



Article Integration of Solar Photovoltaic Distributed Generators in Distribution Networks Based on Site's Condition

Ayooluwa Peter Adeagbo ¹, Funso Kehinde Ariyo ², Kehinde Adeleye Makinde ^{3,*}, Funso Kehinde ², Kehinde ⁵, Kehinde Adeleye Makinde ^{3,*}, Kehinde ³, Kehinde³, Kehinde ³, Kehinde³, Kehinde³, Kehi

- ¹ Department of Electrical and Electronic Engineering, Adeleke University, Ede 232101, Nigeria; ayooluwaadeagbo@yahoo.com
- ² Department of Electronic and Electrical Engineering, Obafemi Awolowo University, Ile-Ife 220282, Nigeria; funsoariyo@yahoo.com
- ³ School of Computing, Engineering and Digital Technologies, Teesside University, Middlesbrough TS1 3BX, UK
- ⁴ Department of Electrical and Electronic Engineering, Ladoke Akintola University of Technology, Ogbomoso 210214, Nigeria; sunnydexs.sa@gmail.com
- ⁵ Department of Electrical and Electronic Engineering, First Technical University, Ibadan 200255, Nigeria; olusola.akinde@tech-u.edu.ng
- * Correspondence: kehindemakinde2003@yahoo.com (K.A.M.); adewuyiobode@gmail.com (O.B.A.)

Abstract: The significance of Distributed Generators (DGs) in the technical and economic operations of electric power distribution systems cannot be overemphasized in recent times. This is essential as a result of the incessant increase in electrical energy demand, which is becoming considerably difficult to meet with the conventional means of energy supply. Thus, DGs offer better alternatives for providing a quality supply of energy near the site of consumption. This type of energy supply is cleaner and cheaper most of the time due to the lessened transmission losses, which consequently reduced the cost of operation at the transmission and distribution levels of the power system. In this work, an approach for placement and sizing of solar PV DGs into radial distribution networks (RDN) based on the solar PV capacity factor of the site was analyzed using particle swarm optimization. The aim of this study is to analyze the effect of the approach on the real and reactive power losses within the network as well as the bus voltage profile. Constraints on credible system operation parameters, which includes bus voltage limits, power balance, and power flow limits, are considered in the formulation of the optimization problem. In order to verify the viability of the deployed approach, steady-state performance analyses were executed on IEEE 33-bus RDN; and the results obtained were compared with the results from other approaches reported in the literature.

Keywords: capacity factor; distributed generation; particle swarm optimization; power loss minimization; voltage profile improvement

1. Introduction

In the early times, centralized generation was the only means for the provision of electricity, which involves using conventional generators for the production of electricity. However, in recent times, the modernization of power system structure is highly essential due to the increase in electrical energy demand, and this has necessitated the need to move from centralized generation to decentralized generation. The decentralized generation consists of using small power-generating units either in the form of renewable or non-renewable energy sources installed and integrated into the power system at the distribution end very close to the local users [1]. The distribution network is usually radial in structure in its operational simplicity [2]. Thus, in recent years, the distribution networks (DN) have witnessed a rapid integration of distributed generators (DGs) as a result of the advances being made in renewable energy technologies. There has also been an increase in government drives to reduce carbon emission, achieve energy sustainability, enhance



Citation: Adeagbo, A.P.; Ariyo, F.K.; Makinde, K.A.; Salimon, S.A.; Adewuyi, O.B.; Akinde, O.K. Integration of Solar Photovoltaic Distributed Generators in Distribution Networks Based on Site's Condition. *Solar* 2022, *2*, 52–63. https://doi.org/10.3390/ solar2010004

Academic Editor: Jürgen Heinz Werner

Received: 11 December 2021 Accepted: 21 February 2022 Published: 24 February 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). energy autonomy as well as the need to increase energy security in line with the United Nation's sustainable development goal agenda [3]; and this can be achieved by DG integration. Some of the network support benefits that can be achieved from DG integration include: avoidance or reduction of transmission and distribution costs, reduction of real power losses, and provision of backup power in the advent of outages from the utility and overall improvement of network reliability [4]. However, the benefits are only realizable through appropriate placement and sizing of DG in distribution networks. Furthermore, improper placement of DG in distribution networks can result in issues such as increased power losses, voltage rise problems, and reduced power qualities, among others. About 30% of the total power losses in electric power systems are incurred in the transmission and sub-transmission networks while the remaining 70% takes place in the distribution networks [5].

