



## Impact of 2.5MW Solar Photovoltaic Generation on Distribution Networks: A Case Study of Nigerian Defence Academy 33/11kv Injection Substation

Asuquo Nsikak Etim, Adejoh Idris Araga, Fatai Olatunde Adunola, Yakubu Abdulrazak  
Department of Electrical/Electronic Engineering,  
Nigerian Defence Academy, Kaduna

### ABSTRACT

Distribution networks in Nigeria had suffered setback such as network losses and inadequate power injection into substations as compared with the net power delivered to the load. This study examines the impact of solar photovoltaic generation on distribution network of Nigerian Defence Academy 33/11KV injection substation. Distribution generation (DG) is to minimize the losses and improve voltage profile of the network. Solar Photovoltaic Generation (SPVG) is one of the DGs that is capable of supplying real and reactive power into an existing distribution network to increase its overall efficiency. The modelling of the power system network of the NDA 33k/11V and that of 2.5MW SPVG model were developed on PSAT. An optimal placement was implemented using Ant Colony Optimization (ACO) for optimal placement of DG. The performance of the developed system was evaluated using static and dynamic response analysis (current and voltage) as performance metrics. The simulation results when the DG was placed within the five (5) buses showed that the impact of the developed 2.5MW SPVG on the network obtained the active and reactive power losses of (0.1887, 0.1317, 0.0942, 0.0886p.u) and (0.3321, 0.2872, 0.2117, 0.1873pu) without the DG placement on the test network. When SPVG was optimally placed on the network, the active and reactive power loss became (0.0091, 0.0043, 0.0037, 0.0022pu) and (0.1413, 0.1222, 0.1077, 0.0810pu). This resulted in 7.00%, 31.57%, 27.81%, 96.38% and 55.90% improvement in steady state response analysis when compared to that without DG placement. Finally, when the techno-economic analysis was carried out using Net Profit Value (NPV) and Internal Rate of Return (IRR). DG installation provides greater savings or revenue due to reduced energy purchases and lower operating expenses. In terms of IRR DG installation has higher IRR of 42%, meaning it is financially more attractive than NEPA under the assumptions used.

### ARTICLE INFO

#### Article History

Received: September, 2025

Received in revised form: October, 2025

Accepted: December, 2025

Published online: January, 2026

### KEYWORDS

Distributed Generation, Solar Photovoltaic Generation, Ant Colony Optimization, PSAT, Optimal Placement

### INTRODUCTION

Nowadays, electrical energy is the most efficient and popular form of energy in modern society. The electrical power system has three broad sub-systems. These are generation, transmission, and distribution systems. These sub-systems use a distribution system to distribute electric power to consumers for utilization purposes [1]. The distribution system consists of

feeders, distributors, and service mains. It is also classified according to the connection scheme as a radial, ring main, and inter-connected system[8]. Historically, electrical power is generated centrally from power stations which are coal-fired power plants, hydroelectric power stations, gas power plants, nuclear power plants, large scale solar power stations or their combinations [5][7]. These conventional power plants are remotely located

Corresponding author: Asuquo Nsikak Etim

✉ [nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



hence electrical energy generated needs to be transmitted over a long distance and to be distributed to awaiting governmental, industrial, commercial and residential consumers[1]. This vertical approach system where electricity is received at the load centers through transmission and distribution network systems have environmental and technical problems associated with it which necessitated the introduction of horizontal approach system that requires DGs to playing prominent role [2].

Distributed generations are categorized into four classes based on delivered capacities. Micro distributed generation with capacity range of 1KW to less than 5KW, small distributed generation having range of 5KW to less than 5MW, medium distributed generation with capacity range of 5MW to less than 50MW and large distributed generation in the range of 50MW to less than 300MW [6]. The DGs are structured mainly to be connected to the distribution system close to the consumption centers [10]. The commonly used DG technologies are photovoltaic arrays, solar thermal, hydro turbine, wind turbine, fuel cells, biomass gasification, battery storage, and geothermal[3].

In this research, an impact of 2.5MW developed solar photovoltaic generation of the Nigerian Defence Academy on 33/11kv feeder network such as inadequate power injection into substations compared to the net power delivered to the load. In order to achieve this, power flow analysis with 2.5MW NDA solar captive power plant was modeled in PSAT in MATLAB/Simulink model. Also, the performance of the distribution network for better performance regarding voltage profile improvement within its acceptable limit and network losses was carried out.

## LITERATURE REVIEW

Some research relevant to the study are reviewed and presented in this section. These literatures include the previous works on DG placement on grid network[4]. Discussed a load response-based economic operation strategy for post-contingency power systems incorporated with DGs after islanding. According to the authors, the system instability is limited to a minimum

region as soon as possible by the optimized operation scheme for islands considering power quality, system efficiency, and transmission security criterion.

