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# Enhancing Voltage Stability in Distribution Networks Using Genetic Algorithms for Distributed Generation

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***Abstract —*** *Globally, energy utilities are increasingly focusing on advancing the control, management, stability, and optimization of energy systems. Traditional methodologies, plagued by inefficiencies, high costs, and unreliability, have proved inadequate. This shortcoming is particularly evident as the electricity structure shifts from a vertically integrated model to a horizontally integrated one. This shift facilitates the integration of technologies such as distributed generation and renewable energies, including wind, solar photovoltaics, and small hydro, into the distribution network, thereby introducing new challenges to existing software in terms of stability, economic performance, and management. This study explores the application of a Genetic Algorithm to determine the optimal placement of distributed generation to enhance system voltage levels. The methodology was applied to a primary distribution network in Ado Ekiti, employing MATLAB to model both the system and the Genetic Algorithm codes. Performance evaluations were conducted using voltage deviation metrics to assess proximity to predefined margins. The findings revealed that arbitrary placement of distributed generation increased the voltage margin, whereas the Genetic Algorithm offered superior optimization. These results demonstrate that the Genetic Algorithm is an effective tool for optimizing distributed generation placement and enhancing voltage margins.*
***Keywords—*** *Genetic Algorithm, Optimal Location, Distributed, Generation, Voltage Stability, Enhancement.*

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## I. INTRODUCTION

Power is generated from the generating center and get a lower kW which eventually was busted to higher MW and from there transmitted from the generating corridor to the transmitting corridor which is latter transmitted to the distribution center and finally distributed to the customers. But due to inability of the distributed energy to be sufficient to the end users, distributed generation has to be used to improve the stability of the distributed voltage. In rural areas, independent power systems harness locally abundant resources to provide significant benefits to local communities. These systems not only meet the energy needs of these regions but also allow for the possibility of surplus energy redistribution or commercialization by the communities themselves. In academic discourse, distributed generation (DG), also referred to as embedded generation, involves integrating small-scale power plants directly into the distribution network to function alongside it. Scholarly literature describes DG as encompassing both combustion technologies, such as reciprocating engines and turbines, and non-combustion technologies, including fuel cells, photovoltaics, and wind turbines. These energy sources, typically located near end-users, are categorized as either renewable or cogeneration non-dispatched sources [1], [2], [3].

The strategic planning and management of Distributed Generation (DG) units are critical in achieving numerous advantages within a distribution network, such as enhanced stability, improved voltage profiles, reduced power losses, increased economic efficiency, and decreased dependency on local utilities [2]. The effective integration of DG units requires the implementation of voltage regulation mechanisms, like voltage regulators and Under-load Tap Changers (ULTCs), alongside reactive power compensation using VAR compensators. These efforts collectively address an Optimal Power Flow (OPF) problem, which is paramount during the integration of the power grid with existing infrastructure [4]. As the grid integrates, the power system evolves from a vertically integrated model, where electricity is generated, transmitted, and distributed sequentially, to a horizontally integrated model. The latter approach necessitates integrating distributed generation capabilities directly within the distribution network [5].

Integrating this novel network architecture into the electrical grid brings about swift and robust optimization, resulting in enhanced voltage profiles and improved power quality, all while maintaining voltage stability. It effectively reduces power losses, contributing to greater energy efficiency. Moreover, it mitigates security threats, alleviates congestion in Transmission and Distribution (T&D) networks, and enhances consumers' capacity to manage their energy consumption. This system supports initiatives aimed at peak load shedding and more effective demand management. Its horizontal layout facilitates the integration of Distributed Generation (DG) at the distribution level, allowing for a comprehensive evaluative analysis.

The bi-directional power flow constitutes transient stability problem, insulation break down, Voltage and control complexity. The challenges become complex when the renewable energy is such as the one that is weather dependent and fluctuate such as wind and solar PV.

