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(Research Article)

Enhancement of Power Flow on Nigerian 33kV network using solar system distribution generation system

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Abstract

The 33kV systems in the Nigerian power system network represents the critical point between the transmission system and the distribution system (to the end-users) hence, the occurrence power flow issues on the systems hampers the distribution of electricity to the consumers. The paper focused on the improvement of the power flow parameters with an optimally allocated solar system PV as a distributive generator (DG). The optimization was performed with particle swarm optimization (PSO) technique with fifth order polynomial model of prediction accuracy of 92.17% (which exceeded the specified threshold of 90%) being the objection function. The cumulative distance of 25.9533km was obtained which points to the line between line 21 and line 22 but the outcome is closer to line 21 which was connecting Alh abdullahi farm and Tahir estate. The DG sizing obtained was 8.92MW which was implemented and the power flow analysis of the system with Optimal DG allocation was also obtained. The results obtained that none of the voltage profile outcome without the DG exceeded the threshold range of 0.95pu and 1.05pu, the active and reactive power flows were generally low and the active and reactive losses were considerably high. But the introduction of the DG being strategically placed improved the voltage profile, the active and reactive flow and active and reactive loss to 18.33%, 24,37%, 21.17%, 26.34% and 29.18%.

Keyword: Kaduna Metropolis; Solar PV; PSO; DG; Power flow; Objective function; Power loss and power flow

1. Introduction

The power system network remains the foundation to the socio-economic development, but many developing countries especially Nigeria, faces persistent challenges with regards to the insufficient power supply, high distribution losses, high transmission losses and poor voltage profiles.[1,2,3] The Nigerian 33kV distribution experiences constant occurrence of voltage instability, power flow congestion, and issues with power losses as a result of power flow equipment aging, uneven load distribution and long radial feeders [4,5,6]

The electricity structure in the Nigeria power system has its structure being centralized as this type of power generation structure dominated the Nigerian power system network since inception. The electricity was generated by large sized power plants and then transmitted through long distances to distribution centers. The execution of the approach has over the years resulted to the occurrence of high technical losses, leading to reduction of efficiency in the distribution network [7,8,23, 24]

In the Nigerian power system design structure, the 33kV network remains the critical link between the transmission system and the consumers and it is considered the most vulnerable to power flow congestion and occurrence of technical losses. Hence improving the power flow of the 33kV is essential for improving stability and reliability of the network [9,10,11]

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Distribution generation (DG) systems has been considered to be a solution to curbing the power flow challenges that has been prevalent in the 33kV power system network. the concept of DG involves integration of generation sources preferably small scale into the distribution system leading to electricity consumption. The electrical sources utilized as DGs were mainly renewable power generation sources such as solar PV systems, wind turbines, micro-hydroelectric generation plants and other sources [29]. The implementation of DG has been seen to reduce the burden on transmission and distribution lines, enhance voltage profiles and reduces losses across the power system network [12,13,14] But among all the existing DGs, solar systems has been identified to be suitable for the Nigeria power system network due to high solar irradiance and favorable climatic conditions [15,16,28]

The implementation of the solar system based-DG into the 33kV power network offers many economic and technical benefits. The integration of solar system-based DG improves voltage stability by ensuring providing of reactive power flow support and minimizes line flow congestion by ensuring provision of electricity closer to the end-users. Also, solar system DG can improve system resilience and reliability especially in locations with week grid infrastructure [17, 18, 19].

For the full benefits of the solar DG integration to the power system network can be visible when the \dg is optimally placed. Hence, it is essential to determine the optimal location for the allocation of the solar PV DG so as to achieve the maximum benefits that comes with the integration of DG in the power system network. these benefits were; power loss reduction, power flow enhancement and voltage profile improvement. Additional some analytical tools such as load flow analysis, optimization tools and simulation were utilized for the determination of impact of DG on the distribution networks [20,21,22]).

The paper involves the model of the Nigeria 33kV system using PSAT. The tool was utilized to generate the power flow analysis using newton-raphson power flow analysis and the outcome was utilized for the generation of the optimal location for the DG allocation. The improvement achieved for with and without DG was determined. The tool utilized for the optimal location for the DG allocation was particle swarm optimization (PSO). MatLab application was utilized for the analysis of the impact of DG on the 33kV network.

2. Literature review

Ejiogu (2015) carried out investigation on the optimal sizing and placement of DG in the Nigeria 33kV using analytical procedures. The author utilized load flow analysis to obtain the optimal DG allocation location for the aim of minimizing losses and improving voltage profile. The results obtained showed active power loss reduction to 6.2% and improved voltage profile of the power system network. however, the author failed to utilize renewable based DG for power flow improvement but indicated the importance of utilizing solar DG system in improving the distribution power system network.

[10] carried out evaluation of the load flow analysis of the Nigerian 33kV distribution system network using the fast decoupled load flow analysis in ETAP application. From the results generated, it was seen that there were existing issues in the power system network which were overload, voltage drops and power losses that affected the power system reliability. After carrying out power system optimization, it was observed that there was voltage deviation improvement which enhanced the power quality of the power system network. But the author failed to study the impact of the integration of the solar system as DG to the power system network but the author pointed out that introducing a DG system would further stabilize the network and mitigate the occurring power flow congestion.

[26] carried out a study on the impact of the integration of the photovoltaic distributed generation (PVDG) on the Nigerain distribution power system network. the author utilized a real time measurement and found that the DG mitigated the grid dependency and enhanced energy efficiency. It was also found that the power quality parameters were improved during off-peak and on-peak periods. But the study centered on a localized network and failed to generalize result to a 33kV systems.

