Signal Processing and Renewable Energy
September 2022, (pp. 13-22)
ISSN: 2588-7327
eISSN: 2588-7335

Reduce Costs and Voltage Droops in Distribution System by Locating DG and Static Synchronous Compensator Using GA

Mohsen Najafi[1], Fariborz Haghighatdar Fesharaki[2,3]*

[1] Faculty of Electrical Engineering, Shahid Ashrafi Esfahani Non Profit University, Isfahan, Iran
[2] Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[3] Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

Received: 17-Apr-2022, Revised: 20-May-2022, Accepted: 21-May-2022.

Abstract
With the development of industry and the demand for electricity, energy supply is economically important with respect to environmental issues. The use of small, distributed products has spread near the subscribers' locations. Determining the location and capacity of products at the distribution network level has a great impact on managing financial resources and improving network parameters. In this paper, the optimal model for determining the location and capacity of distributed generation and static synchronous compensator (STATCOM) is presented, which is economically and technically multi-objective. In the economic part, the reduction of the installation cost of distributed products and STATCOM has been considered, and in the technical part, the reduction of losses and the reduction of the voltage droop of the network bus have been considered. This problem is solved using a genetic algorithm. The simulation results are determined using MATLAB software. The results show the effect of location on voltage reduction..

Keywords: Distributed Generation, STATCOM, Genetic Algorithm.

1. INTRODUCTION

The basis of development, progress, economic and social growth, and the provision of national resources and welfare and life owes to the electricity industry and engineers, specialists, and those involved in the electricity industry. Attention to the cycle of production, transmission, and distribution

***Corresponding Authors Email: fr_haghighat@yahoo.com**

of electricity throughout the country has always been and always has been considered by researchers and scholars, and certainly the expansion of the electricity industry will have a very important impact on the development of technology and economy. Variety of electricity applications in all forms of human life and the increase of electrical systems in factories, industrial centers, production and service units, and the widespread use of electrical systems in improving the quality and quantitative development of human ability to use as much as possible natural resources and talents in order to further progress in all cultural, social, and economic fields determines the necessity and importance of this science [1-7].

With the increasing penetration of distributed generation (DG) resources into distribution systems, the concept of microgrid has been introduced in the field of electrical energy systems [8-11]. The micro-grid is considered as a set of scattered sources and their close loads that are connected by an optical system and can be separated from the main network [12-14]. The microgrid consists of a number of distributed generation units (renewable and non-renewable), energy stores, and loads that are controllable and provide electrical power and heat if needed [15,16]. In connecting new distributed sources to microgrids, voltage source inverters are used, which have high flexibility in supplying controlled energy and high quality for loads [17,18].

For determining the suitable location for distributed generation sources in radial feeders of unbalanced distribution networks, a formulated solution has been proposed in [19] that the application of proposed distributed generation sources in this project is independent of the voltage level of the studied system. The distribution system is considered radial and unbalanced.

The implementation of an artificial ecosystem optimization technique for distributed generators and the allocation of capacitors with regard to the reconfiguration of power distribution systems is presented in [20], which a practical case study of a 59 Cairo-like bus distribution system is studied with different loading percentages.

A methodology based on bio-inspired cuckoo search algorithm, which can analyze simultaneous allocation of DG and Distribution STATCOM in the radial distribution systems is proposed in [21], which optimal locations of the DG and DSTATCOM are determined using voltage stability index and loss sensitivity factor respectively.

Fuzzy-lightning search algorithm is proposed in [22] to minimize the power loss in the radial distribution network by solving the optimal placement problem of distribution STATCOM and photo voltaic (PV) array unit, which the improved voltage profile values, less power loss, and reduced stability problems have been attained by using this method.

The optimal location and sizing of two DGs in the power system with the heuristic probability distribution method and artificial neural network method are presented in [23], which to improve the distortion level in real and reactive power, multi-FACTS are used.