## II. DISTRIBUTED GENERATION (DG)

Distributed power generation refers to a range of technologies that enable the localized production of electricity, usually situated close to where it will be consumed. This approach not only enhances the economic efficiency of existing power distribution systems but also addresses the growing demand for electricity [6]. It includes cogeneration methods, also known as combined heat and power systems, as well as renewable energy sources such as wind, solar, hydroelectric, geothermal, and biomass [3]. Notably, renewable energy sources are valued for their minimal environmental impact, largely owing to the absence of carbon dioxide and other greenhouse gas emissions. However, these sustainable resources often produce less electricity compared to traditional energy generation methods. Centralized traditional generation systems rely on vast plants that produce significant amounts of energy. This energy is subsequently distributed to consumers via an expansive network for transmission, facilitating a unidirectional flow from the production facilities straight to the end-users. In contrast, Distributed Generation (DG) integrates smaller technologies like wind turbines, photovoltaic panels, and CHP units either at the consumer level or within local distribution networks permitting bidirectional electricity flow—both from and to the grid—thus reducing losses while simultaneously enhancing both quality and reliability of supply throughout the network [7].

## III. SMART ENERGY OR INTELLIGENT POWER GRIDS

The integration of large-scale, variable renewable energy sources is supported by a network that enhances the efficiency of power distribution. This network leverages distributed energy resources along with advanced communication and management technologies to deliver electricity in a cost-effective and environmentally friendly manner, which reduces carbon emissions and fosters consumer engagement [8]. To manage power system demand effectively, various small-scale electricity generation methods are employed. These include technologies such as wind turbines, solar panels, microturbines, fuel cells, and combined heat and power systems, often located closer to consumers than traditional large-scale power plants. This proximity reduces transmission losses and boosts overall system efficiency [9]. As Franco notes, these decentralized energy generation methods not only significantly improve the efficiency of the electric system but also facilitate the integration of substantial amounts of clean, renewable energy into the grid [8]. The transition to a Smart Grid is a gradual process, often described as 'smartening' or 'modernizing' the grid [10]. Building on the existing infrastructure helps maintain reliable service while aiming to lower costs and enhance efficiency in electricity supply.

Smart energy embodies a transformative approach that advances beyond traditional energy generation and consumption methods, concentrating on process efficiency [11]. This paradigm places consumers at the core of its model, prioritizing environmentally sustainable and efficient service delivery. Illustrated in Fig.1, smart grid is an electrical network that is meticulously engineered to smoothly harmonise the activities and interactions of all its stakeholders—generators, consumers, and prosumers. The goal is to realize an economically viable power system marked by minimized losses and upheld standards of quality, supply security, and safety [12].