[16] analyzed the implementation of the solar DG in a 33/11 kV feeder in Delta state, south southern Nigeria. The load flow analysis carried out compared the power flow parameters of the power system network for with and without DG. The results generated showed improved power losses and enhanced voltage profiles. The author failed to carry out advanced optimization techniques for the optimal location for the DG allocation but supported the integration of DG as an important solution for power quality improvement of the power system network.

[1] explored the integration of the solar system into the Nigerian power system network to enhance power transfer capability. Furthermore, the author utilized FACTS device along side solar system network and the outcome generated

showed enhanced transmission capacity and enhanced power system stability. Though the author focused on the Nigerian 330kV network, but emphasized that the system can be implemented in a 132kV and 33kV network. the author failed to isolate the impact of solar DG alone.

The author in [14] examined the impact of the solar system DG on the voltage profile of the Nigeria distribution system network using the load flow analysis. the result generated showed that solar system DG mitigated voltage violations and improved the voltage profiles and the reactive power from the DG enhanced the stability of the system. Optimal location for the DG allocation was not considered in the research which was the limitation of the paper.

3. Methods

The methods carried out was summarized in the flow diagram presented in figure 1.

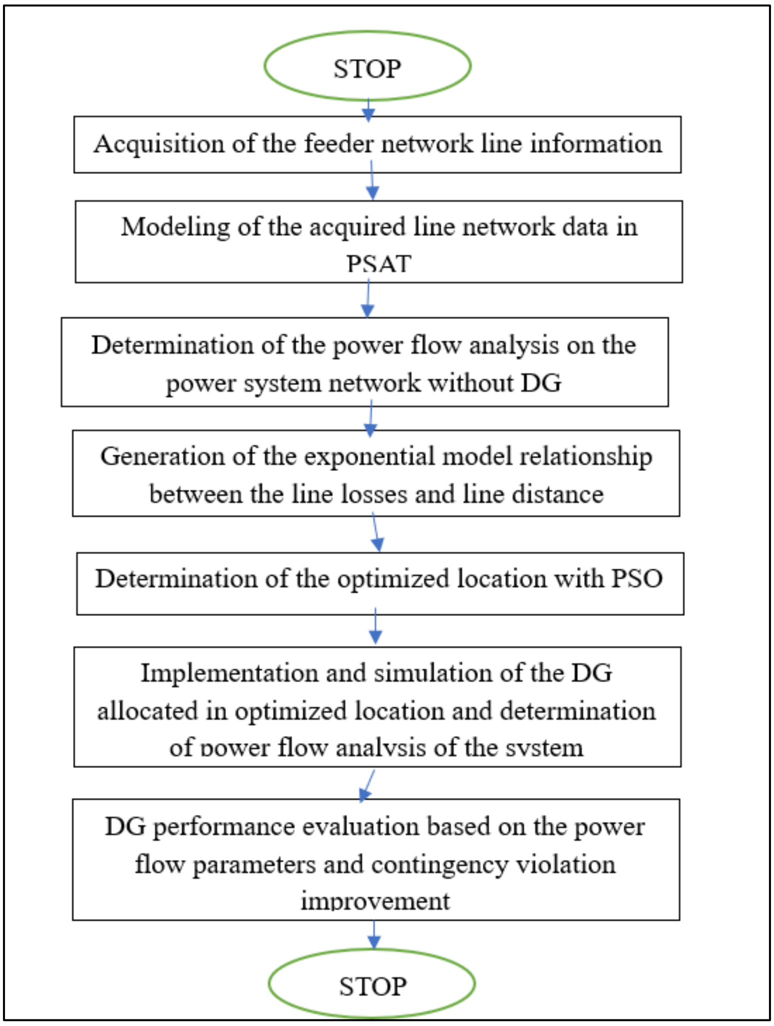

Figure 1 Flow diagram of the methods utilized

The data utilized was a Kaduna 33kV transmission system for the Kaduna metropolis with the line diagram shown in figure 2.

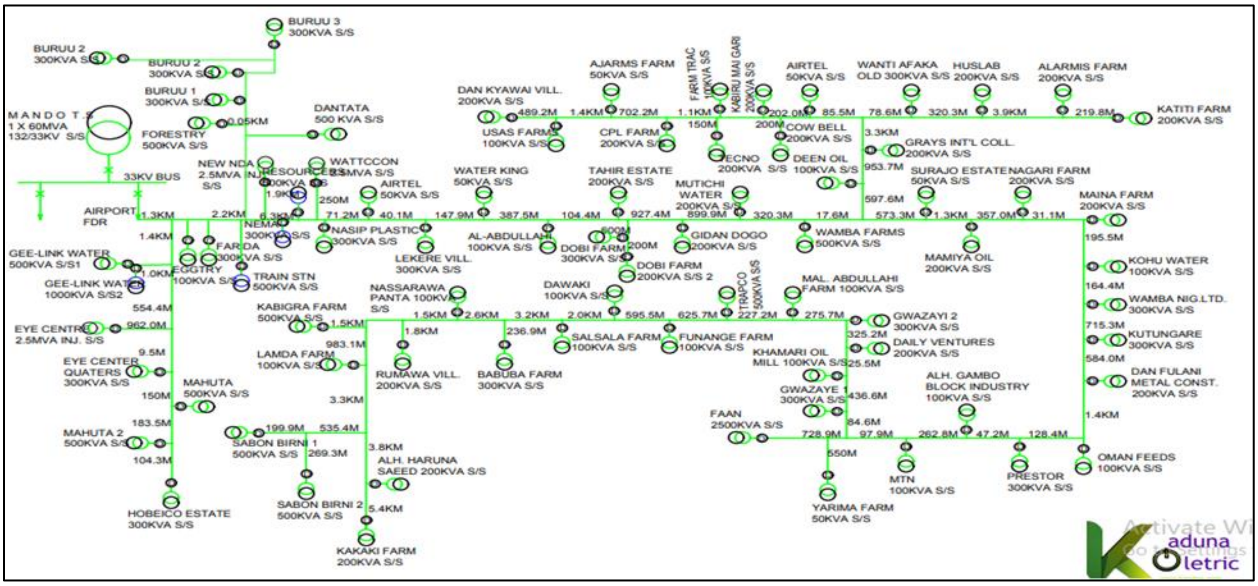

Figure 2 Line diagram of the 33kV of the Kaduna metropolis

The line diagram in figure 2 was modeled in PSAT and the model was presented in figure 3.