Author in reference [11] designed an optimal size and location of DG-unit (for planning purposes) based on a pre-determined power loss reduction level (up to 25%) were proposed. The objective of the method was to reach that level with minimum net DG-unit cost (i.e., DG-unit cost subtracted from savings). The maximum number and size of the DG units were found to be two and 40% of peak loads, respectively. The solution was achieved using sequential quadratic programming.

Author in reference [12] work on power loss minimization considering an unbalanced test system. Here, the placement and sizing of a single DG unit have been considered. Besides, the comparison among different DG technologies is not addressed here. These issues were considered later by[45], where multiple DG placement and sizing were discussed for two unbalanced multi-phase distribution networks. In all the research studies, optimum DG planning makes the system more efficient by significantly reducing the loss[32] discussed the maximization of the voltage support in radial distribution feeders using a DG unit. The method used a voltage sensitivity index to determine the DG unit's optimal location. Then, the DG-unit active and reactive powers were adjusted to obtain maximum voltage support. The weakest bus was identified using Thevenin's theorem. The results showed that the network's real and reactive power significantly improved.

Author in reference [13] aimed at improving the performance of a deficient 11kV distribution network using optimally placed and sized DG units. The specific case study was the Okada Community distribution network in Edo State, Nigeria. To actualize the aim of the work, relevant data from the Benin Electricity Distribution Company (BEDC) for the 27-bus Okada distribution network, network diagram, transformer ratings, line parameters, and loads were collected. Thereafter, load flow analysis was performed using the Newton-Raphson iteration

---

Corresponding author: *Asuquo Nsikap Etim*

✉ [nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

technique under three conditions: base, minimum, and maximum loading, to ascertain the deficient state of the original network (voltage profile, losses, loading).

The Loss Sensitivity Factor (LSF) technique was used to determine the candidate buses for DG placement. Buses were ranked based on LSF, proximity to load, and proximity to other generation units. The best-performing buses were identified as Igbinedion University, Estate, and Celiwe. The simulation was carried out where the optimal placement and sizing of DG units drastically improved the network's voltage profile across all loading conditions, bringing bus voltages into the acceptable range, which was not the case before enhancement. The system's total power loading also increased, indicating a more robust and efficient distribution capability. The paper demonstrates a practical, quantifiable solution for improving a real-world, highly deficient distribution network (Okada Community, Nigeria) using DG. It provides clear evidence of the effectiveness of combining Loss Sensitivity Factor analysis with the Newton-Raphson load flow technique for optimal DG placement and sizing in enhancing system performance, specifically voltage stability and power transfer capacity. The

steady-state analysis does not account for transient events or the system's reaction to sudden disturbances (e.g., faults, sudden load changes, or DG trip). The improvement observed might not translate directly into system stability or resilience during dynamic events.

Author of [14] Presented a power loss minimization by finding the optimal size, location, and operation point of the DG unit. A sensitivity analysis relating to the power loss with respect to DG-unit current injection was used to identify the DG-unit size and operation point. The proposed method was tested for constant impedance. One of the test systems assumed that loads were uniformly distributed, which was rare in practical feeder systems. The location of the DG unit was based on the assumption of downstream load buses, which may not be appropriate for different feeder configurations

#### MATERIALS AND METHODS

The materials and methods used to determine the impact of 2.5MW developed solar photovoltaic generation of the Nigerian Defence Academy on 33/11kv injection substation are presented in this section.

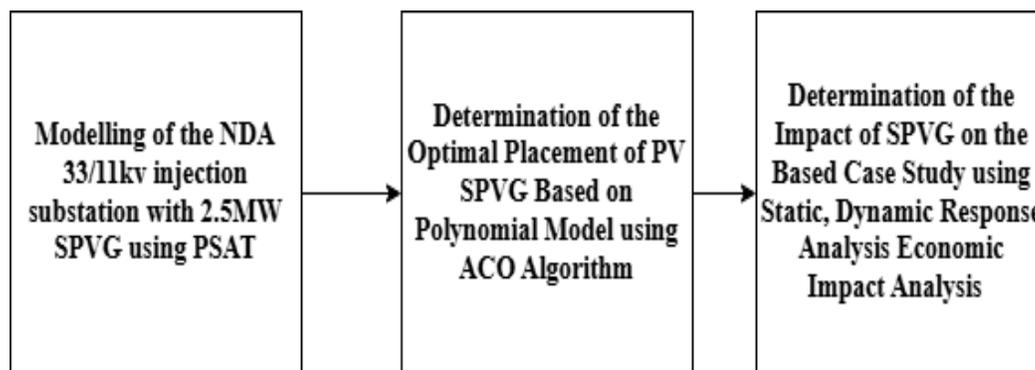


Fig.1: Framework for the Implementation of 2.5MW SPVG of the NDA on 33/11kv injection substation.