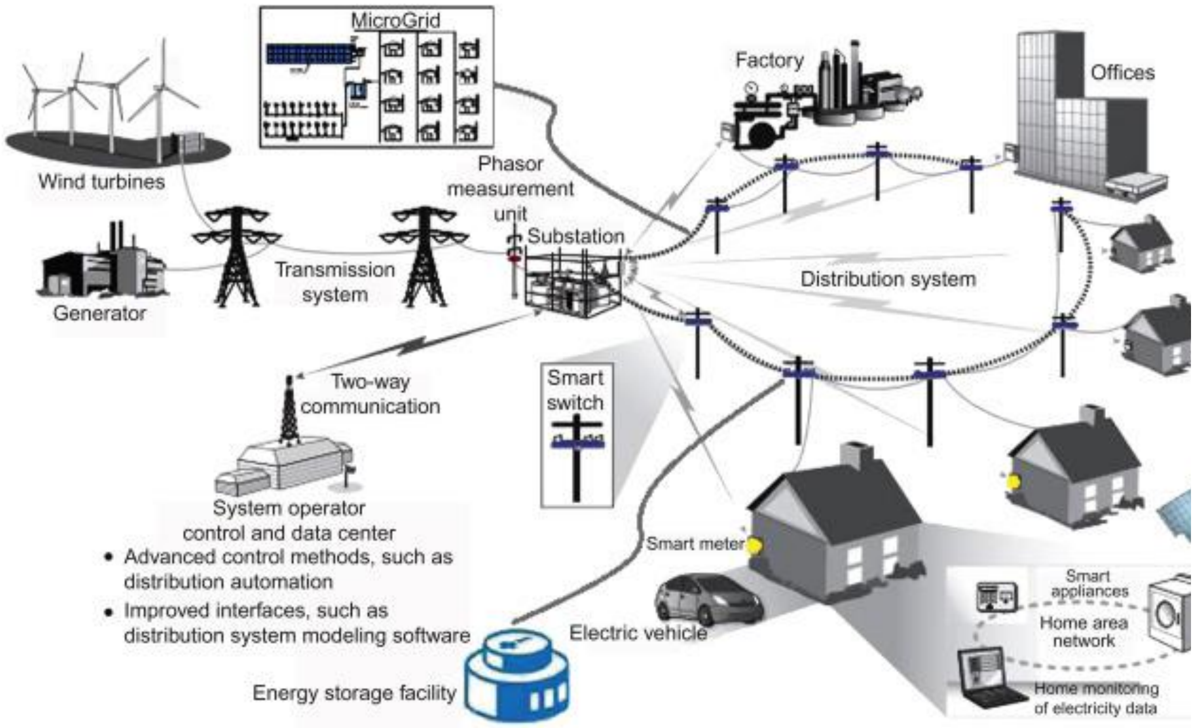


Fig. 1. Smart Grid Diagram Depicting Generation, Transmission and Distribution [11].

## IV. DYNAMIC / STATIC VOLTAGE STABILITY IN POWER SYSTEMS

The escalating demand for electricity, particularly in developing nations like Nigeria, is pushing power systems to their operational limits. This surge in demand originates from various sectors including residential, commercial, and industrial areas. Consequently, guaranteeing the delivery of reliable and high-quality power has emerged as a significant challenge. These concerns underscore the importance of understanding dynamic power system stability. This research seeks to explore strategies for assessing and enhancing the stability of these systems to prevent instability. According to academic literatures, power system stability can be said to be the capacity of systems to return to a state of equilibrium following disturbances, provided certain conditions are met. This concept necessitates keeping various parameters within predefined boundaries to maintain the integrity of the system [13]. Preserving this integrity is essential, ensuring continuous interconnection across nearly all segments of the electrical network. Exceptions include necessary disconnections for fault isolation or as part of scheduled maintenance activities. Stability is characterized by a harmony between competing forces; instability arises when such disturbances lead to extended disruptions in this balance [14]. Various disturbances can affect stability such as faults, changes in load demands, outages at generator stations or transmission lines leading up voltage collapses or combinations thereof [15].

## V. RESEARCH METHODOLOGY

The research was conducted by adhering to the following sequence of methods.

1. Collection and Manipulation of Data.
2. Modeling the Primary Distribution network.
3. Optimization of system modeling through genetic algorithms (GA). Power.

The primary 11 kV feeder, which derives its power from A transformer at the Agric 11 kV injection substation with a capacity of 15 MVA, is responsible for supplying electricity to diverse areas including Odo ado axist, agric axis and parts of Ado-Ekiti. Within this network are seventeen transformers with varying capacities. Critical data for analysis were gathered from these transformers and utilized in MATLAB simulations to facilitate accurate modeling.

## VI. DATA GATHERING

Table 1 provides relevant data that have been collected from the Benin Electricity Distribution Company (BEDC). Table 1 presents the data collected from the primary 11kV feeder. Extracted from the daily logs at a primary injection substation in Ado Ekiti, which is being managed by Benin Electricity Distribution Company (BEDC).

## VII. GENETIC ALGORITHM APPLICATION IN THE MODELING OF PRIMARY DISTRIBUTION NETWORKS

In this network analysis, the power input source is characterized by a photovoltaic (PV) generator. Transmission lines are modeled using a pi network configuration, while transformers and loads are also effectively represented; the latter specifically in terms of lumped load capacities measured in megawatts (MW) and reactive powers quantified in mega volt-ampere reactive (MVAR). The Newton-Raphson algorithm facilitates the computation of load flow. Initially, energy totaling 6 MW from Basiri's 15 MVA substation was directed into the feeder; however, this proved inadequate for meeting customer demands. Consequently, additional increments of power—1 MW, 2 MW, and 3.5 MW, were integrated into the system before implementing modifications via the Genetic Algorithm to enhance both capacity and operational efficiency.