Determining the position and size of DGs in optimal locations is crucial for managing and regulating energy in power system networks. The main objectives of this paper are:

- Minimization of power losses in the distribution network (loss target function)
- Improve voltage droop of network bus (voltage droop target function)
- Minimization of equipment installation costs (economic objective function)

This paper is organized as follows: Section 2 is describing optimal placement in distribution network. Section 3 presents the simulation results and section 4 draws the conclusion.

2. OPTIMAL PLACEMENT IN DISTRIBUTION NETWORK

The economic objective function minimizes the cost of providing electricity to subscribers. Subscribers' electricity is provided through the purchase, installation, and operation of DGs in the distribution network. This objective function consists of two parts: capital cost and operation cost. The cost of operation includes two costs, namely the cost of maintenance and fuel cost. The total cost of purchasing, installing distributed products, and STATCOM are investment costs. Mathematical expression is a function of economic purpose as follows:

$$ECOF = \sum_{t=1}^{T}[\sum_{n=1}^{N}(\alpha + \beta * P_{DG}^{n,t}) + \sum_{s=1}^{S}(\rho_{SEC} * SEC^{s,t})] \tag{1}$$

In relation to the economic objective function, α is equal to the annual investment cost for each unit of electricity generation and is calculated as follows:

$$\alpha = \frac{\rho_{capital}^{n} * P_{DG}^{n,t} * r}{\sigma * 365 * 24 * LF^{n,t}} \tag{2}$$

The objective function of reducing energy losses is expressed as follows, which depends on the voltage, impedance, and the difference between the angles of the two lines.

$$LEOF = \sum_{t=1}^{T}\sum_{i=1}^{K}\sum_{j=1}^{K}(G^{ij}((V^{i})^{2} + (V^{j})^{2} - 2 * V^{i} * V^{j} * \cos(\theta^{i} - \theta^{j})) \tag{3}$$

The magnitude of the voltage deviation of the network buses from the nominal value as a target function is modeled as follows.

$$\mathrm{VOF} = \sum_{t=1}^{T}\sum_{i=1}^{K}\left|\frac{V^{i} - V_{ref}^{i}}{V_{ref}^{i}}\right| \tag{4}$$

3. SIMULATION RESULTS

In this section, the numerical results of the optimal placement of scattered products and STATCOM devices are presented. The standard 33-bus IEEE network is considered as shown in Figure (1), and the optimization problem is solved using a genetic algorithm. The simulation was performed in MATLAB software environment.

The distribution network has 33 buses that are connected to the upstream network by bus 1. The required power of network loads is provided through this substation. The total active and reactive network load is 3.519

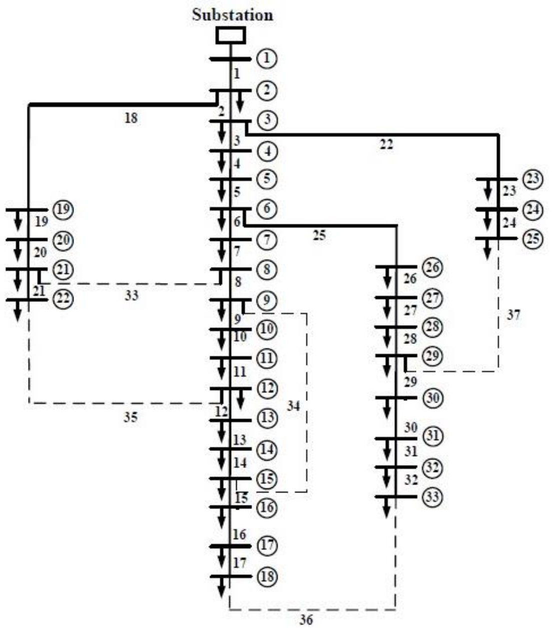

Fig. 1. The studied network structure.

MW and 1.80 MVAr, respectively, which are distributed at the network level. The mains voltage is 11.66 kV and the allowable voltage variation range is 0.95 to 1.05 pu. Information about network lines is given in [24].

The purchase price of energy from the upstream network to supply local loads of the distribution network is 7000 $/MWh [25].