#### Modeling of the power system network of the NDA 33/11kV injection substation in PSAT.

The power system line diagram was first obtained from the research of the TCN regional centre as shown in Figure 3.1. The one-line

diagram of 33/11kV NDA Injection substation was modelled using Power System Analysis Toolbox (PSAT) software in MATLAB/Simulink and then an SPVG was developed as shown in Figure 2.

Corresponding author: Asuquo Nsirik Etim

✉ [nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

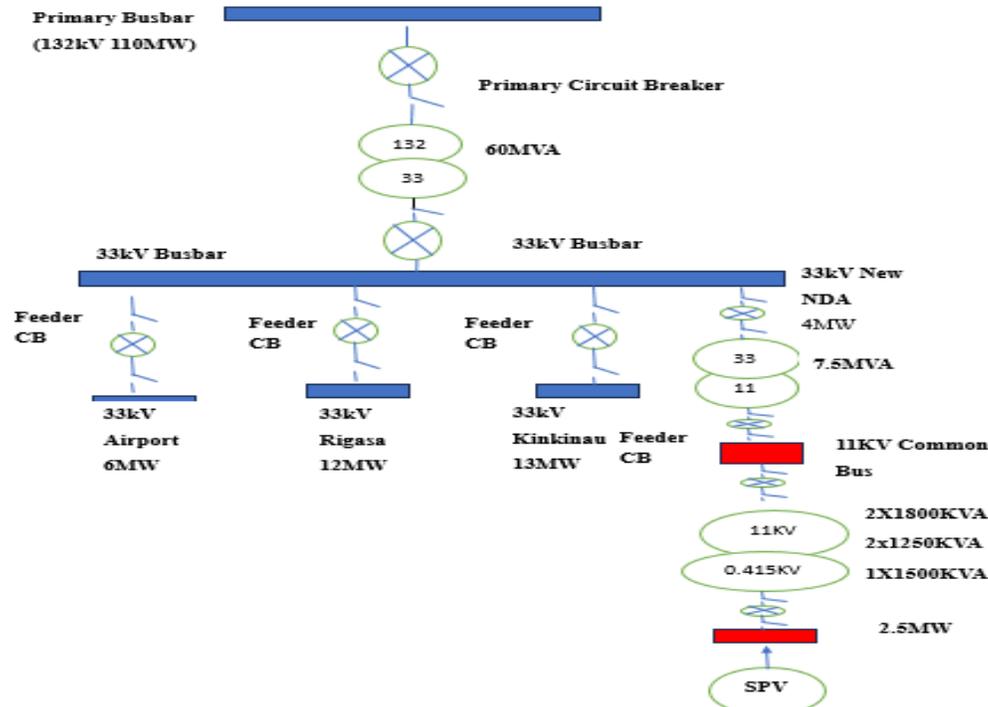


Fig.2:Single line diagram of the case study

### Data Acquisition and analysis

The data used in this work were collected from the public utility service provider known as Transmission Company of Nigeria (TCN) Kaduna regional centre, during visitation to the station. The Company provides Power to

Kaduna and other states within the Northwest part of Nigeria. The bus information, line information and information of the existing solar system used as the DG of the power system network were shown in Table 1, Table 2 and Table 3.

Table 1: Bus data

Bus number	Bus location	Voltage (pu = kV/basekV)
1	(location of PB)	1
2	NDA	1
3	Airport	1
4	Rigasa	1
5	Kinkinau	1

Table 2: Line data

Line number	From bus	To bus
1	1	2
2	2	3
3	2	4
4	2	5

Corresponding author: Asuquo Nsikak Etim

✉ [nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

Table 3: The information of the existing solar system used as the DG

Parameters (units)	Values
Power rating (MW)	2.5
Number of panels	5,460
Daily temperature (°C)	25
Sun irradiance	800
Percentage efficiency (average)	86
Number of inverters	13
Power rating per inverter (Kw)	185
Current rating of batteries (Amps)	1300
Number of batteries	162

**Modeling of the Power system Network in PSAT using MATLAB**

The datasets obtained from section 3.2 were used to model the power system network in

PSAT using MATLAB. The procedure for the modeling of the power system network in PSAT was shown in the flow diagram in Fig. 3.