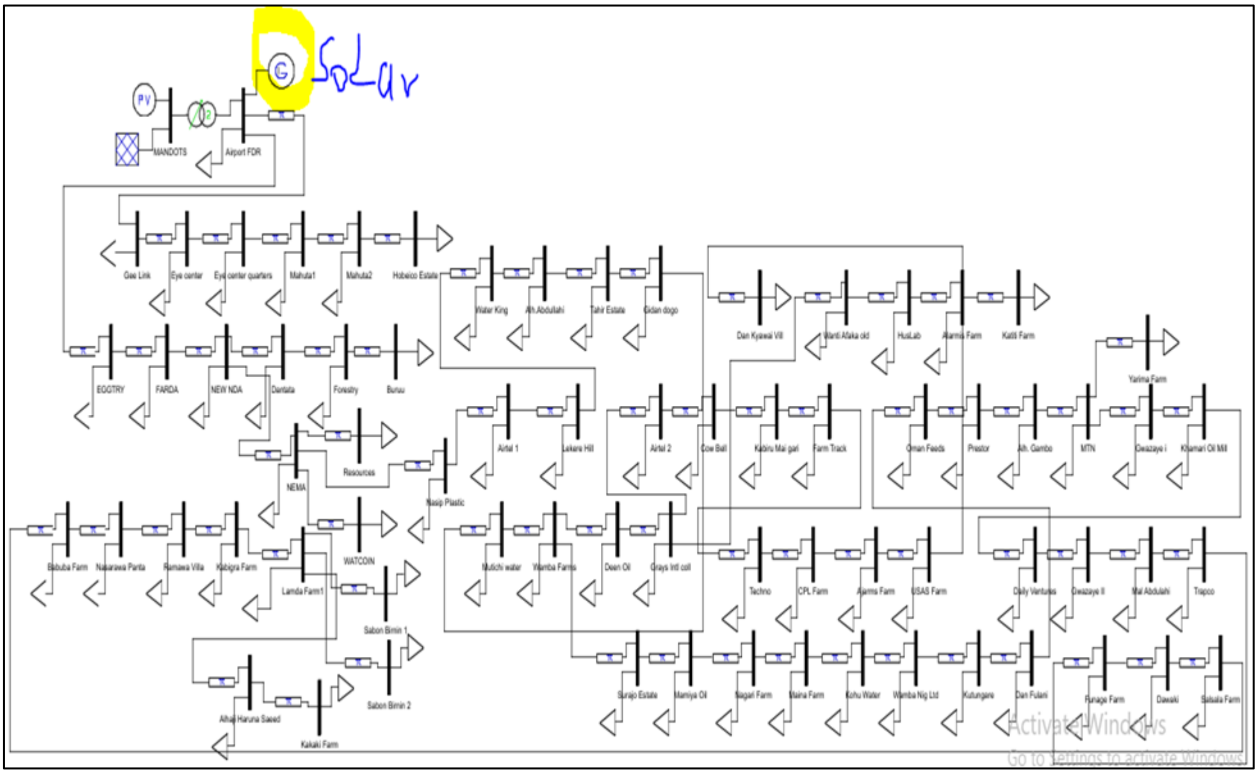

Figure 3 Power system modeling in PSAT

For the optimal location determination for the DG allocation, the power system network without DG was simulated then followed by the simulation of the system with the optimally located and sized DG which led to comparative analysis determination.

The procedure carried out in the modeling of the power system line diagram in PSAT was shown in flow chart presented in figure 4.