Moreover, the losses in the distribution networks directly influence the operational cost of the system and can also lead to a poor voltage profile, especially in the condition of high load. Thus, the conventional methods to reduce losses have focused on network reconfiguration [6] and reactive power support through capacitor placement [7]. Several kinds of research have shown that the optimal placement and sizing of DG at carefully identified buses can effectively minimize the system power losses [8]. Most of the conventional distribution networks are passive but become active when DG units that are capable of supplying electrical power to the national grid are added to the system, bringing about bidirectional flows of power in the network. Hence, in order to avoid reverse power flow, which can be harmful to the operation of power systems, especially at the distribution network, energy storage facilities can be included [9]. Explicitly, some of the issues related to the conventional distribution system that can be solved by DG integration include technical, economic, and environmental issues [10]. The key goal of power system distribution planning is to plan the distribution system in a way that it can meet demand growth in a cost-effective but safe and reliable manner. The renewable DG technologies produce minimal or no emissions compared with non-inexhaustible DG technologies, but the extensive adoption of renewable DG technology could be limited by specific mandatory power systems' technical and economical operational limits and constraints [11].

Solar PV is one of the widely deployed DGs, and this is due to its numerous advantages, which includes abundant availability of primary energy from sun, easy installation and setup, sufficient technologies for deployment for both industrial and domestic purposes, minimum maintenance requirements and readily available personnel and resources with much needed technical know-how on solar PV technologies [12]. However, the solar PV technology, like other weather-dependent DG technologies, suffers from the problem of output uncertainties, which can cause both technical and economic issues if not properly planned and designed. In the present unbundling rules, due to power industry deregulation, the planning of DG location and sizes can be effectively carried out by DG owners/investors and not by power system operators. There might also be issues about selecting optimal location due to the availability of primary sources of energy such as wind or solar or availability of a sufficient piece of land and other factors. However, by providing the right information and incentives, power system operators can influence the DG owners/investors' decisions in selecting locations that give credible techno-economic benefits [13].

Hence, the purpose of optimal DG placement is to provide the best sites and sizes of DG units for an overall improvement in network performance in terms of improved reliability, minimal active power losses, improved voltage profile, reduced cost of operation, ensuring environmental sustainability, etc. In this paper, photovoltaic (PV) is integrated into standard IEEE 33 Bus RDN using the capacity factor of the site for determining the safe level for real power injection by monitoring important steady-state performance of the distribution system. Since PV can also inject reactive power into the system in accordance with the current drawn and grid codes through the inverter, the distribution system performance on the real and reactive power losses as well as the bus voltage was analyzed

and compared with similar works of literature. The remaining sections of this paper are organized as follows: credible information of relevant concepts on optimal integration of distributed generators is discussed under Section 2, and the adopted mathematical and optimization models and methods are described under Section 3. The simulation results are discussed in Section 4, and the report is concluded in Section 5.

2. Review of Relevant Concepts on Optimal Integration of Distributed Generators

On the basis of real and reactive power generation ability, distributed generator units are categorized into four types [14]: Type 1 DGs such as solar PV systems, microturbines that deliver only active power P—this type of DG unit ensures MWh profitability for distribution network operators (DNOs) but may lack voltage support capability, especially if the DN is not able to supply the necessary reactive power. Type 2 DGs include synchronous generators and a voltage source inverter (VSI) based PV array, which delivers both active power P and reactive power Q. Type 3 DGs include synchronous compensators, static capacitors etc., which delivers only reactive power Q. Type 4 DGs, such as wind turbines with induction generators, require reactive power for the magnetization of the rotor circuit and therefore consume reactive power but deliver active power. Depending on the inherent capacity of the type of DG to be integrated to the grid, especially at the distribution side, the DG can be modeled as either a PV or PQ bus. Due to the capacity of DGs which are normally of smaller size compared to the traditional power sources, the constant PQ model is usually adequate for the distribution system load flow analysis [15].

Quite a number of optimization tools have been presented in the literature for determining the optimal location and sizing of DG in the distribution network for improved network performance; these can be broadly divided into analytical, numerical, meta-heuristic, and hybrids of any of these methods. The analytical methods are gaining the interest of researchers owing to their straightforwardness, accuracy and the fact that the analytical techniques require less computational time since it does not involve many iterations [16]. The major drawback of this method is that it is not efficient for solving large and complex systems with a large number of state variables. The numerical approaches are easy to implement, efficient in computation and the objectives are met on time. However, the application of this technique is limited to linear systems, failure to meet the global optimal and is not effective for a high amount of load flow computation [17].