A. Test network in normal mode.

Distributed generation units and STATCOM devices are not considered and all the required network power is provided through the substation in bus 1. With the radial distribution network, all the power required for the downstream loads must cross the upstream lines; Therefore, high power passes through these lines. Lines 2-1 and 3-2 have the most active and reactive throughput, and the closer we get from these lines to the end of the network and the end of the sub-branches, the lower the throughput. Therefore, the power flow is from the upstream bass to the end bobs. Line-through power is directly related to the value of losses, and most network losses are related to elementary feeders. High power passing through the lines, especially the basic lines, in addition to increasing the need for network development and increasing losses, increases the voltage droop across the lines and thus reduces the voltage of the network bus. This voltage droop across the terminals is so significant that becomes difficult to supply the load of these areas and the voltage value goes out of range.

B. Reducing casualties in test network

Along with economic and reliability target functions, the loss reduction objective function is also considered. The capacity and installation location of the dispersed products are shown in Figure (2). STATCOM location and capacity are listed in Table (1).

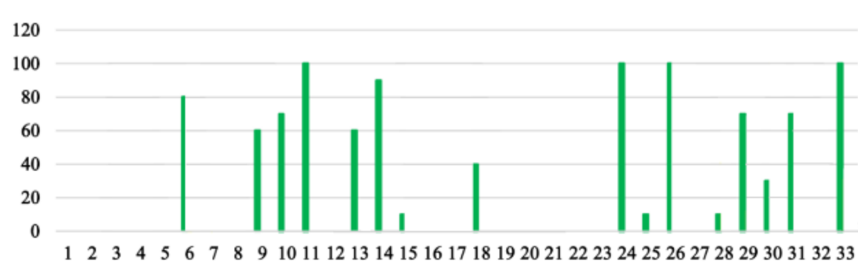

Fig. 2. Capacity and optimal installation location of distributed generation in kilowatts in the reducing casualties.

Table 1. ***Location and capacity of STATCOM devices in the Reducing casualties*.**

installation location	Capacity
2	200
12	80
26	80

Table 2. ***Redistributed energy in the reducing casualties.***

Parameter	Reducing casualties in test network	Test network in normal mode
Lost energy	2333	3396
Lost energy penalty	6042	8765

The amount of losses is directly related to the power passing through the lines. Scattered production units and STATCOM are positioned to minimize line throughput.

The economic objective function seeks to minimize the installation of units due to their financial burden. Other target functions seek to install maximum units to improve network parameters. Optimization creates a balance between different goals. However, excessive penetration of its resources causes the reverse flow of power in the lines, which if not controlled, may inject power from the distribution network to the upstream network, the amount of power passing through the lines exceeds the base state, which leads to increased losses.

Therefore, maximum penetration of distributed generation and STATCOM does not mean solving the technical problems of the network, and the number and capacity of these units should be selected optimally and within the network constraints.

The best case scenario for network losses is when the least power passes through the network lines. Network losses decrease as you approach the end lines. This rule, of course, is not permanent and may be different in some lines due to high resistance. According to the results of the genetic algorithm, distributed generation units and STATCOM are installed in the bus with the highest feeders upstream in order to reduce losses as much as possible. Table (2) shows the energy distributed in this state compared to the normal state.

C. Increasing the voltage stability in the test network

In this case, the priority of optimization is reducing the voltage droop of the bus hosts,

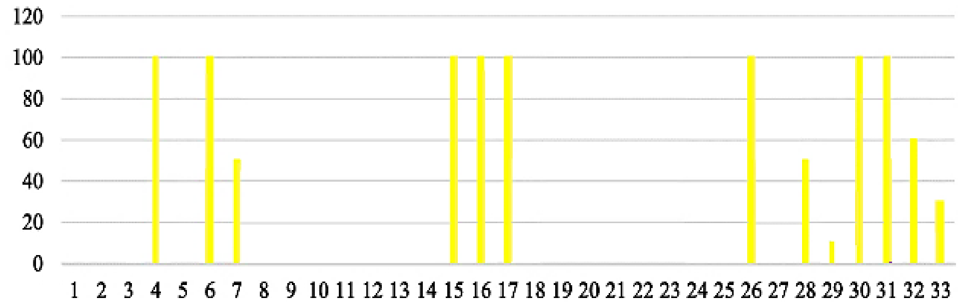

Fig. 3. Capacity and optimal installation location of distributed generation in kilowatts in increasing the voltage stability manner.