**TABLE I: CURRENT LOAD CAPACITY ON ADO-EKITI FEEDER (DATA COLLECTED FROM 21ST OF AUGUST TO 30TH, 2023)**

| Date | Energy available (MW) |
|---|---|
| 21st | 2.0 |
| 22nd | 2.2 |
| 23rd | 2.4 |
| 24th | 2.1 |
| 25th | 2.2 |
| 26th | 2.2 |
| 27th | 2.6 |
| 28th | 2.1 |
| 29th | 2.1 |
| 30th | 2.0 |

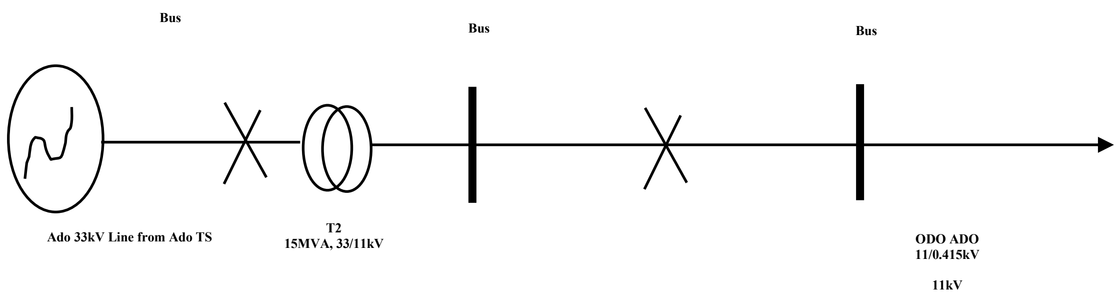


**Figure 2: Schematic Representation of the Primary 11/0.415Kv Injection Substation**

## VIII. RESULT AND DISCUSSION

The discussion of the results is divided into two ways:
A. Optimal power flow with/without DG integration
*B.* Optimal power flow with/without DG integration using GA.

### *A. Optimal Power Flow With/Without Dg Integration*

The analysis of optimal power flow within a primary distribution network encompassed 17 buses. Results are displayed in the following table, which details voltage in per-unit (PU), angle, and both load and generated active and reactive powers. This study assessed scenarios with and without the integration of Distributed Generation (DG), incorporating DG at a capacity of 2.0 MW when included.
Results obtained from increased penetration of Solar PV levels without integrating genetic algorithms (GA).
The following penetration levels were carried out to explain the two conditions.

i. without DG integration
ii. with 0.75 MW DG integration
iii. with 1.5 MW DG integration
iv. 2.0 MW DG integration

The distribution of ii to iv across the chosen feeder, as illustrated in Table 2, is arbitrary according to the above analysis.

**TABLE II. ARBITRARY DISTRIBUTION OF DG ON PRIMARY FEEDER WITHOUT GA**

| S/N | 0.75 MW | Locations | 1.5 (MW) | Locations | 2.0 MW | Locations |
|---|---|---|---|---|---|---|
| 1 | 0.15 | MATHEW | 0.40 | Gbohunalore | 0.50 | Gbohunalore |
| 2 | 0.15 | ST PAUL | 0.40 | Agip | 0.50 | Agip |
| 3 | 0.15 | AJENIKOKO | 0.40 | Omisanjana2 | 0.50 | Omisanjana2 |
| 4 | 0.30 | IYANA EMIRIN | 0.30 | Omisanjana3 | 0.50 | Omisanjana3 |

The distribution is done optimally and reported in the table on primary feeder.

**TABLE III. STEADY VOITAGE RESUIT OF PRIMARY FEEDR WITH/WITHOUT DG PENETRATION**

| SUBSTATION | Voltage Deviation (pu) | | | |
|---|---|---|---|---|
| | No DG Generation | 0.75 MW Connected | 1.5 MW Connected | 2.0 MW Connected |
| MATHEW | 0.45 | 0.60 | 0.78 | 0.89 |
| ODO ADO | 0.40 | 0.68 | 0.80 | 0.92 |
| ST PAUL | 0.40 | 0.65 | 0.75 | 0.90 |
| IGIRIGIRI | 0.40 | 0.64 | 0.77 | 0.91 |
| AKINYEDE | 0.48 | 0.60 | 0.80 | 0.90 |
| ITA EKU | 0.46 | 0.65 | 0.76 | 0.91 |
| ADO GRAMMER | 0.42 | 0.66 | 0.76 | 0.90 |
| ILUPRJU AVE | 0.45 | 0.64 | 0.79 | 0.91 |
| IMMIGRATION 1 | 0.40 | 0.60 | 0.78 | 0.92 |
| IMMIGRATION 2 | 0.40 | 0.60 | 0.75 | 0.89 |
| OLUWASEFUNM | 0.44 | 0.60 | 0.77 | 0.90 |
| AJENIKOKO | 0.43 | 0.64 | 0.80 | 0.93 |
| POLY ROAD 1 | 0.42 | 0.65 | 0.80 | 0.92 |
| POLY ROAD 2 | 0.42 | 0.66 | 0.80 | 0.91 |
| IYANA EMIRIN | 0.44 | 0.68 | 0.78 | 0.90 |
| UNITY | 0.45 | 0.64 | 0.78 | 0.91 |
| NEW IMMIGRATION | 0.44 | 0.65 | 0.80 | 0.90 |