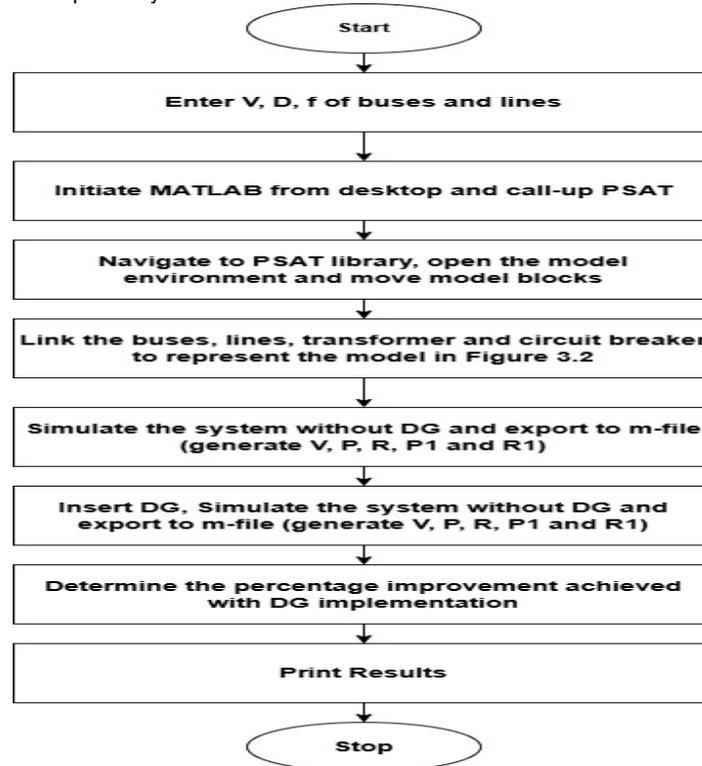


Fig.3: Flow diagram of the procedure of PSAT modeling of the power system network.

Fig. 4 represents one-line diagram of 33/11kV NDA injection Substation using PSAT software

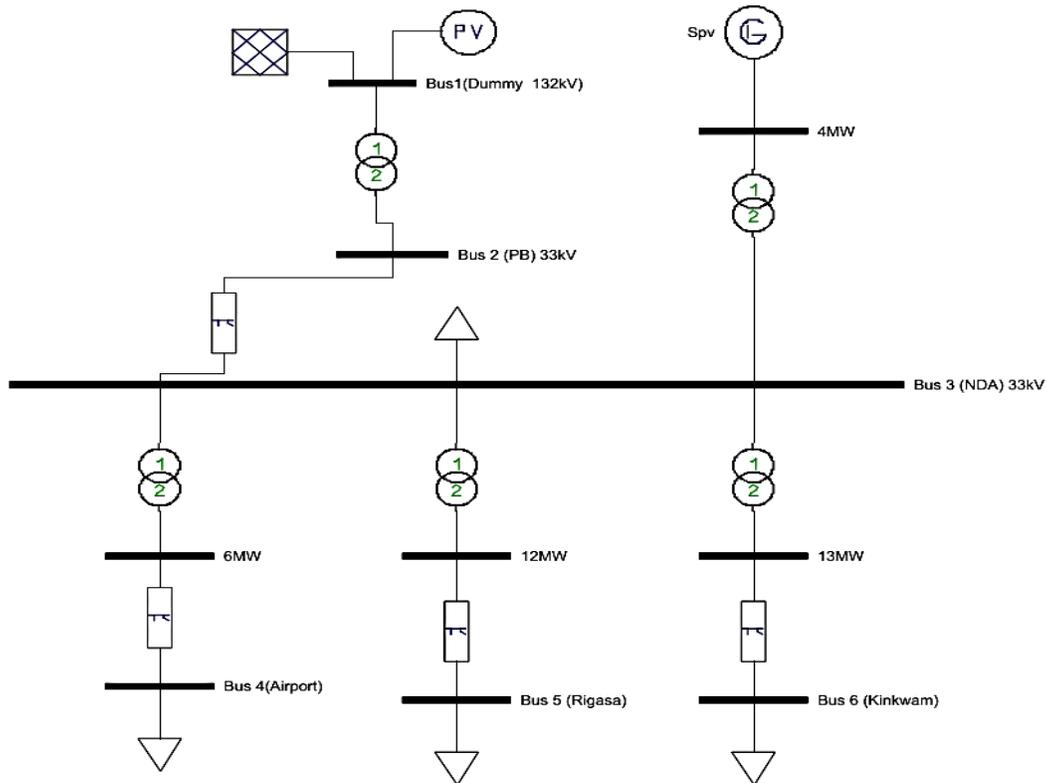


Fig.4: PSAT model of the power system network with DG

The model in Figure 4 was simulated and the data exported to MATLAB environment for the generation of tables, plots and charts for the power system network static and dynamic parameters for with and without DG. The outcome was presented in the result section.