The metaheuristic methods are also known as evolutionary algorithms, and they are based on the implementation of artificial intelligence (AI) techniques such as Genetic algorithm (GA), Particle Swarm Optimization (PSO), Tabu Search (TS), etc. Their relative advantages such as computational robustness, ability to explore a large space for global optimal solution and high efficiency for solving multi-objective problems makes them the frequently adopted tool for optimal solution of DG planning problems in recent time. These algorithms are employed for multiple DG placements and single and varying power load models. However, they can also fail to give definite and completely accurate results if the parameters are not properly tuned [18]. Due to the nature of the design variables in this study, which entails a discrete nature on one hand (DG site identification) and continuous nature on the other hand (PV DG size optimization including the time-dependent site's irradiance), the particle swam optimization approach was deployed for optimal sizing alongside the loss sensitivity index approach [19] for suitable site (bus) identification.

3. Models and Methods

Unlike in the transmission systems, the characteristics of the conductors deployed in distribution systems such as high resistance to reactance ratio and a radial form with many nodes, branches, DGs, and complex configuration are not favorable to be addressed using the conventional iterative approaches [20,21]. A backward-forward sweep is an efficient approach mainly developed for load flow solutions in RDN. It has the benefits of great computational performance, ease of implementation, stable convergence and low memory

usage [22,23]. As a result, the load flow solution is executed using the Backward-Forward Sweep technique in this study.

3.1. Backward/Forward Sweep Load Flow for a Radial Distribution System

This work takes into consideration the inherent characteristics of the radial network as analyzed using the backward/forward sweep (BFS) load flow algorithm [24]. Considering a simple radial distribution network (RDN) of Figure 1, the real and reactive power flows and losses are as expressed by Equations (1)–(4) [20,25].



Figure 1. Single line diagram of a radial distribution network [19].

$$P_{i} = P_{i+1}^{\prime} + r_{ik} \frac{(P_{i+1}^{\prime 2} + Q_{i+1}^{\prime 2})}{V_{i+1}^{\prime 2}},$$
(1)

$$Q_{i} = Q_{i+1}^{'} + x_{ik} \frac{(P_{i+1}^{'2} + Q_{i+1}^{'2})}{V_{i+1}^{'2}},$$
(2)

Equations (1) and (2) represent the active and reactive powers (P_i and Q_i) flowing through the branch 'j' from node 'i' to 'i+1' calculated backwards.

The real and reactive power losses of branch 'j' are calculated using Equations (3) and (4) as follows:

$$P_{lossj} = r_{ik} \frac{(P_i^2 + Q_i^2)}{V_i^2},$$
(3)

$$Q_{lossj} = x_{ik} \frac{(P_i^2 + Q_i^2)}{V_i^2},$$
(4)

The above equations represent the active and reactive power losses along the branch 'j' (P_{lossj} and Q_{lossj}) from node 'i' to 'i + 1' using the backward calculation. V_i is the voltage at node 'i', r_{ik} and x_{ik} are the resistance and reactance of the branch 'j' between any two nodes 'i' and 'k'. The total real and reactive losses in the RDN are thus calculated as:

$$P_{Tloss} = \sum_{j=1}^{N_{br.}} P_{loss_j} \tag{5}$$

$$Q_{Tloss} = \sum_{j=1}^{N_{br.}} Q_{loss_j} \tag{6}$$

where N_{br} is the total number of branches. The superiority of this load flow analysis method is such that, regardless of the original network topology, the distribution network is first converted to a radial network. In addition, a node and branch-oriented approach is incorporated using an efficient numbering scheme to enhance the numerical performance of the solution method as described with details in [21].

3.2. Solar PV Modelling and DG Injection Approach

The DG model deployed in this work is the Solar Photovoltaic model The PV output at any instantaneous time (t) is modeled considering the effect of the time-varying solar irradiance in the solar PV DG sizing. The capacity factor approach is deployed to obtain an estimate of the net power injectable from the solar PV DGs, and the output power of the PV system at a time, *t*, which is a function of the size/rated power of the DG, is calculated accordingly [26]:

$$P_{pv}(t) = \begin{cases} P_{pvrated} \left(\frac{G_t^2}{G_{std}R_c} \right) & \text{for } 0 \le G_t \le R_c \\ P_{pvrated} \left(\frac{G_t}{G_{std}} \right) & \text{for } G_t > R_c. \end{cases}$$
(7)

where $P_{pv}(t)$ is the power generated by the photovoltaic panel at any time instance, which is calculated on an hourly average. $P_{pvrated}$ is the rated capacity of the chosen PV panel, G_t is the instantaneous solar radiation, G_{std} is standard irradiance (1000 Wm⁻²) and R_c is the radiation threshold/setpoint (150 Wm⁻²).