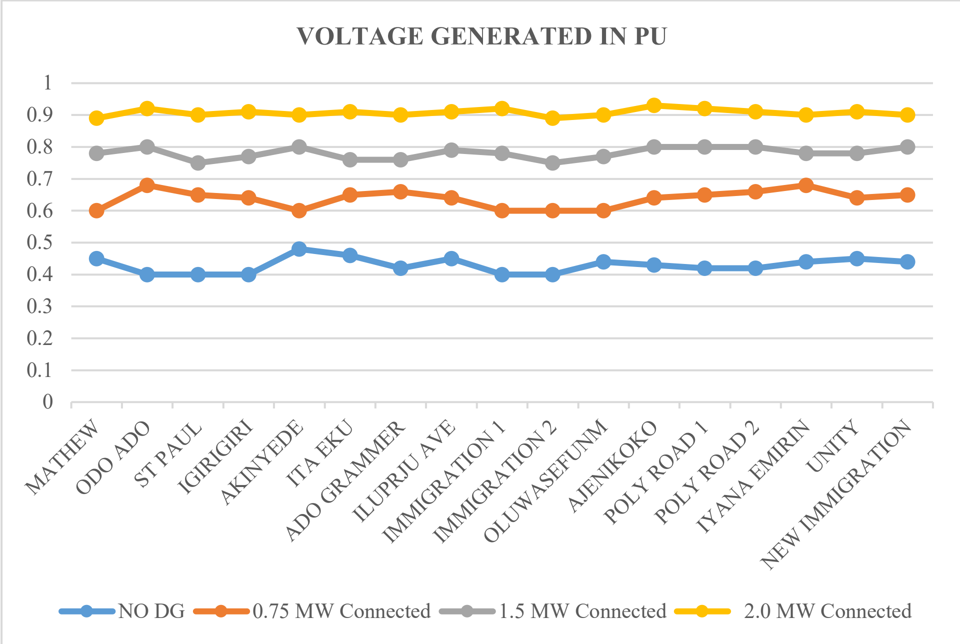


**Fig. 3. Steady State Voltage Result of Primary feeder with/without DG without GA**

Figure 3 shows the voltage deviation with increasing penetration of DG and the DG were manually placed. The placement is done by arbitrarily locating the bus with DG, which resulted in extremely low voltage from 0.40 to 0.45. Though the whole result are on positive side but it is all very low results

### *B. Optimal Power Flow With/Without DG Integration Using GA*

In this section, the DG was optimally located by GA. The DG ranged from 0.75MW to 2.0MW, which were all optimally located to the low buses out of the 17 units of buses, and the analysis of this is shown in Table IV below the result followed in Table V. Steady State Voltage Result of Primary Feeder when the DG was Optimally Located by GA

The existing penetration level is

i. without DG integration
ii. with 0.75MW DG integration
iii. with 1.50 MW DG integration
iv. 2.0 MW DG integration

The distribution is done optimally and reported in the table on primary feeder

**TABLE IV: OPTIMAL DISTRIBUTION OF DG ON PRIMARY FEEDER WITH GA**

| S/N | 0.75 MW | Locations | 1.5 MW | Locations | 2.0 MW | Locations |
|---|---|---|---|---|---|---|
| 1 | 0.15 | IGIRIGIRI | 0.40 | Ilupeju avenue | 0.50 | Iyana emirin |
| 2 | 0.15 | ITAEKU | 0.40 | Iyana emirin | 0.50 | Akinyede |
| 3 | 0.15 | OLUWASEYIFUNMI | 0.40 | Mathew | 0.50 | Odo Ado |
| 4 | 0.30 | UNITY | 0.30 | Ita Eku | 0.50 | Immigration 2 |