#### Determination of the optimal placement of the PV DG based on the Polynomial using Ant Colony Optimization (ACO)

In this research, ant colony was utilized for the determination of the optimal location for the implementation of the DG. The procedures utilized were outlined in the specific steps. The active power flow outcome and the cumulative distance were presented in Table 4.

Table 4: Active Power Flow and Cumulative Distance

Line number	Dc	APF
1	8	1.1421
2	12	0.9977
3	20	0.9813
4	25	0.9810
5	40	0.9113

The polynomial model order and the R-square value was shown in Table 5.

Corresponding author: Asuquo Nsirik Etim

[nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

Table 5: Polynomial model order

Polynomial order N	R-square value
1	0.34
2	0.73
3	0.91

From Table 5, the 3<sup>rd</sup> degree polynomial exceeded the R-square threshold with value of 91% and the model utilized as the objective function to the ACO technique was shown in equation 1

$$Apf = 2.3317 + 0.7121Dc - 0.0162Dc^2 + 0.000031Dc^3 \quad (1)$$

The flowchart for the implementation is shown in Fig.5

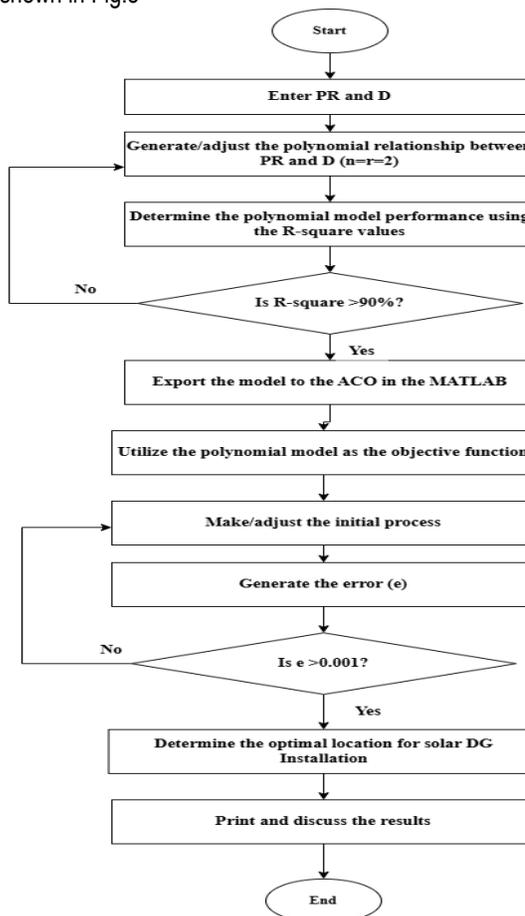


Fig. 5: Flowchart of the Optimal Location using ACO

### Determination of the Economic Impact

The model for the NPV was shown in equation 2

$$NPV = \frac{NCF}{(1-r)^t} - IN \quad (2)$$

Where NPV is the net profit value, NCF represents the net cash flow, r is the discount rate, t is the period (in months) and IN represents the initial investment.

For the IRR;

$$NPV = \sum \frac{NCF}{(1-IRR)^t} \quad (3)$$

Having obtained NPV in equation 2, compute equation 3 and make IRR the subject of the formula. The outcome of the techno-economic analysis was presented in the result section

### Determination of the system impact without and with the implementation of the DG on the NDA 33/11Kv network feeder

The equation for the determination of the improvement for each voltage profile (%V<sub>imp</sub>) was shown in equation 4.

$$\%V_{imp_i} = \frac{V_{DG} - V}{V_{DG}} 100 \quad (4)$$

Then

$$\%V_{imp} = \frac{\text{sum}(V_{imp_i})}{n} \quad (5)$$

Where %V<sub>imp<sub>i</sub></sub> represents the voltage improvement for each bus, V<sub>DG</sub> represents the voltage with DG, V represents the voltage without DG and n represents the number of stations.

The percentage real power improvement was shown in equation 6.

$$\%P_{imp} = \frac{\text{sum}(P_{DG} - P)}{\text{sum}(P)} 100 \quad (6)$$

Where %P<sub>imp</sub> represents the real power improvement achieved, P<sub>DG</sub> represents the real power flow with DG, P represents the real power flow without DG and n represents the number of stations. Other parameters such as reactive power flow, active power loss and reactive power loss followed the format as shown in equation 6

## RESULTS AND DISCUSSION

The results obtained based on the methodologies presented in chapter three that addressed the research objectives are discussed and presented in this section.