The capacity factor is introduced in this work to measure the performance of the PV system. By definition, the capacity factor of a solar PV facility is a measure of the energy production efficiency of that facility over a period of time, usually a year, based on the solar resource potential of the site. Since the power flow analysis is often calculated as per hour simulation of the steady-state condition of the power system, the maximum available a.c. power injection into the RDN from the solar PV DG units in per hour equivalent can be obtained as a function of the site's capacity factor (Cf_{pv}) and inverter's efficiency ($\eta_{inv.}$) as described [27]:

$$P_{PV} = N_{pv} \times P_{pv} \times Cf_{pv} \tag{8}$$

where the capacity factor is calculated as:

$$Cf_{pv} = \frac{\sum_{t=1}^{8760} P_{pv}(t)}{P_{vvrated} \times 8760}$$
(9)

The capacity factor of a good site with sufficient solar potential is considered to be 20% and above [28], where Cf_{pv} is the capacity factor, N_{pv} is the conversion efficiency or derating factor and P_{PV} is the size of the DG that will be integrated into the system. The inverter efficiency η_{inv} is obtained as:

$$\eta_{inv.} = \frac{P_{AC}}{P_{PV}} \times 100\% \tag{10}$$

where P_{AC} is the output of the inverter. The resultant (effective) active and reactive loads after the injection of DG power at the selected buses are obtained as:

$$P_{Deff,i} = P_{Di} - \eta_{inv} P_{PV}; \tag{11}$$

$$Q_{Deff,i} = Q_{Di} - Q_{inv.} \tag{12}$$

where P_{Di} and Q_{Di} are the active and reactive load demands at bus i without DG, and $Q_{inv.}$ is the reactive power from the inverter output.

3.3. Problem Formulation and DG Modelling

The active power and reactive power losses and the voltage at each node in the RDN are evaluated using a Backward-Forward Sweep Approach. The considered objective function is the minimization of the active and reactive power losses in the RDN as defined below:

minimize
$$F = \omega_1 \times P_{Tloss} + \omega_2 \times Q_{Tloss}; \quad \omega_1 + \omega_2 = 1.$$
 (13)

The constraints considered are:

Power balance constraint:

$$\sum_{i=1}^{N_{bus}} P_{DGi} = \sum_{i=1}^{N_{bus}} P_{Deff,i} + P_{Tloss}; \quad \sum_{i=1}^{N_{bus}} Q_{DGi} = \sum_{i=1}^{N_{bus}} Q_{Deff,i} + Q_{Tloss}; \quad \forall i \in N_{bus}$$
(14)

• Voltage magnitude limit:

$$|V_i|^{min} \le |V_i| \le |V_i|^{max}; \quad \forall i \in N_{bus}$$
(15)

Current limit constraint:

$$0 \le I_j \le I_j^{max}; \quad \forall j \in N_{br.}$$
 (16)

• DG Capacity Limit:

$$P_{DGi}^{min} \le P_{DGi} \le P_{DGi}^{max}; \quad Q_{DGi}^{min} \le Q_{DGi} \le Q_{DGi}^{max}; \quad \forall i \in N_{DG}.$$

$$(17)$$

where $N_{br.}$ is the total number of lines/branches, N_{bus} is the number of buses/nodes, N_{DG} is the number of DG injection nodes, P_{DGi} and Q_{DGi} signify active (true) and reactive power available at bus i due to the location of DG, P_{Di} and Q_{Di} signify the active and reactive power demand at bus i, V_i^{min} and V_i^{max} are the lowest and highest voltage limits of the system and I_j^{max} is the maximum allowable current in the network branch. The voltage magnitude limit is set to 0.90 pu and 1.00 pu [29].