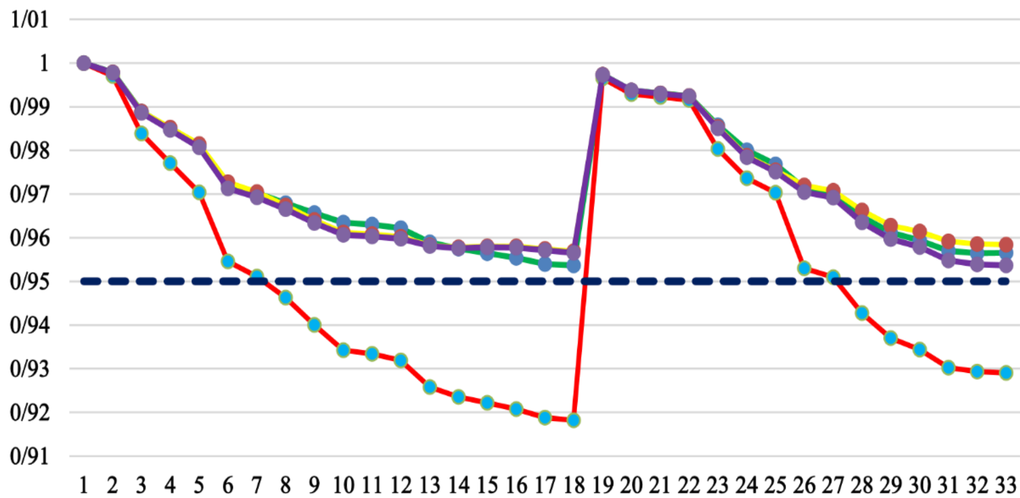

Fig. 4. The amount of prionite voltage of different buses in the scenarios performed (Red: Reduce the number/capacity of DG units, Green: Loss reduction, Yellow: Increase voltage stability, Purple: Versatile objective function).

along with economic target functions and reliability, the objective function of reducing the voltage deviation of the network. The placement is done in such a way that in addition to minimizing costs, the voltage droop across the network is also reduced. Figure (3) shows the installation location of the dispersed production units and table (3) shows the capacity and installation location of STATCOM.

Table 3. ***Location and capacity of STATCOM devices in increasing the voltage stability manner.***

installation location	Capacity
2	200
14	70
8	80
30	60

Scattered production units are usually mounted on the end bus of the network. But in the previous case, the units were mostly installed in places that have the greatest impact on reducing losses.

The reduction of losses, in this case, is not considered a function of the target, but the losses are due to the reduction of power passing through the lines compared to the normal case.

The greatest reduction in throughput compared to the normal state has occurred in the initial line of the network. Therefore, the post load connecting the distribution network to the upstream network is also reduced. This is predictable because by installing the desired units, part of the load power is provided by them and the amount of power received from the upstream network is reduced. The voltage values of different network basses in different modes are shown in Figure (4). As can be seen in the ground state in many basses the voltage has exceeded the range of nominal values. By installing distributed generation and STATCOM, the amount of power passing through the network lines is reduced and as a result, the voltage drop across the line resistance is also reduced. This has a significant effect on the voltage of the network buses, especially the end buses, which are all in the range of nominal values. According to this figure, the voltage droop reduction performance in the second mode, especially in the end bars, is better than the first and fourth modes, due to the fact that more attention is paid to the target function of the voltage droop.