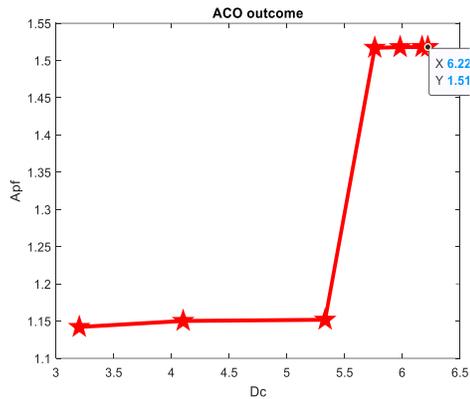


Fig.6: Outcome of the ACO optimization

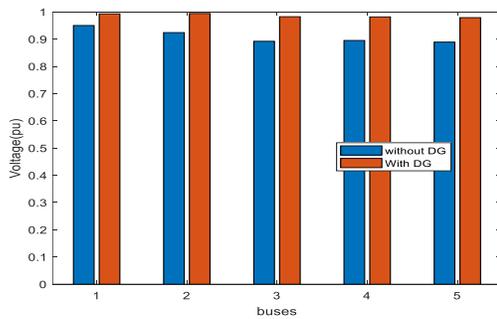


Fig.7: The voltage profile for with and without DG

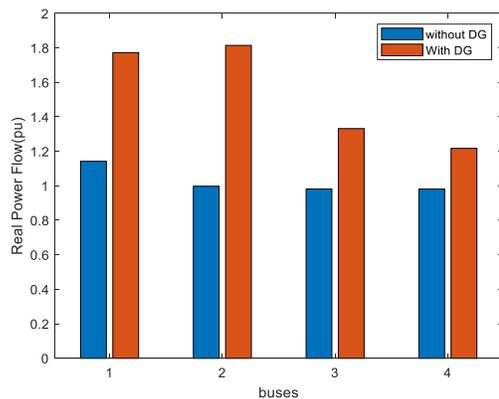


Fig.8: The Active Power flow for with and without DG

Fig.6 below shows the convergence curve of optimal placement of DG on the NDA 33/11kv network obtained using Ant Colony Optimization (ACO) algorithm.

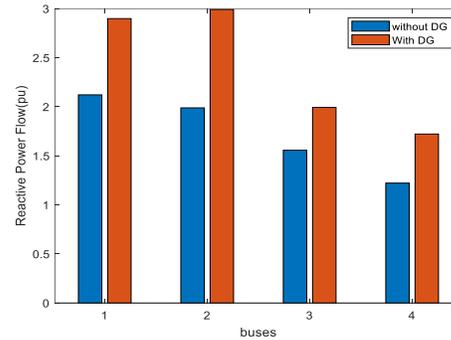


Fig.9: The reactive power flow for with and without DG

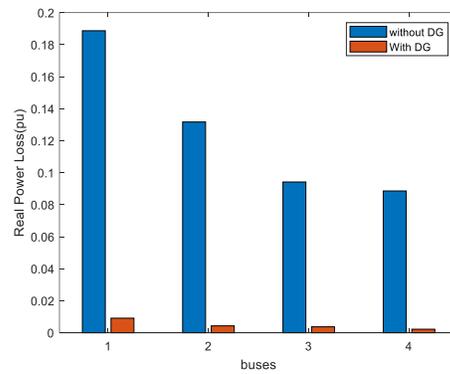


Fig.11 The active power loss for with and without DG

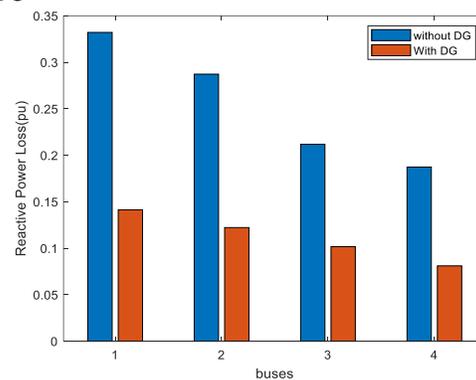


Fig.10: The Reactive Power Loss for with and without DG

Corresponding author: *Asuquo Nsikak Etim*

[nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

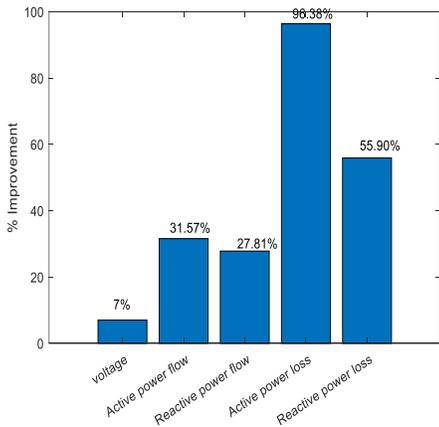


Fig.12: Impact of DG

The parameters utilized to study the DG impact on the dynamics of the power system were current and voltage signals. The current signal of bus 1 for with and without DG was shown in Fig.13.