**TABLE V: STEADY STATE VOLTAGE RESULT OF PRIMARY FEEDER WITH/WITHOUT DG WHEN GA WAS USED FOR OPTIMAL LOCATION**

| | No Generation | 0.75 MW Connected | 1.5 MW Connected | 2.0 MW Connected |
|---|---|---|---|---|
| MATHEW | 0.38 | 0.62 | 0.90 | 0.99 |
| ODO ADO | 0.38 | 0.63 | 0.91 | 1.00 |
| ST PAUL | 0.36 | 0.62 | 0.88 | 0.98 |
| hIGIRIGIRI | 0.42 | 0.58 | 0.89 | 1.01 |
| AKINYEDE | 0.41 | 0.60 | 0.88 | 1.02 |
| ITA EKU | 0.42 | 0.63 | 0.90 | 0.98 |
| ADO GRAMMER | 0.38 | 0.64 | 0.92 | 0.99 |

| | | | | |
|---|---|---|---|---|
| ILUPRJU AVE | 0.40 | 0.64 | 0.91 | 1.02 |
| IMMIGRATION 1 | 0.42 | 0.62 | 0.90 | 1.01 |
| IMMIGRATION 2 | 0.41 | 0.62 | 0.92 | 1.02 |
| OLUWASEFUNM | 0.42 | 0.64 | 0.91 | 0.99 |
| AJENIKOKO | 0.38 | 0.63 | 0.90 | 0.98 |
| POLY ROAD 1 | 0.40 | 0.62 | 0.88 | 0.99 |
| POLY ROAD 2 | 0.40 | 0.63 | 0.89 | 0.98 |
| IYANA EMIRIN | 0.38 | 0.62 | 0.90 | 1.01 |
| UNITY | 0.44 | 0.64 | 0.92 | 0.98 |
| NEW IMMIGRATION | 0.42 | 0.64 | 0.91 | 1.01 |

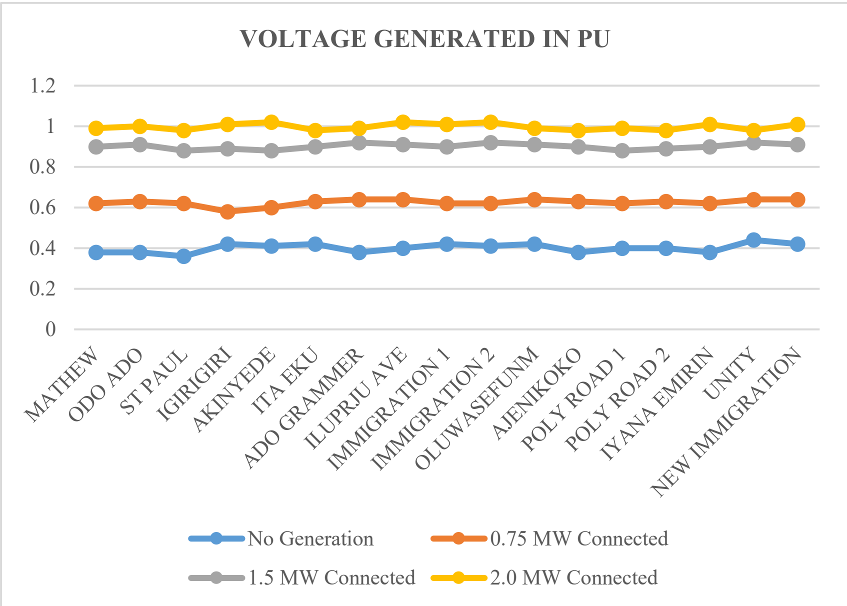


Fig. 4: Steady State Voltage Result of Primary feeder with/without DG with GA

Figure 4 show that voltage deviation without DG the voltage was extreemly low, and it was 0.38pu to 0.44pu but when the DG of 0.75MW was integratited in to the feeder , GA was optimaly used to distribute it the voltage level got improved to a range of 0.58 to 0.64PU but when the DG penetration was increase to 1.5MW the voltage got improve to 0.88pu to0.92pu but when 2.0MW was integrated with GA the voltage becomes more stable to 0.98PU to 1.02PU that needed for an average voltage level.