4. CONCLUSION

The location and determination of the optimal capacity of dispersed products and STATCOM devices are investigated in this paper. A comprehensive multi-objective model with economic, technical and reliability approach was considered. In the economic objective function, the reduction of installation cost by considering the equipment life, in the technical objective function, the reduction of losses and reduction of network voltage droop, and in the reliability objective function, the reduction of unsupplied energy is considered. Genetic algorithm has been used to solve the optimization problem. The simulation results showed that the optimal installation of distributed generation and STATCOM, in addition to reducing the annual energy lost, significantly reduces the amount of voltage droop and network losses. Under basic conditions, the mains voltage droop, especially at the end busbars, is out of range and then this problem is solved with optimal placement without the need for network expansion.

REFERENCES

[1] E. Hosseini, N. Behzadfar, M. Hashemi, M. Moazzami, M. Dehghani, “Control of pitch angle in wind turbine based on doubly fed induction generator using fuzzy logic method”, Journal of Renewable Energy and Environment, 2022, doi: 10.30501/jree.2021.293546.1226.

[2] A. Ahmadpour, S. Seyed Shenava, A. Dejamkhooy, E. Mokaramian, “Electromagnetic force analysis of transformer on the ferroresonance due to consecutive 3–phase short–circuit

faults using finite element method (FEM)", Journal of Intelligent Procedures in Electrical Technology, vol. 11, no. 41, pp. 47-60, June 2020, dor: 20.1001.1.23223871.1399.11.41.4.3.

[3] K. Sayahi, A. Kadri, F. Bacha, H. Marzougui, "Implementation of a D-STATCOM control strategy based on direct power control method for grid connected wind turbine", International Journal of Electrical Power and Energy Systems, vol. 121, Article Number: 106105, Oct. 2020, doi: 10.1016/j.ijepes.2020.106105.

[4] G. Shahgholian, K. Khani, M. Moazzami, "Frequency control in autanamous microgrid in the presence of DFIG based wind turbine", Journal of Intelligent Procedures in Electrical Technology, vol. 6, no. 23, pp. 3-12, December 2015, dor: 20.1001.1.23223871.1394.6.23.1.9.

[5] A. Khaledian, "High-reliability electric power generation system for aircraft based on generators smart droop control method", Journal of Intelligent Procedures in Electrical Technology, vol. 13, no. 52, pp. 19-32, March 2023.

[6] G. Shahgholian, S. Eshtehardiha, H. Mahdavi-Nasab and M. R. Yousefi, "A novel approach in automatic control based on the genetic algorithm in STATCOM for improvement power system transient stability", Proceeding of the IEEE/IS, pp. 14-19, 2008, doi: 10.1109/IS.2008.4670419.

[7] M. Borhani, S. Yaghoubi, "Improvement of energy dissipative particle dynamics method to increase accuracy", J Therm Anal Calorim, vol. 144, pp. 2543–2555, 2021, doi: 10.1007/s10973-020-10362-1.

[8] S. Hashemi Zadeh, O. Zeidabadi Nejad, S. Hasani, A. Gharaveisi, G. Shahgholian, "Optimal DG placement for power loss reduction and improvement voltage profile using smart methods", International Journal of Smart Electrical Engineering, vol. 1, no. 3, pp. 141-147, 2012.

[9] R. Borjali-Navesi, D. Nazarpour-Akbari, R. Ghanizadeh, P. Alemi, "Switchable capacitor bank coordination and dynamic network reconfiguration for improving operation of distribution network integrated with renewable energy resources", Journal of Intelligent Procedures in Electrical Technology, vol. 12, no. 48, pp. 43-59, March 2022.

[10] H. Fayazi, B. Fani, M. Moazzami, G. Shahgholian, "An offline three-level protection coordination scheme for distribution systems considering transient stability of synchronous distributed generation", International Journal of Electrical Power and Energy Systems, vol. 131, Article Number: 107069, Oct. 2021, doi: 10.1016/j.ijep-es.2021.107069.

[11] E.A. Mahdiraji, N. Ramezani, "Optimal in Smart Grids Considering Interruptible Loads and Photo-voltaic Sources Using Genetic Optimization", Signal Processing and Renewable Energy, vol. 4, no. 1, pp. 37-50, 2020.