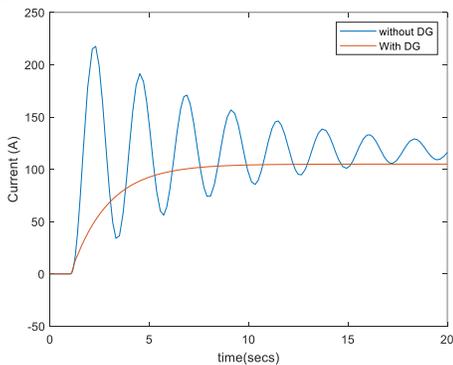


Fig.13: Current Signal for bus 1

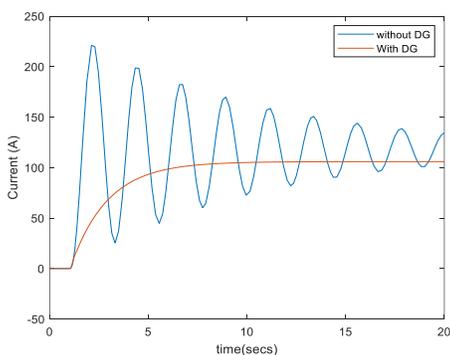


Fig.14: Current signal for bus 2

The NPV of the system before and after DG allocation was shown in the bar chart presented in Fig.15.

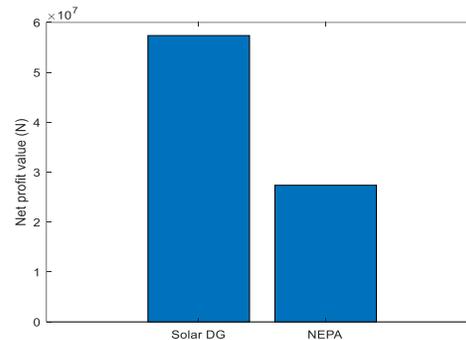


Fig.15: NPV comparative analysis

The IRR of the system before and after DG allocation was shown in Fig.16.

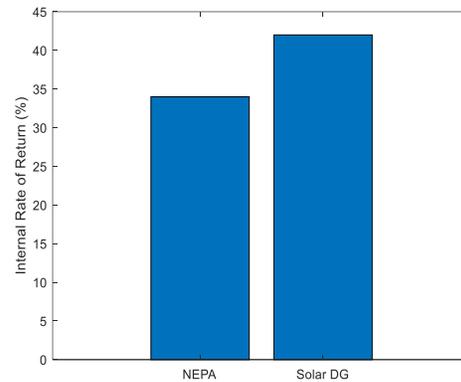


Fig.16: IRR Comparative Analysis

### CONCLUSION AND RECOMMENDATION

The research presents an impact of 2.5MW developed solar photovoltaic generation of the Nigerian Defence Academy on 33/11kV injection substation in order to improve the voltage profile and minimize power loss, a scientific solution is highly required. Thus, this thesis introduces distributed generation Solar Photovoltaic Generation (SPVG) at the feeder to achieve this purpose. The feeder lines under consideration are Airport, Rigasa, Kinkinau and NDA 33/ 11kV injection substation. The data used in this work were collected from the public utility



service provider known as Transmission Company of Nigeria (TCN) Kaduna Region, during visitation to the station and the 2.5MW NDA solar captive power plant located at the permanent site of NDA Afaka. Subsequently, modeling of the Power system network in PSAT using MATLAB/Simulink. Thereafter, optimal placement of DG was implemented where it was observed that, the maximum APF achieved was 1.5181pu at distance (Dc) of 6.22km which is on line 1 (the line connecting primary bus and the NDA) and finally an economic impact assessment was carried out using NPV and IRR.

The Simulation of the developed system was carried out by considering static and dynamic response improvement. The performance evaluation of the results was carried out and compared to the system with and without DG placement in terms of voltage profile improvement, power loss minimization and dynamic improvement (voltage and current signal). The simulation results reveal that the impact of the developed 2.5MW NDA solar captive power plant on NDA 33/11Kv injection substation has the overall improvement of voltage profile improvement when considering the buses the DG placement on the network. For power loss minimization and dynamic improvement, the implementation of the DG has an improvement without the placement on the network.