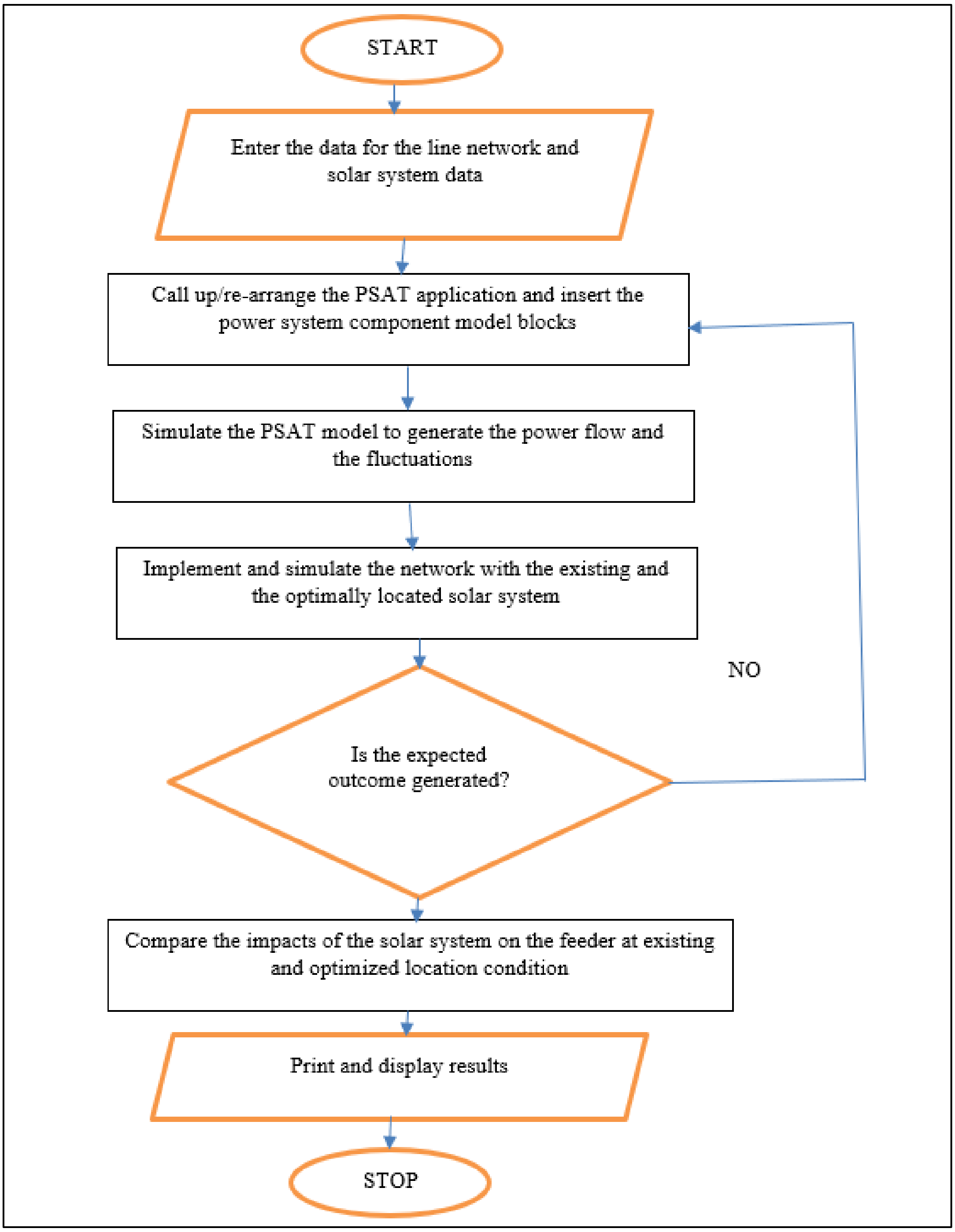

Figure 4 Flow Chart of the PSAT modeling procedure

The relationship between the real power from the power flow of the feeder and the line distance was developed with the increasing order of polynomial model as shown in equation 1.

$$P_R = a_0 + a_1 D + a_2 D^2 + \cdots + a_n D^n \quad (1)$$

Where P_R represents the real power loss of the power flow analysis, D represents the distance of the transmission lines from each bus station and a represents the coefficient of the model.

The exponential model was subjected to PSO techniques where the optimal location was obtained for the solar implementation in the PSAT model.

The summary of the optimal location modeling process was shown in figure 5.

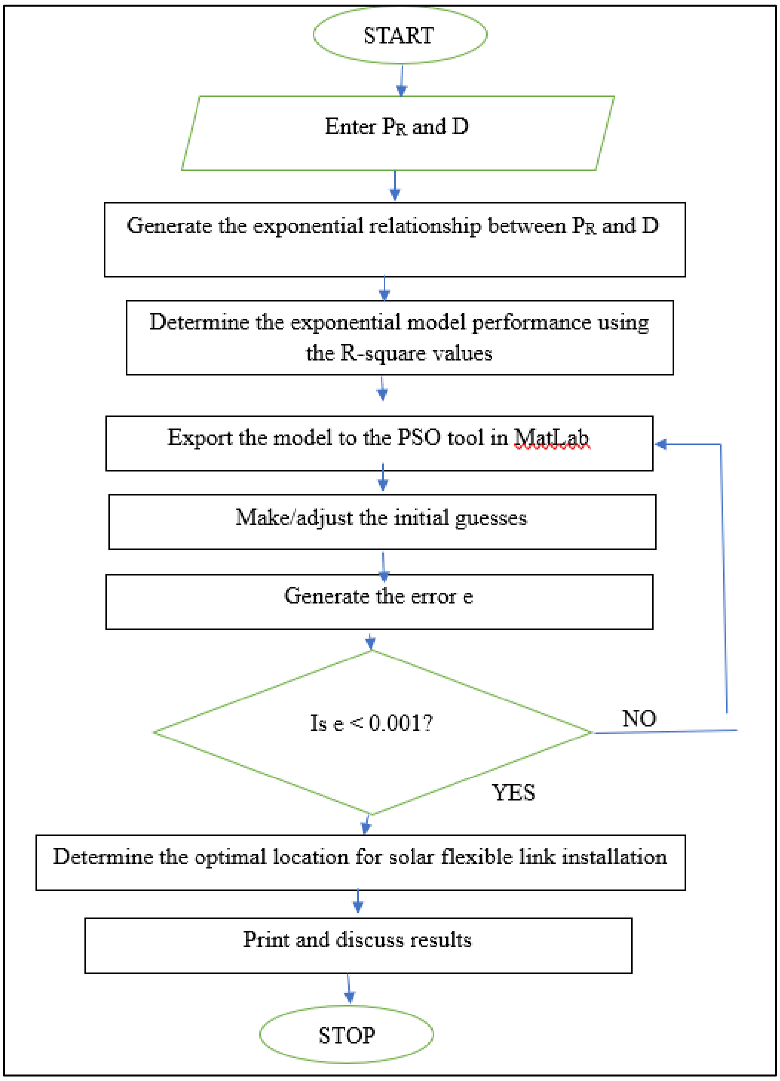

Figure 5 Flow chart for the optimal location of the solar system

The exponential model obtained was implemented as an objective function to the ant colony optimization (PSO) unconstrained optimization process.