[12] M. Salari, F. Haghighatdar-Fesharaki, "Optimal placement and sizing of distributed generations and capacitors

for reliability improvement and power loss minimization in distribution networks", Journal of Intelligent Procedures in Electrical Technology, vol. 11, no. 43, pp. 83-94, December 2020.

[13] S. Farhang, S. Zanjani, B. Fani, "Analysis and simulation of inverter-based microgrid droop control method in island operation mode", Signal Processing and Renewable Energy, vol. 6, no. 1, pp. 65-81, 2022.

[14] M. Alilou, S. Sadi, S. Zamanian, J. Gholami, S. Moshari, "Improving the efficiency of actual distribution system by allocating multi-DG and DSTATCOM", Journal of Intelligent Procedures in Electrical Technology, vol. 12, no. 45, pp. 1-15, June 2021.

[15] M. H. Saeed, W. Fangzong, B. A. Kalwar and S. Iqbal, "A review on microgrids' challenges & perspectives," IEEE Access, vol. 9, pp. 166502-166517, 2021, doi: 10.1109/ACCESS.2021.3135083.

[16] E. Hosseini, G. Shahgholian, "Output power levelling for DFIG wind turbine system using intelligent pitch angle control", Automatika, Vol. 58, No. 4, pp. 363-374, 2017, doi: 10.1080/00051144.2018.1455017.

[17] M. Zhang et al., "Cooperative operation of DG inverters and a RIHAF for power quality improvement in an integrated transformer-structured grid-connected microgrid," IEEE Trans. on Industry Applications, vol. 55, no. 2, pp. 1157-1170, March-April 2019, doi: 10.1109/TIA.2018.2882504.

[18] G. Shahgholian, "A brief review on microgrids: Operation, applications, modeling, and control", International Transactions on Electrical Energy Systems, vol. 31, no. 6, Artiacl Number. e12885, June 2021, doi: 10.1002/2050-7038.12885.

[19] A. Seif, "Determining the optimal location and amount of distributed generation sources in an unbalanced radial distribution grid", International Journal of Smart Electrical Engineering, vol. 9, no. 1, pp. 41-46, 2020.

[20] A. Shaheen, A. Elsayed, A. Ginidi, R. El-Sehiemy, E. Elattar, "Reconfiguration of electrical distribution network-based DG and capacitors allocations using artificial ecosystem optimizer: Practical case study", Alexandria Engineering Journal, vol. 61, no. 8, pp. 6105-6118, 2022, doi: 10.1016/j.aej.2021.11.035.

[21] T. Yuvaraj, K. Ravi, "Multi-objective simultaneous DG and DSTATCOM allocation in radial distribution networks using cuckoo searching algorithm", Alexandria Engineering Journal, Vol. 57, no. 4, pp. 2729-2742, 2018, doi: 10.1016/j.aej.2018.01.001.

[22] G. Isha, P. Jagatheeswari, "Optimal allocation of DSTATCOM and PV array in distribution system employing fuzzy-lightning search algorithm", Automatika, vol. 62, no. 3-4, 2021, doi: 10.1080/00051144.2021.1963080.

[23] A.S. Siddiqui, "Optimal location and sizing of conglomerate DG-FACTS using an artificial neural network and heuristic probability distribution

methodology for modern power system operations”, Protection and Control of Modern Power Systems, vol. **7,** Article number: 9, 2022, doi: 10.1186/s41601-022-00230-5.

[24] S. H. Dolatabadi, M. Ghorbanian, P. Siano and N. D. Hatziargyriou, "An enhanced IEEE 33 bus benchmark test system for distribution system studies," IEEE Trans. on Power Systems, vol. 36, no. 3, pp. 2565-2572, May 2021, doi: 10.1109/TPWRS.2020.3038030.

[25] Z. Liu, Q. Wu, S. S. Oren, S. Huang, R. Li and L. Cheng, "Distribution locational marginal pricing for optimal electric vehicle charging through chance constrained mixed-integer programming," IEEE Trans. on Smart Grid, vol. 9, no. 2, pp. 644-654, March 2018.