## REFERENCES

- [1] A. Harb *et al.*, "Impact of Smart Inverters on Feeder Hosting Capacity of Distribution Networks," *IEEE Access*, vol. 7, no. 1rec, pp. 2–7, 2019, doi: 10.1109/ACCESS.2019.2952569.
- [2] H. Suyono, M. Shidiq, A. N. Ferdianzah, T. Utomo, I. Musirin, and L. J. Awal, "Dynamic Stability Impact of the Hybrid Wind and Microhydro Renewable Energy Sources on the Distribution System," *2018 Electr. Power, Electron. Commun. Control. Informatics Semin. EECCIS 2018*, pp. 15–20, 2018, doi: 10.1109/EECCIS.2018.8692793.
- [3] J. H. C. Yong, J. Wong, Y. S. Lim, and J. H. Tang, "Assessment on various allocations of energy storages systems on radial distribution network for maximum PV systems penetration," *2018 Int. Conf. Smart Grid Clean Energy Technol. ICSGCE 2018*, pp. 89–94, 2018, doi: 10.1109/ICSGCE.2018.8556803.
- [4] A. A. Saleh, A. A. A. Mohamed, A. M. Hemeida, and A. A. Ibrahim, "Multi-Objective Whale Optimization Algorithm for Optimal Allocation of Distributed Generation and Capacitor Bank," *Proc. 2019 Int. Conf. Innov. Trends Comput. Eng. ITCE 2019*, no. February, pp. 459–465, 2019, doi: 10.1109/ITCE.2019.8646352.
- [5] M. Z. Ul Abideen, O. Ellabban, and L. Al-Fagih, "A review of the tools and methods for distribution networks' hosting capacity calculation," *Energies*, vol. 13, no. 11, pp. 1–25, 2020, doi: 10.3390/en13112758.
- [6] A. B. Abdullahi, L. Olatomiwa, J. Tsado, and A. A. Sadiq, "Impact Assessment of Wheeling Renewable Distributed Generation to Residential Load," *Int. Conf. Electr. Comput. Energy Technol. ICECET 2021*, no. December, pp. 9–10, 2021, doi: 10.1109/ICECET52533.2021.9698780.
- [7] M. S. Turiman, M. Khairun Nizam Mohd Sarmin, N. Saadun, M. F. Zamri, H. Ali, and Q. Mohammad, "Determination of Optimal Distributed Generation Penetration Level in Distribution Networks based on Normalized Impact Factor Score," *2023 IEEE 3rd Int. Conf. Power Eng. Appl. Shap. Sustain. Through Power Eng. Innov. ICPEA 2023*, no. March, pp. 274–278, 2023, doi: 10.1109/ICPEA56918.2023.10093149.
- [8] I. Dumancic, C. Tranchita, and J. Kluge, "Dynamic simulation of distribution power systems with distributed renewable generation," *2021 IEEE PES/IAS PowerAfrica, PowerAfrica 2021*, 2021, doi: 10.1109/PowerAfrica52236.2021.9543396.
- [9] R. Sastre, R. Demes, and J. Garcia, "Power Voltage Transformers for Renewable Energy Substations Auxiliary Services Supply," *2019 IEEE PES GTD Gd. Int. Conf. Expo. Asia, GTD Asia 2019*, pp. 643–648, 2019, doi: 10.1109/GTDAsia.2019.8715926.

Corresponding author: Asuquo Nsikak Etim

✉ [nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



- [10] G. A. Gomez-Ramirez, I. A. Luevano-Reyes, G. Mora-Jimenez, L. Garcia-Santander, M. Z. Laskano, and C. Meza, "Increasing Distribution Network Capacity through Storage in Central American Countries: A Case Study," *2022 IEEE Int. Conf. Autom. Congr. Chil. Assoc. Autom. Control Dev. Sustain. Agric. Syst. ICA-ACCA 2022*, no. October, 2022, doi: 10.1109/ICA-ACCA56767.2022.10006043.
- [11] M. Khasanov, S. Kamel, E. Halim Houssein, C. Rahmann, and F. A. Hashim, "Optimal allocation strategy of photovoltaic- and wind turbine-based distributed generation units in radial distribution networks considering uncertainty," *Neural Comput. Appl.*, vol. 35, no. 3, pp. 2883–2908, 2023, doi: 10.1007/s00521-022-07715-2.
- [12] A. Anwar and H. R. Pota, "Loss reduction of power distribution network using optimum size and location of distributed generation," *2011 21st Australas. Univ. Power Eng. Conf. AUPEC 2011*, no. August 2013, 2011.
- [13] Agbontaen Festus Osazee & Idiagi Neville Simon "Improving the Performance of a Deficient 11kV Distribution Network Using Distributed Generation," *Journal of Electrical Engineering, Electronics, Control and Computer Science –JEECCS, Volume 8, Issue 27, pages 7-18, 2022*
- [14] K. Anderson *et al.*, "Integrating the Value of Electricity Resilience in Energy Planning and Operations Decisions," *IEEE Syst. J.*, vol. 15, no. 1, pp. 204–214, 2021, doi: 10.1109/JSYST.2019.2961298.

---

Corresponding author: Asuquo Nsikap Etim

✉ [nsiasug@gmail.com](mailto:nsiasug@gmail.com)

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved