ah, and a rated open circuit voltage of 1001 volts.



Interconnection of The Distributed Network with The Distributed Generation



III. Result

Losseson The Distribution Network Without Distributed Generation

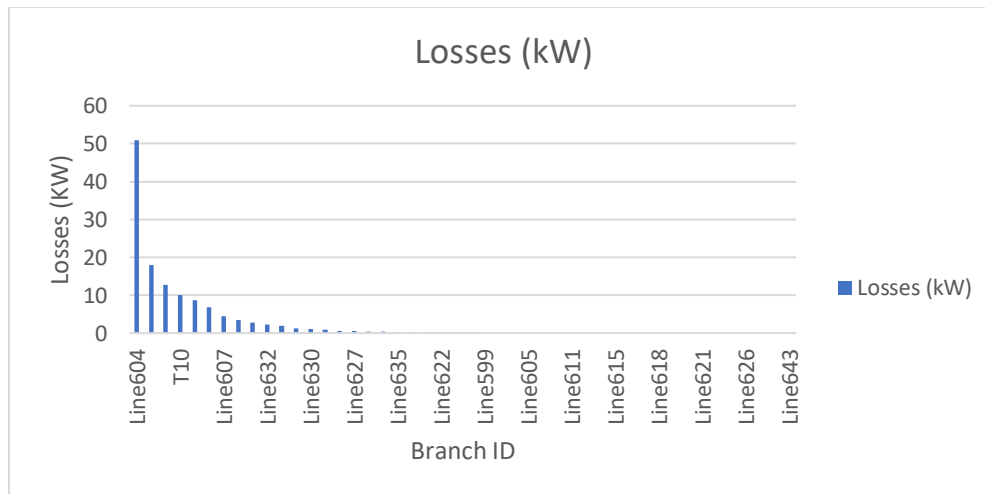
Line losses were calculated using $I^2 R$

$$P_{loss} = \sum_{i=1}^N \sum_{j=1}^N I_{ij}^2 R_{ij}$$

Where I_{ij} = the current flow in line i and j that is derived form the load flow results

Branch ID	Losses (kW)	Losses (kvar)
Line604	50.9	24.5
Line602	17.9	25.5
Line608	12.8	18.2
T10	10.1	201.4
Line603	8.7	12.3
Line609	6.8	9.7
Line607	4.5	-64.8
Line633	3.4	4.8
Line634	2.8	4
Line632	2.2	3.1
Line629	1.9	2.6
Line631	1.2	1.7
Line630	1	1.3
Line639	0.9	1.1
Line641	0.6	0.6
Line627	0.5	0.8
Line628	0.4	0.4
Line638	0.4	0.5
Line635	0.3	0.3
Line636	0.3	0.4
Line640	0.3	0.4
Line622	0.2	0.2
Line613	0.1	0.1
Line625	0.1	0.1
Line599	0	0
Line600	0	0
Line601	0	-0.1
Line605	0	-0.1
Line606	0	-0.1
Line610	0	-0.1
Line611	0	-0.3

Line612	0	0
Line614	0	0
Line615	0	0
Line616	0	0
Line617	0	0
Line618	0	-0.1
Line619	0	0
Line620	0	0
Line621	0	0
Line623	0	0
Line624	0	-0.1
Line626	0	0.1
Line637	0	-0.1
Line642	0	0
Line643	0	0



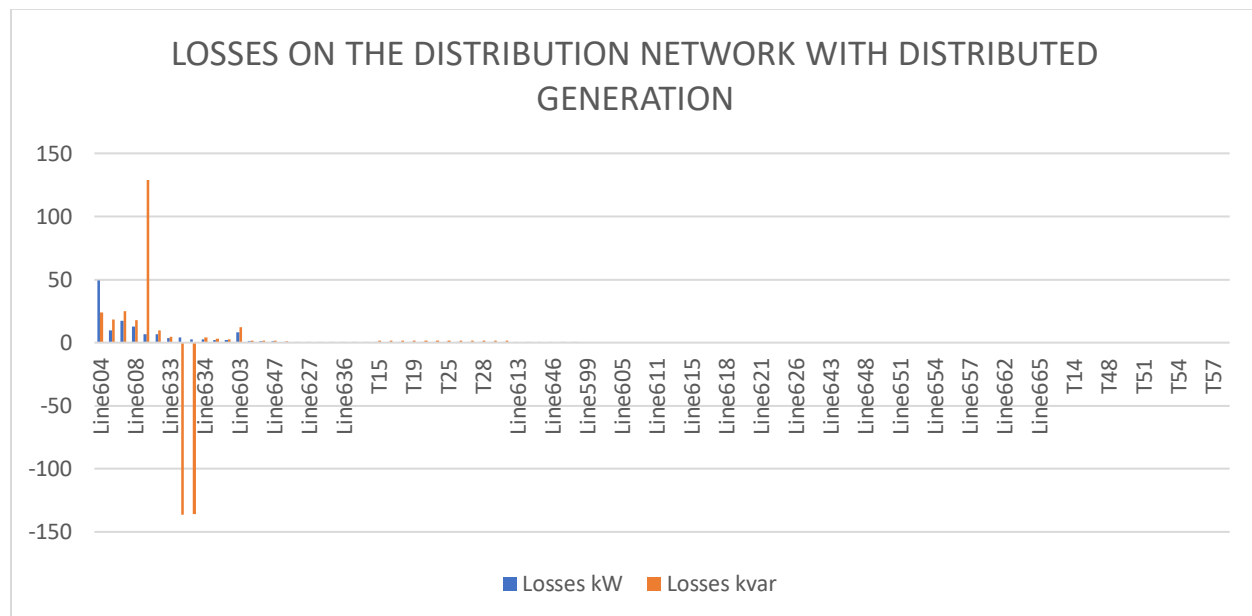
Losses on The Distribution Network with Distributed Generation

Branch ID	Losses kW	Losses kvar
Line604	49.5	23.8
Line667	9.7	18.5
Line602	17.4	24.8
Line608	12.7	18
T10	6.4	128.8
Line609	6.8	9.6
Line633	3.4	4.8
Line671	3.9	-136.6
Line607	2.8	-136

Line634	2.8	3.9
Line632	2.2	3.1
Line629	1.9	2.6
Line603	8.4	12
Line631	1.2	1.7
Line630	1	1.4
Line647	1	1.4
Line639	0.8	1.1
Line641	0.6	0.7
Line627	0.5	0.7
Line628	0.4	0.5
Line638	0.4	0.5
Line636	0.3	0.4
Line640	0.3	0.4
Line635	0.3	0.3
T15	0.2	1.6
T17	0.2	1.6
T18	0.2	1.6
T19	0.2	1.6
T20	0.2	1.6
T22	0.2	1.6
T25	0.2	1.6
T26	0.2	1.6
T27	0.2	1.6
T28	0.2	1.6
T31	0.2	1.6
T32	0.2	1.6
Line613	0.1	0
Line622	0.1	0.2
Line625	0.1	0
Line646	0.1	0
Line660	0.1	0.1
Line661	0.1	0.1
Line599	0	0
Line600	0	0
Line601	0	0
Line605	0	0
Line606	0	0

Line610	0	0
Line611	0	0
Line612	0	0
Line614	0	0
Line615	0	0
Line616	0	0
Line617	0	0
Line618	0	0
Line619	0	0
Line620	0	0
Line621	0	0
Line623	0	0
Line624	0	0
Line626	0	0
Line637	0	0
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Line659	0	0
Line662	0	0
Line663	0	0
Line664	0	0
Line665	0	0
Line666	0	0
Line669	0	0
T14	0	0

T46	0	0
T47	0	0
T48	0	0
T49	0	0
T50	0	0
T51	0	0
T52	0	0
T53	0	0
T54	0	0
T55	0	0
T56	0	0
T57	0	0
T58	0	0



The findings of this research, which investigated how distributed energy resources (DERs) is integrated into the Enugu distribution network to reduce power losses, provide valuable insights into how well distributed generation might improve power system efficiency. This research compared the distribution network losses with and without a hybrid distributed generation station which consists of diesel generators, solar photovoltaic (PV) panels, and battery storage connected. The results highlight distributed generation 's capacity to reduce technical and non-technical losses, which is consistent with the larger goals of enhancing Nigeria's energy accessibility and dependability.

Distribution Network Losses Without Distributed Generating

Significant power losses were seen in a number of branches in the base case, in which the distribution network functions without distributed generation. The power loss formula was used to determine the overall active power losses (measured in kW) and reactive power losses (measured in kvar), which represent the system's inherent inefficiencies. Significant energy dissipation over long distances owing to conductor resistance was seen in Line 604, which had the maximum active power loss at 50.9 kW and reactive loss of 24.5 kvar. A reactive power loss of 201.4 kvar was also reported by transformer T10, indicating inefficiencies brought either by overloading or low power factor. According to the introduction, other branches, including Line 602 (17.9 kW, 25.5 kvar) and Line 608 (12.8 kW, 18.2 kvar), also showed significant losses. These were caused by factors such as harmonic distortion, unequal phase loading, and improper conductor size. The distribution of losses demonstrates the difficulties the Enugu network faces, especially in rural regions where resistance losses are made worse by lengthy single-phase lines. Certain branches (such as Line

607) may have negative reactive power losses, which might be a sign of capacitive effects or measurement irregularities that need further research. Although they were not specifically measured in the data, the overall losses in the absence of distributed generation show a system affected by technical losses and maybe worsened by non-technical elements like theft or inaccurate metering.

Power Losses with Distributed Generation

Power losses across many branches were significantly reduced as a due to the hybrid distributed generation station's integration into the distribution network. For example, Line 6 and Line 604's reactive power loss decreased from 24.5 kvar to 23.8 kvar, and its active power loss decreased from 50.9 kW to 49.5 kW. Significantly less reactive power losses were seen in transformer T10, where they fell by almost 36% from 201.4 kvar to 128.8 kvar. This significant improvement may be attributed to the distributed generation station's close proximity to the load centers, which minimizes losses by reducing the distance across which electricity must be transported. Furthermore, by providing power locally, the distributed generation lessens the strain on transformers and lines, improving the voltage profile and lowering overloading circumstances. Branches showed lower losses as well. Line 602 saw a dip from 17.9 kW to 17.4 kW, while Line 608 experienced a little decrease from 12.8 kW to 12.7 kW. The findings with distributed generation showed several interesting new branches, which probably indicate extra connections or reconfigurations brought forth by the distributed generation link. Certain branches, like Line 607, showed a sharp change to negative reactive losses (-136 kvar), which can be a sign of better reactive power compensation or power factor correction from the distributed generation system, especially from the PV inverters or battery storage.

Comparative Analysis and Implications

In both cases, the majority of branches saw a consistent decrease in active and reactive power losses as a result of the integration of distributed generation. High loss components like transformer T10 and important lines like Line 604, along with distributed generation's efficacy in mitigating technical losses resulting from equipment inefficiencies and lengthy transmission lengths, showed the biggest savings. Reactive power losses are reduced, especially in transformers, which implies that distributed generation raises power factor and system stability. It is shown that integrating distributed generating stations to the distribution network will not only lower losses but will also expand access to energy for rural communities. Additionally, there are significant economic implications of this integration which may include lower operating expenses for utilities, which may lessen the high energy rates that customers must pay. In comparison to fossil fuel-based generation, the environmental advantages of distributed generation, especially when solar PV is used, are in line with Nigeria's Renewable Energy Roadmap and the global sustainability objectives. This helps to lower greenhouse gas emissions.

IV. Conclusion

It is shown that integrating distributed generation into the Enugu distribution network lowers power losses, improving system dependability and efficiency. The findings support the theory that distributed generation may solve both operational and technological inefficiencies in Nigeria's power system because of its close proximity to load centers, which reduce grid pressure. These encourages the use of decentralized energy solutions to lower prices, achieve universal access to power, and advance sustainable development. These advantages may be amplified by further optimization, capacity, and integration techniques, opening the door to a more robust and effective power distribution system.

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