(

3.4. Evolutionary Optimization Algorithm

Particle swarm optimization (PSO) is adopted in this research because it has been found as an effective method for solving diverse complex nonlinear optimization problems [30,31]. The modification of the particle's velocity is considered as shown below:

$$V_i^{k+1} = w \cdot V_i^k + c_1 \cdot r_1 \cdot (Pbest_i^k - X_i^k) + c_2 \cdot r_2 \cdot (Gbest^k - X_i^k)$$

$$\tag{18}$$

The velocity is the factor for updating the particle's position as obtained below:

$$X_i^{k+1} = X_i^k + V_i^{k+1} (19)$$

where w is the weighting function, c_1 and c_2 are the acceleration coefficients, r_1 and r_2 are random numbers between 0 and 1, V_i^k and X_i^k are the current velocity and position of particle i at iteration k, V_i^{k+1} and X_i^{k+1} are the modified velocity and position of particle i and P_{besti}^k and G_{besti}^k are the personal and global bests of particle i. The dynamically changing inertia weight or weighting factor is employed because it guides the exploration and utilization of the search space, and it is expressed as [32]:

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{max_{it}}\right) \times It$$
⁽²⁰⁾

where w_{max} and w_{min} are the inertia weight's final and initial values, respectively, *It* and max_{it} are current and maximum iteration number, respectively. w_{max} and w_{min} are taken to be 0.4 and 0.9, respectively [33]. The flowchart illustration of the adopted PSO algorithm is shown in Figure 2.



Figure 2. Particle swarm optimization flowchart.

4. Simulation Results and Discussion

To demonstrate the effectiveness of the discussed technique, it was applied to IEEE 33-bus standard RDN. The IEEE 33-bus radial distribution system as shown in Figure 3 consists of thirty-three buses operated at a voltage level of 12.66 kV and thirty-two lines. The maximum and minimum voltage deviations are constrained to $\pm 5\%$ at all the buses, and the total real and reactive loads at all the buses are 3.715 MW and 2.3 MVar, respectively [34]. The base MVA is considered as 100 MVA, and the base voltage is taken to be 12.66 kV. In the base scenario, the system's overall real and reactive power losses are 202.66 kW (5.45%) and 135.22 kVar (5.9%), respectively. Tables 1 and 2 demonstrate the simulation results for the DG locations, bus voltage magnitude, active power loss reduction, and reactive power loss reduction utilizing PSO, as well as a comparison with the results of different methods reported in the literature.



Figure 3. IEEE 33-bus radial distribution network.

Table 1. Simulation Results.

Case	Base Case	1 DG	2 DGs	3 DGs
Optimal Location	-	[8]	[8; 30]	[8; 19; 30]
Installed DG (kW)	-	[1725]	[1129; 721]	[1245; 950; 655]
Total DG Size (kW)	-	1725	1850	2850
Total Real Power Loss	202.66	119.26	101.94	98.94
Total Real Power Loss Reduction	-	83.39	100.72	103.72
Real Power Loss Reduction	-	41.2%	49.7	51.2%
Total Reactive Power Loss	135.22	80.38	68.45	66.75
Total Reactive Power Loss Reduction	-	54.84	66.78	68.48
Reactive Power Loss Reduction	-	40.6%	49.4	50.6%
Min. Bus Voltage	0.9131	0.9376	0.9405	0.9416

Table 2. Results comparison with various approaches for 3 DGs.

	SOS [35]	GA [2]	TLBO [36]	QOTLBO [36]	HAS [35]	GAPSO [36]
Real Power Loss (kW)	104.26	106.30	124.70	103.41	135.69	103.40
Total DG Size (MW)	3.13	2.99	3.56	3.47	0.99	2.98

The 'actual' penetration level of solar PV DG power is kept within 30–35% of the total load and the average instantaneous power injected from the solar PV DGs is calculated as a fraction of the optimal DG sizes based on the irradiance per time and the site capacity factor as discussed under the methodology. For results comparison, the maximum number of DG injection points considered in this study is three in line with a number of works available in the literature. Based on the loss sensitivity approach discussed in [19], the identified DG injection points are buses 8, 19, and 30 in the order of priority as indicated in Figure 3. The simulation was carried out for three scenarios involving 1 DG, 2 DGs, and 3 DGs, respectively; without DG, the actual power loss is 202.66 kW, and the reactive power loss is 135.22 kVar, according to Table 2. In addition, the minimum voltage is 0.9131 per unit, and this occurs at bus 18; the minimum voltage increases to 0.9376, 0.9405 and 0.9416 for single, double and triple DGs, respectively. Placing a single DG at bus 8 in the network reduces active and reactive power losses by 119.28 (41.2%) and 80.38 (40.6%), respectively; when two DGs are installed at the same time, active and reactive power losses were reduced by 49.7% and 49.4%, respectively. When three DGs are installed at the same time, active and reactive power losses decrease by 51.2 percent and 50.6 percent, respectively. The active and reactive power losses, apparent power flow in each line, and bus voltage at different buses for varying numbers of DGs included in the network are shown in Figures 4–6.



Figure 4. Real power loss in the RDN.



Figure 5. Reactive power loss in the RDN.



Figure 6. Voltage magnitude levels in the RDN.

5. Conclusions

The performance of a power system can be essentially assessed by the customers at the distribution end of the network. Thus, several research efforts are being devoted to improving the quality and reliability of power supply to the consumers' loads by the optimal deployment of distributed generators (DGs). In this study, an approach for optimally integrating solar PV distributed generators into radial distribution networks based on the solar capacity factor has been discussed. The heuristic optimization approach was utilized in this research to solve the problem of optimal DG location and size in the considered electric power distribution network using a particle swarm optimization algorithm. The technique was used to place and size the DG on an IEEE 33-bus network to reduce the power (active and reactive) losses and improve the voltage profile. The loss sensitivity factor was used to create a priority list of prospective locations for DG units, and the buses with the lowest sensitivity values were deemed suitable for DG installation. Compared to the base condition, installing a single DG yielded a reduction in real and reactive power loss of 41.2% and 40.6%, respectively; installing two DGs simultaneously yielded an active and reactive power losses reduction of 49.7% and 49.4%, respectively, and with the simultaneous installation of three DGs, the active and reactive power losses decreased by 51.2% and 50.6%, respectively. The obtained results using PSO for DG placement considering the site capacity factor were compared to Genetic Algorithm (GA), Symbiotic Organism Search (SOS), Teaching Learning Based Optimization, Quasi-Oppositional Teaching Learning Based Optimization, and GAPSO to demonstrate the effectiveness of the deployed methodology for the improvement of the performance of distribution networks.

Author Contributions: A.P.A.—conceptualization, resource, modelling and writing; F.K.A.—validation and supervision; K.A.M.—resource and writing of reviews; S.A.S.—resource and validation; O.B.A.— modelling, writing, editing, funding acquisition; O.K.A.—resource and proofreading. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The main data used for this work are the bus and line parameters for the standard IEEE 33 bus radial distribution network [37].

Acknowledgments: Special thanks to F. K. Ariyo and O. B. Adewuyi for their invaluable contributions to this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Ali, E.S.; El-Sehiemy, R.A.; El-Ela, A.; Adel, A.; Mahmoud, K.; Lehtonen, M.; Darwish, M.M. An Effective Bi-Stage Method for Renewable Energy Sources Integration into Unbalanced Distribution Systems Considering Uncertainty. *Processes* 2021, 9, 471. [CrossRef]
- Moradi, M.H.; Abedini, M. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. *Int. J. Electr. Power Energy Syst.* 2012, 34, 66–74. [CrossRef]
- Zsiborács, H.; Pintér, G.; Vincze, A.; Birkner, Z.; Baranyai, N.H. Grid balancing challenges illustrated by two European examples: Interactions of electric grids, photovoltaic power generation, energy storage and power generation forecasting. *Energy Rep.* 2021, 7, 3805–3818. [CrossRef]
- Essallah, S.; Khedher, A. Optimal multi-Type DG integration and distribution system reconfiguration for active power loss minimization using CPSO algorithm. In Proceedings of the 2019 International Conference on Control, Automation and Diagnosis (ICCAD), Grenoble, France, 2–4 July 2019; pp. 1–6.
- Ahmadi, M.; Adewuyi, O.B.; Danish, M.S.S.; Mandal, P.; Yona, A.; Senjyu, T. Optimum coordination of centralized and distributed renewable power generation incorporating battery storage system into the electric distribution network. *Int. J. Electr. Power Energy Syst.* 2021, 125, 106458. [CrossRef]

- 6. Reddy, A.S.; Reddy, D.M.D. Application of whale optimization algorithm for distribution feeder reconfiguration. *Imanager's J. Electr. Eng.* **2018**, *11*, 17–24.
- Jahromi, M.H.M.; Dehghanian, P.; Khademi, M.R.M.; Jahromi, M.Z. Reactive power compensation and power loss reduction using optimal capacitor placement. In Proceedings of the 2021 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, USA, 2–5 February 2021; pp. 1–6.
- 8. Ogunjuyigbe, A.; Ayodele, T.; Akinola, O. Impact of distributed generators on the power loss and voltage profile of subtransmission network. *J. Electr. Syst. Inf. Technol.* **2016**, *3*, 94–107. [CrossRef]
- 9. Emara, D.; Ezzat, M.; Abdelaziz, A.Y.; Mahmoud, K.; Lehtonen, M.; Darwish, M.M. Novel Control Strategy for Enhancing Microgrid Operation Connected to Photovoltaic Generation and Energy Storage Systems. *Electronics* **2021**, *10*, 1261. [CrossRef]
- Ahmadi, M.; Lotfy, M.E.; Shigenobu, R.; Howlader, A.M.; Senjyu, T. Optimal Sizing of Multiple Renewable Energy Resources and PV Inverter Reactive Power Control Encompassing Environmental, Technical, and Economic Issues. *IEEE Syst. J.* 2019, 13, 3026–3037. [CrossRef]
- Wei, Y.M.; Kang, J.N.; Yu, B.Y.; Liao, H.; Du, Y.F. A dynamic forward-citation full path model for technology monitoring: An empirical study from shale gas industry. *Appl. Energy* 2017, 205, 769–780. [CrossRef]
- 12. Adeagbo, A.; Olaniyi, E.; Ofoegbu, E.; Abolarin, A. Solar photo-voltaic system efficiency improvement using unitary-axis active tracking system. *Int. J. Sci. Eng. Res.* **2020**, *11*, 502–508.
- 13. Adewuyi, O.B.; Ahmadi, M.; Olaniyi, I.O.; Senjyu, T.; Olowu, T.O.; Mandal, P. Voltage security-constrained optimal generation rescheduling for available transfer capacity enhancement in deregulated electricity markets. *Energies* **2019**, *12*, 4371. [CrossRef]
- 14. Ochoa, L.F.; Keane, A.; Harrison, G.P. Minimizing the reactive support for distributed generation: Enhanced passive operation and smart distribution networks. *IEEE Trans. Power Syst.* **2011**, *26*, 2134–2142. [CrossRef]
- Ali, Z.M.; Diaaeldin, I.M.; HE Abdel Aleem, S.; El-Rafei, A.; Abdelaziz, A.Y.; Jurado, F. Scenario-based network reconfiguration and renewable energy resources integration in large-scale distribution systems considering parameters uncertainty. *Mathematics* 2021, 9, 26. [CrossRef]
- Nawaz, S.; Bansal, A.K.; Sharma, M.P. A novel DG allocation method for power loss reduction in radial distribution system. In Proceedings of the 2016 IEEE 7th Power India International Conference (PIICON), Bikaner, India, 25–27 November 2016; pp. 1–4.
- Suvarchala, K.; Yuvaraj, T.; Balamurugan, P. A brief review on optimal allocation of Distributed Generation in distribution network. In Proceedings of the 2018 4th International Conference on Electrical Energy Systems (ICEES), Chennai, India, 7–9 February 2018; pp. 391–396.
- 18. Karunarathne, E.; Pasupuleti, J.; Ekanayake, J.; Almeida, D. Optimal Placement and Sizing of DGs in Distribution Networks Using MLPSO Algorithm. *Energies* 2020, *13*, 6185. [CrossRef]
- 19. Adewuyi, O.B.; Adeagbo, A.P.; Adebayo, I.G.; Howlader, H.O.R.; Sun, Y. Modified Analytical Approach for PV-DGs Integration into a Radial Distribution Network Considering Loss Sensitivity and Voltage Stability. *Energies* **2021**, *14*, 7775. [CrossRef]
- 20. Ouali, S.; Cherkaoui, A. An improved backward/forward sweep power flow method based on a new network information organization for radial distribution systems. *J. Electr. Comput. Eng.* **2020**, 2020, 5643410. [CrossRef]
- Rupa, J.A.M.; Ganesh, S. Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method. Int. J. Electr. Comput. Eng. 2014, 8, 1628–1632.
- 22. Chang, G.W.; Chu, S.Y.; Wang, H.L. An Improved Backward/Forward Sweep Load Flow Algorithm for Radial Distribution Systems. *IEEE Trans. Power Syst.* 2007, 22, 882–884. [CrossRef]
- 23. Salimon, S.A.; Adepoju, G.A.; Adebayo, I.G.; Adewuyi, O.B.; Amuda, S.O. Simultaneous Placement and Sizing of Distributed Generation Units and Shunt Capacitors on Radial Distribution Systems Using Cuckoo Search Algorithm. *Curr. J. Appl. Sci. Technol.* **2021**, *40*, 43–58. [CrossRef]
- 24. Bompard, E.; Carpaneto, E.; Chicco, G.; Napoli, R. Convergence of the backward/forward sweep method for the load-flow analysis of radial distribution systems. *Int. J. Electr. Power Energy Syst.* 2000, 22, 521–530. [CrossRef]
- Amara, T.; Asefi, S.; Adewuyi, O.B.; Ahmadi, M.; Yona, A.; Senjyu, T. Technical and economic performance evaluation for efficient capacitors sizing and placement in a real distribution network. In Proceedings of the 2019 IEEE Student Conference on Research and Development (SCOReD), Bandar Seri Iskandar, Malaysia, 15–17 October 2019; pp. 100–105. [CrossRef]
- 26. Adewuyi, O.B.; Shigenobu, R.; Senjyu, T.; Lotfy, M.E.; Howlader, A.M. Multiobjective mix generation planning considering utility-scale solar PV system and voltage stability: Nigerian case study. *Electr. Power Syst. Res.* **2019**, *168*, 269–282. [CrossRef]
- Adewuyi, O.B.; Lotfy, M.E.; Akinloye, B.O.; Howlader, H.O.R.; Senjyu, T.; Narayanan, K. Security-constrained optimal utility-scale solar PV investment planning for weak grids: Short reviews and techno-economic analysis. *Appl. Energy* 2019, 245, 16–30. [CrossRef]
- 28. Moraes, L., Jr.; Bussar, C.; Stoecker, P.; Jacqué, K.; Chang, M.; Sauer, D. Comparison of long-term wind and photovoltaic power capacity factor datasets with open-license. *Appl. Energy* **2018**, 225, 209–220. [CrossRef]
- 29. Salimon, S.A.; Aderinko, H.A.; Fajuke, F.I.; Suuti, K.A. Load flow analysis of Nigerian radial distribution network using backward/forward sweep technique. *J. VLSI Des. Adv.* **2019**, *2*, 1–11.
- 30. Valle, Y.D.; Venayagamoorthy, G.K.; Mohagheghi, S.; Hernandez, J.C.; Harley, R.G. Particle swarm optimization: Basic concepts, variants and applications in power systems. *IEEE Trans. Evol. Comput.* **2008**, *12*, 171–195. [CrossRef]
- Adewuyi, O.B.; Howlader, H.O.R.; Olaniyi, I.O.; Konneh, D.A.; Senjyu, T. Comparative analysis of a new VSC-optimal power flow formulation for power system security planning. *Int. Trans. Electr. Energy Syst.* 2020, 30, e12250. [CrossRef]

- 32. Talukder, S. Mathematical Modelling and Applications of Particle Swarm Optimization. Ph.D. Thesis, School of Engineering Blekinge Institute of Technology, Karlskrona, Sweden, 2011.
- Rathore, A.; Sharma, H. Review on inertia weight strategies for particle swarm optimization. In Proceedings of the Sixth International Conference on Soft Computing for Problem Solving, School of Mathematics, Thapar University, Patiala, India, 13 April 2017; Springer: Singapore, 2017; pp. 76–86.
- 34. Vita, V. Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks. *Energies* **2017**, *10*, 1433. [CrossRef]
- 35. Nguyen, T.P.; Vo, D.N. Optimal number, location, and size of distributed generators in distribution systems by symbiotic organism search based method. *Adv. Electr. Electron. Eng.* **2018**, *15*, 724–735. [CrossRef]
- 36. Sultana, S.; Roy, P.K. Multi-objective quasi-oppositional teaching learning based optimization for optimal location of distributed generator in radial distribution systems. *Int. J. Electr. Power Energy Syst.* **2014**, *63*, 534–545. [CrossRef]
- 37. Dolatabadi, S.H.; Ghorbanian, M.; Siano, P.; Hatziargyriou, N.D. An Enhanced IEEE 33 Bus Benchmark Test System for Distribution System Studies. *IEEE Trans. Power Syst.* 2020, *36*, 2565–2572. [CrossRef]