The Design of the Solar PV system based on the active power rating required was shown in equation 2.

$$SD = \frac{RP_T}{N}\log\left(V_R\right) \qquad (2)$$

Where SD represents the solar system design model, RP_T represents the total real power flow generated with any DG and V_R represents the voltage rating of the system which was 33kV.

4. Results

The voltage profile of the power system network was shown in figure 6.

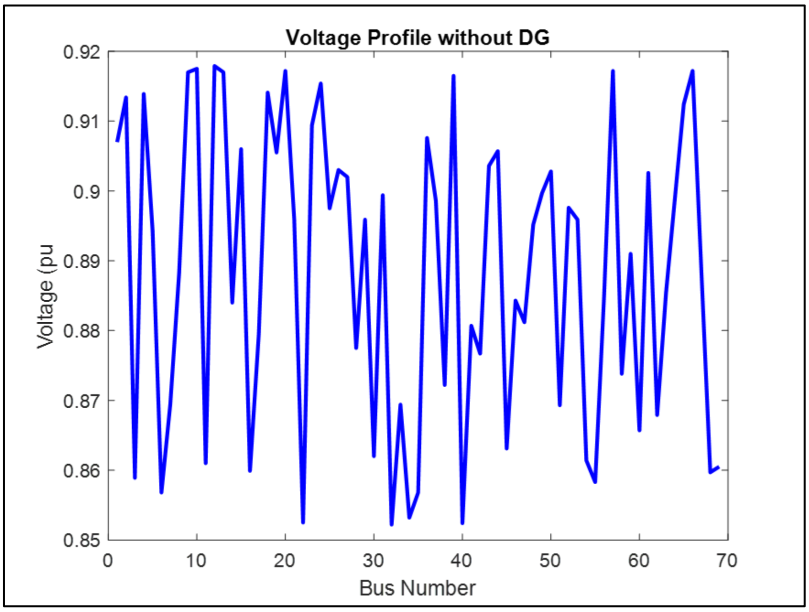

Figure 6 Voltage profile of the system

The number of buses in table 6 was 69.

The voltage profile of the feeders was shown in figure 6. it was observed that none of the stations without the DG had its voltage signal value up to the specified threshold range of 0.95pu and 1.05pu.

The active power flow of the power system network without DG allocation was shown in figure 7.

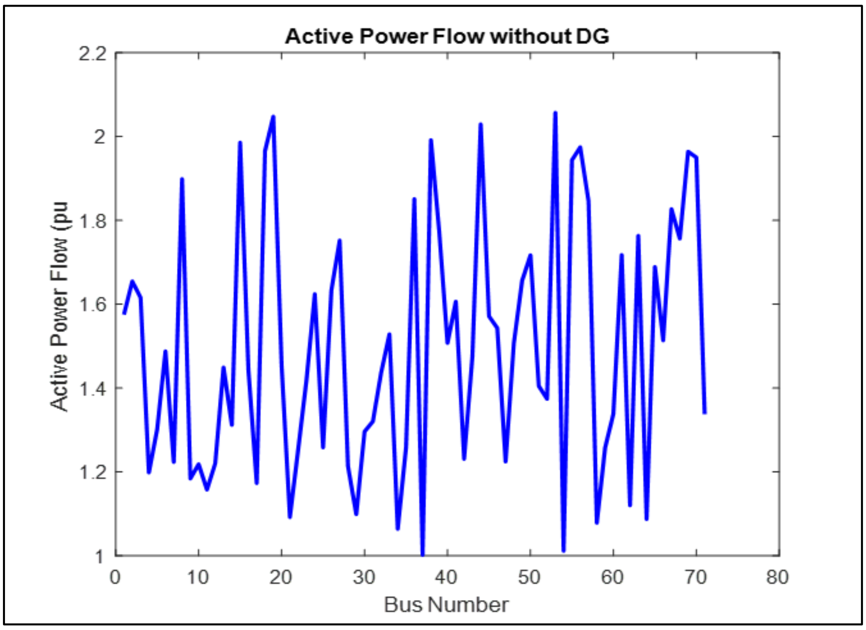

Figure 7 Active Power Flow of the System

The reactive power flow of the power system network without DG allocation was shown in figure 8.