**TABLE VI. COMPARISON OF LOAD FLOW RESULT AND OPTIMAL LOAD FLOW RESULT OF 2.0 MW FOR PRIMARY FEEDERS WITH/WITHOUT GA**

| Primary Feeders | Voltage without GA(PU) | Voltage (PU) with GA |
|---|---|---|
| MATHEW | 0.89 | 0.99 |
| ODO ADO | 0.92 | 1.00 |
| ST PAUL | 0.90 | 0.98 |
| IGIRIGIRI | 0.91 | 1.01 |
| AKINYEDE | 0.90 | 1.02 |
| ITA EKU | 0.91 | 0.98 |
| ADO GRAMMER | 0.90 | 0.99 |
| ILUPRJU AVE | 0.91 | 1.02 |
| IMMIGRATION 1 | 0.92 | 1.01 |

| | | |
|---|---|---|
| IMMIGRATION 2 | 0.89 | 1.02 |
| OLUWASEFUNM | 0.90 | 0.99 |
| AJENIKOKO | 0.93 | 0.98 |
| POLY ROAD 1 | 0.92 | 0.99 |
| POLY ROAD 2 | 0.91 | 0.98 |
| IYANA EMIRIN | 0.90 | 1.01 |
| UNITY | 0.91 | 0.98 |
| NEW IMMIGRATION | 0.90 | 1.01 |

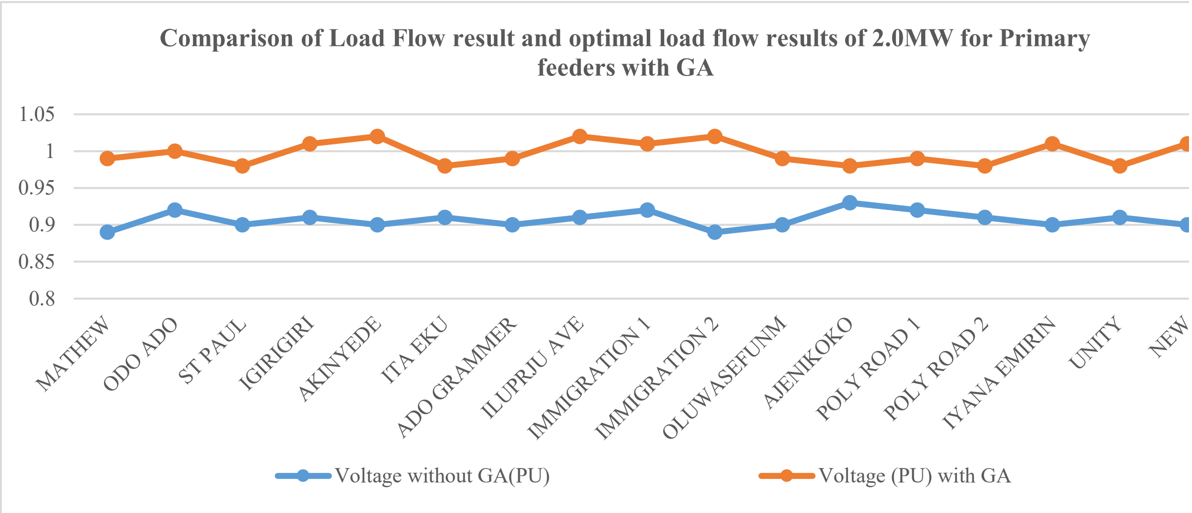


**Fig. 5. Comparison of optimal load flow results when 2.0 MW was integrated into primary distribution network feeders with and without GA**

Figures 5 show that the appropriate penetration level for the feeder is average of 2.0 MW. In figure 5, the voltage when 2.0 MW was integrated. Genetic Algorithm was able to place the DG which resulted in minimising the loses by placing the DG to the low buses areas to prevent energy wastage and increase the voltage margin thereby making the network stronger and stable, but in many buses it has not reach average pu of 1.04pu for the standard voltage of 240V which is an indication that the DG can still be increase minimally but the network is stable under this condition

## IX. CONCLUSION

The introduction of this new framework facilitates the inclusion of Distributed Generation (DG) and other enhancements, transforming it into a complex power network characterized by bidirectional power flows. If not appropriately designed, this structure could lead to issues such as congested transmission lines and high levels of power and voltage losses. To fully harness the advantages offered by the system—namely improved voltage regulation and minimized energy waste—the network requires optimization through swift computational algorithms. Among these solutions, heuristic programming-based intelligent algorithms stand out, renowned for their precision, efficiency, and accuracy in delivering results.

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