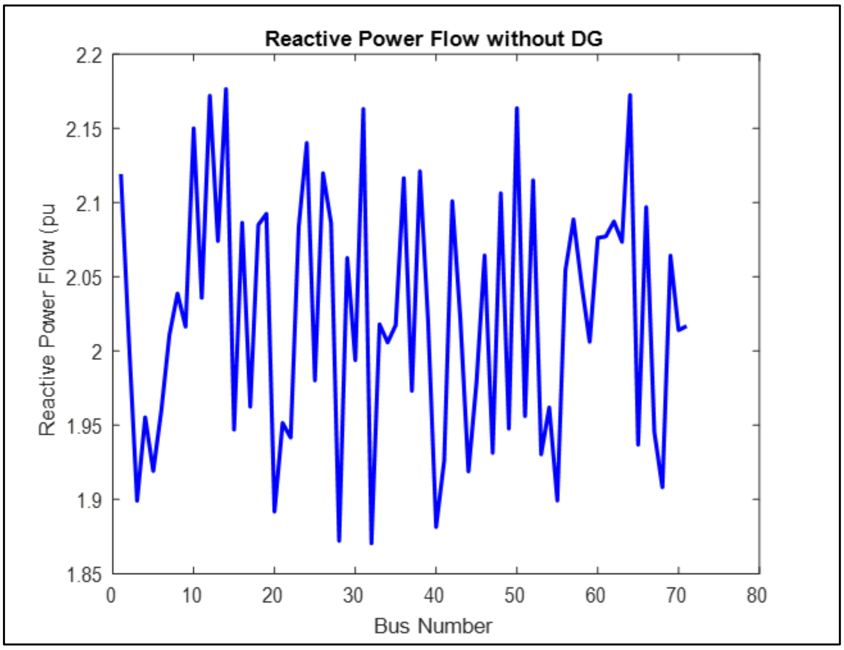

Figure 8 Reactive Power Flow of the System

The active power loss of the power system network without DG allocation was shown in figure 9.

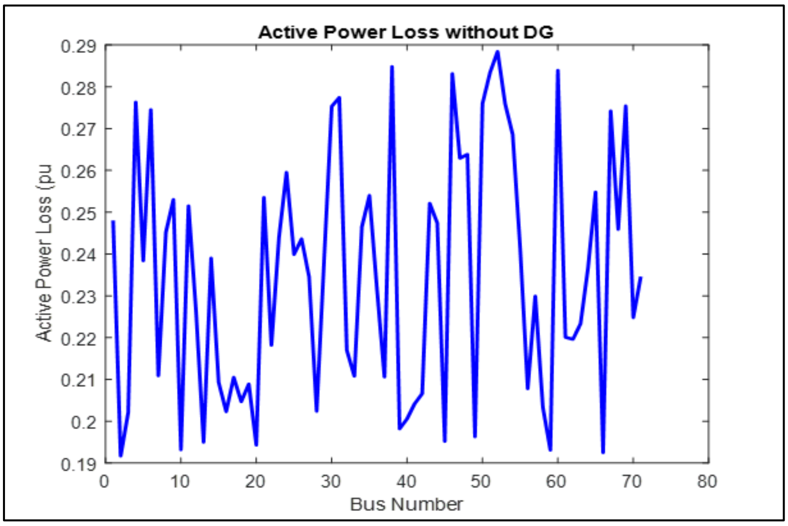

Figure 9 Active Power Loss of the System

The reactive power loss of the power system network without DG allocation was shown in figure 10.

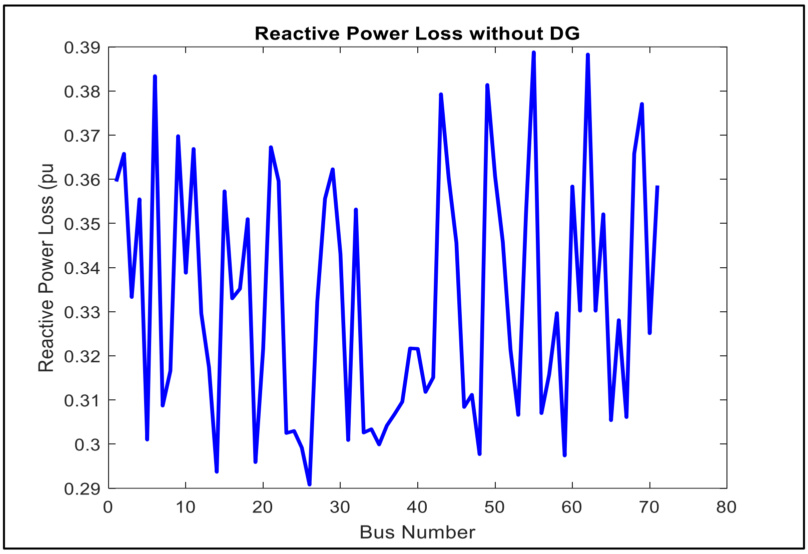

Figure 10 Reactive Power Loss of the System

The active power flow of the system without DG and the cumulative distance of the lines utilized for the generation of the polynomial model was presented in table 1.

Table 1 Active power flow and cumulative distance

Active power flow	Cumulative distance	Line
1.5752	2.4000	1
1.6547	3.9200	2
1.6157	3.9290	3
1.1985	4.0790	4
1.3014	4.2620	5
1.4880	4.3663	6
1.2235	5.6663	7
1.8987	5.8763	8
1.1842	8.0763	9
1.2185	8.1543	10
1.1578	8.1923	11
1.2204	8.2423	12
1.4493	10.4423	13
1.3122	12.3423	14
1.9857	18.8923	15
1.4432	25.1923	16
1.1733	25.2635	17
1.9654	25.3045	18
2.0477	25.4524	19
1.4528	25.8399	20
1.0020	25.9443	21
1.2539	26.8717	22
1.4196	27.7716	23
1.6244	28.0919	24
1.2584	28.7071	25

1.6331	29.6608	26
1.7523	33.0463	27
1.2139	33.2463	28
1.0992	33.4483	29
1.2963	34.5483	30
1.3207	34.6983	31
1.4366	35.7983	32
1.5286	36.5005	33
1.0641	37.9005	34
1.2587	38.3897	35
1.8511	41.7683	36
1.0021	42.0886	37
1.9917	45.9886	38
1.7734	46.2084	39
1.5075	46.7817	40
1.6064	48.0817	41
1.2310	48.4387	42
1.4747	48.4698	43
2.0294	48.6653	44
1.5715	48.8297	45
1.5432	49.5450	46
1.2248	50.1290	47
1.5078	51.5290	48
1.6565	51.6574	49
1.7170	51.7046	50
1.4051	51.9674	51
1.3742	52.1499	52
2.0568	52.5865	53
1.0115	52.6115	54
1.9437	52.9367	55
1.9746	53.2124	56
1.8458	53.4396	57
1.0786	54.0653	58
1.2581	54.6608	59
1.3389	56.6608	60
1.7177	60.0977	61
1.1202	62.6977	62
1.7634	64.1977	63
1.0874	65.6977	64
1.6891	66.6808	65
1.5136	70.7851	66
1.8270	74.8200	67
1.7565	78.6200	68
1.9641	84.0200	69
1.9500	84.6679	70
1.3376	85.4947	71

The polynomial order and the corresponding R-square values for each order was shown in table 2.

Table 2 Polynomial model order and the R-square values

Polynomial order n	R-square values
1	0.4337
2	0.6772
3	0.87724
4	0.9217

From table 2, it was seen that the 4th order polynomial exceeded the specified R-square threshold of 90% (92.17%) and hence, the polynomial model representing the relationship between the active power flow RP and the distance D was shown in equation 4.1.

$$RP = 5.332 + 0.9821D - 0.1147D^2 + 2.2815D^2 - 1.9927D^4 \quad (4)$$

Equation 4.1 was used in the ACO tool as the objective function and the outcome of the iterations leading to the optimal distance determination was shown in figure 11.

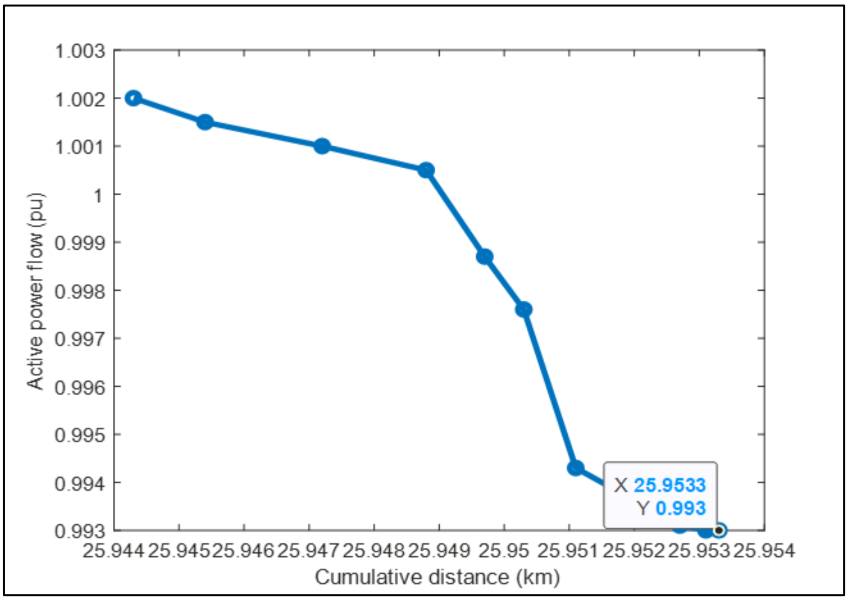

Figure 11 Optimal location for the DG implementation

The cumulative distance of 25.9533km was obtained as shown in figure 11 hence, from table 1, the cumulative distance points to between line 21 and line 22 but the outcome is closer to line 21 which was the line connecting Alh abdullahi farm and Tahir Estate which was the optimal location for the DG placement.

The DG sizing obtained was 8.92MW which was implemented and the power flow analysis of the system with Optimal DG allocation was obtained and presented.

The voltage profile of the power system network for with and without DG allocation was shown in figure 12.

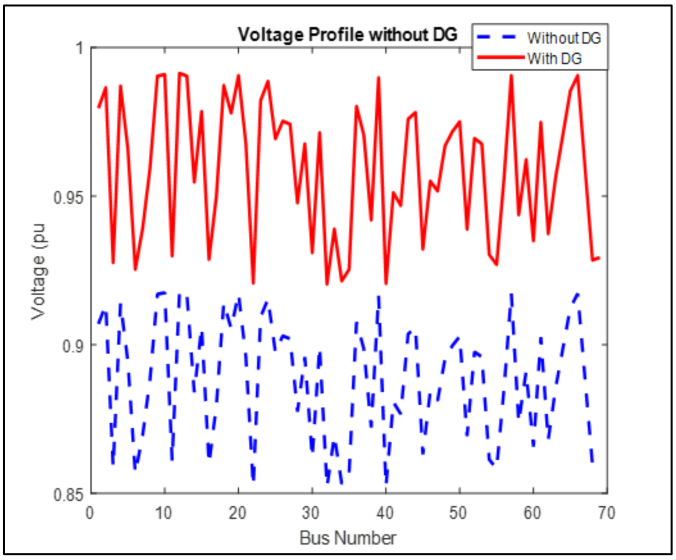

Figure 12 Voltage profile of the system

The active power flow of the power system network with and without DG allocation was shown in figure 13.

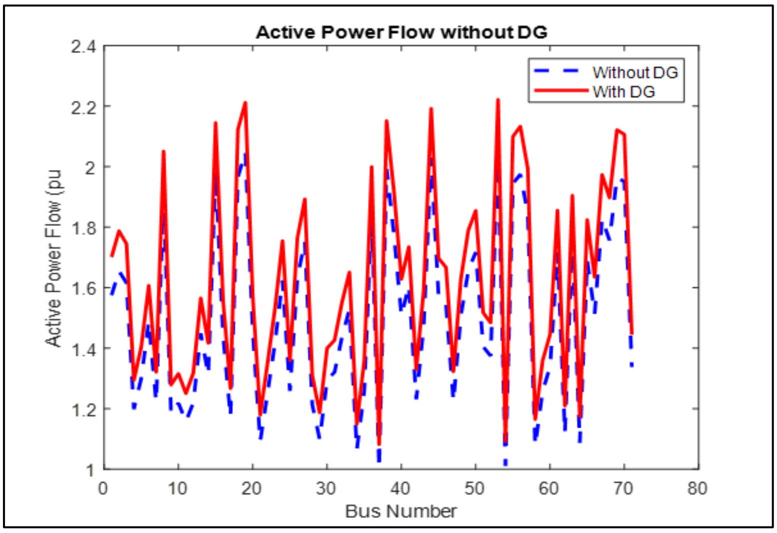

Figure 13 Active Power Flow of the System

The reactive power flow of the power system network with and without DG allocation was shown in figure 14.

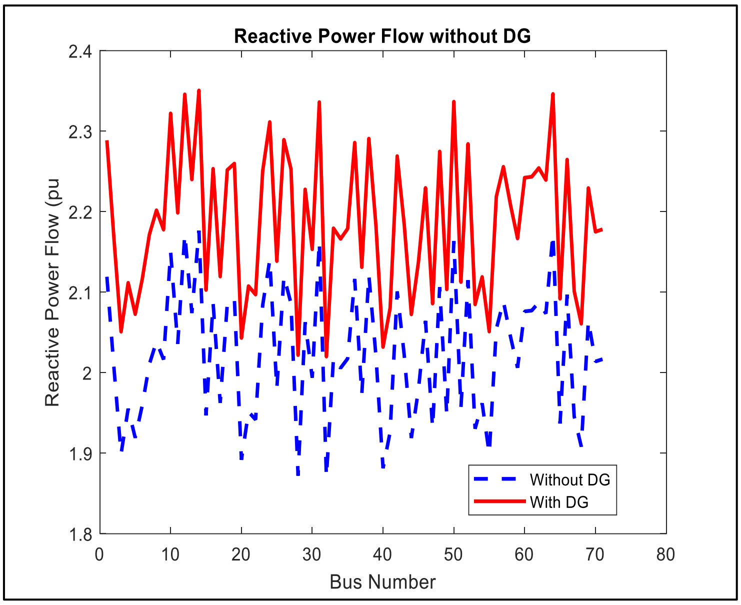

Figure 14 Reactive Power Flow of the System

The active power loss of the power system network with and without DG allocation was shown in figure 15.

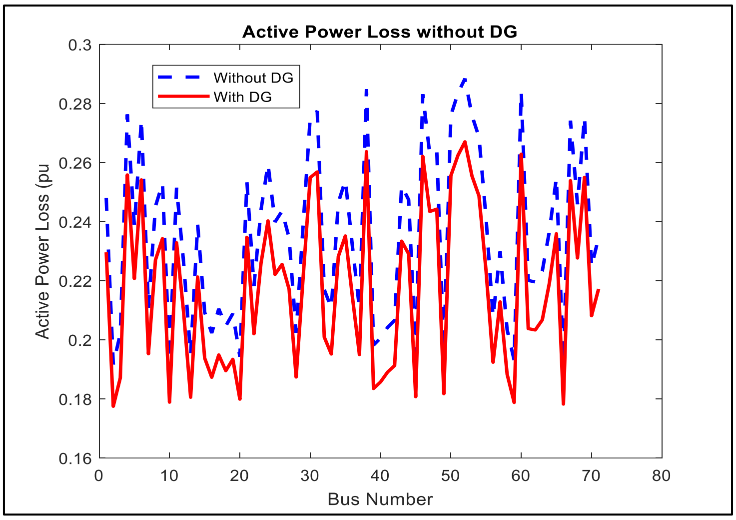

Figure 15 Active Power Loss of the System

The reactive power loss of the power system network with and without DG allocation was shown in figure 16.

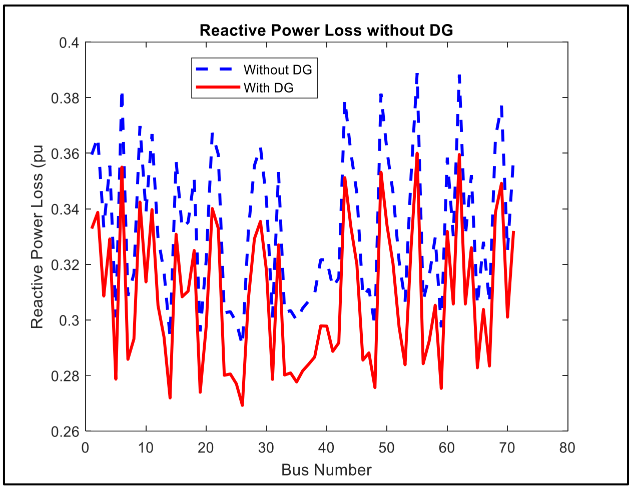

Figure 16 Reactive Power Loss of the System

In general, it was observed that the allocation of the dg improved the power flow of the 33kV power system network feeder in kaduna metropolis.

5. Conclusion

The paper focused on improvement of the power flow parameters of the real time Nigerian 33kV power system network in Kaduna metropolis using solar system DG. The data of the power system network was obtained from the kaduna metropolis feeder. The network was modeled in PSAT and simulated to generate the power flow parameters utilized for the generation of the optimal location for the DG allocation with particle swarm optimization (PSO). The objective was a polynomial model showing the relationship between the active power loss and the cumulative distance of the line. The integration of the DG significantly improved the voltage profile, active power flow, active power loss, reactive power flow and reactive power loss. Hence, it is advised that a solar system be designed to be implemented in the optimal location for the improvement of the power quality of the distribution feeder.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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