Harmonics and Reliability Analysis for Renewable Energy System using Optimization Technique

[1] Ankita Kumari. [2] Priyanka Kumari, [3] Jagdish Koli, [4] Madhu Upadhayay

Dept. of Electrical Engineering NRI Inst. of Research & Tech. Bhopal, India

ankita.sevda69@gmail.com apriyankakumari98727@gmail.com Jagdishkoli47@gmail.com Madyant44@gmail.com

Abstract: This paper presents an approach to the PSO for the optimal allocation of DGs. To improve the voltage profile and to mitigate harmonics, an Objective Function (OF) has been implemented. This OF might also decreases reactive and active power losses. The optimization process involves load flow calculations for the Distribution system and computer simulations performed using MATLAB-DigSILENT to analyze the impact of DG. The IEEE 69 bus DN is executed in this work to incorporate DG. DG effects are investigated for harmonics under with-DG and without-DG conditions. The system performance outcomes have been improved, such as reactive power, active power, and voltage profiles and mitigate harmonics. Thus, the suggested approach produces superior effects using the presented method.

Keywords: Particle Swarm Optimization (PSO), Distribution Network (RDN), Distributed Generation (DG).

1. Introduction:

The presented research [1] explores the use of D-STATCOM for harmonic mitigation in low voltage distribution networks with high penetration of nonlinear loads. Their work provides insights into the application of dynamic reactive power compensation to mitigate harmonic distortions, thereby improving the overall power quality in distribution networks. [2] investigate harmonic emissions from three-phase diode rectifiers in distribution networks. The study contributes to understanding the impact of these rectifiers on harmonic content, addressing challenges related to the integration of nonlinear loads into power distribution systems. [3] Propose a high-impedance arc fault detection method based on harmonic randomness and waveform distortion in the distribution system. This work focuses on improving the reliability of distribution networks by detecting and addressing high-impedance arc faults through harmonic analysis. [4] provide a comprehensive review of challenges and perspectives related to micro grids. The study discusses the role of micro grids in the context of power distribution, offering insights into the challenges and potential solutions for integrating these decentralized energy systems into distribution networks.

In[5] propose a novel reliability index-based approach for electric vehicle (EV) charging station allocation in distribution systems. Their research addresses the challenges associated with the integration of EV charging stations, providing a methodology for optimal station allocation to enhance the reliability of the distribution network. [6] analyze the impact of varying photovoltaic (PV) penetration levels on the harmonic content of active distribution systems. The study explores the harmonic distortions introduced by grid-integrated solar farms, contributing insights into the challenges and considerations for managing harmonics in the presence of renewable energy sources. [7] present a harmonic transform-based non-parametric density estimation method for forward uncertainty propagation and reliability analysis. Their work introduces an innovative approach to assessing reliability in power distribution systems, considering uncertainties, and providing a tool for effective risk management. [8] focus on probabilistic harmonic forecasting of the distribution system, considering time-varying uncertainties of distributed energy resources and electrical loads. This research contributes to forecasting methodologies that account for dynamic uncertainties, enhancing the ability to predict and manage harmonic content in distribution networks.

The paper [9] concludes by emphasizing the significance of the integrated approach, highlighting its potential to enhance the automation of distribution systems. Future research directions may include further refinement of the algorithm, validation through practical implementations, and exploration of broader applications in power network optimization. The paper [10] concludes by emphasizing the importance of the developed heap-based optimizer for DG allocation in reconfigured radial feeder distribution systems. Future research directions may include further refinement of the optimization algorithm, validation through practical applications, and exploration of its adaptability to different network configurations.

[11] investigates the short circuit analysis of power distribution networks incorporating distributed generations. The study emphasizes the importance of understanding the impact of distributed generations on the short-circuit characteristics of the network. The findings provide valuable insights into the challenges and considerations for ensuring the stability and reliability of power distribution networks in the presence of distributed energy sources. Paper [12] addresses the issue of harmonic pollution in distribution networks through reconfiguration. Their work introduces a modified discrete particle swarm optimization method with a smart radial approach to optimize network configuration. This research contributes to the field by proposing a novel technique to mitigate the effects of harmonics, presenting a promising avenue for enhancing power distribution systems' overall performance and quality. Contributions by [13] assessing the reliability of electrical equipment in the presence of higher current and voltage harmonics. The study offers a comprehensive evaluation of the impact of harmonics on equipment reliability. This research is crucial for designing resilient systems capable of withstanding harmonic-related challenges and ensuring the continued functionality of electrical equipment. Work in

[14] explores the impact of electric vehicle (EV) charging stations on the reliability of distribution networks. Considering the increasing integration of EVs into the power grid, their research addresses the challenges and opportunities associated with the proliferation of charging stations. The findings contribute to understanding the dynamics of network reliability and suggest enhancements needed to accommodate the growing demand for electric transportation.

$$EPLOSS = \frac{with\ DG\ Loss}{without\ DG\ Loaa} = \frac{P}{P0} \qquad (1)$$

$$EQLOSS = \frac{with\ DG\ Loss}{without\ DG\ Loaa} = \frac{Q}{Q0} \qquad (2)$$

$$EV == \frac{del\ v}{Vr} \qquad (3)$$

B. Optimization Technique

[15] focus on the reliability analysis of distribution networks with distributed power supply. Their study explores the impact of distributed power generation on the reliability of the distribution network. The findings contribute valuable insights into the challenges and considerations for ensuring the robustness and dependability of power distribution systems incorporating distributed energy sources.[16] address the optimal mitigation of harmonics in distribution systems with inverter-based distributed generation. The research presents strategies to minimize harmonic distortions introduced by distributed generation, offering practical solutions to enhance the quality and performance of power distribution systems. In summary, these research works contribute to advancing the understanding of power distribution network analysis and optimization. They address various aspects, including distributed generations, harmonic pollution, reliability assessment, and the impact of emerging technologies like electric vehicles, providing a comprehensive overview of the current state of research in this critical domain.

These selected works collectively contribute to the evolving landscape of power distribution network analysis and optimization. They address a range of challenges, from distributed generation and harmonic mitigation to the integration of new technologies, providing valuable insights for researchers, engineers, and practitioners in the field. These papers collectively address vital topics in power distribution systems, including reliability assessment, advanced learning algorithms for reliability analysis, optimization, fault detection, and location in DN incorporating distributed generation and micro grids

2. Proposed Methodology

A. Formulation of Primary Optimization Function (POF)

This section presents the enhanced Primary Optimization Function (POF), which comprises many system performance factors. This POF is used with the PSO approach for the suggested work. PSO is a heuristic optimization algorithm inspired by the collective behavior of social organisms, particularly birds and fish. Introduced as a population-based optimization technique, PSO simulates the collaborative movement of particles through a multidimensional search space.

Particle Representation: PSO employs a population of potential solutions represented as particles. Each particle's position in the search space corresponds to a possible solution to the optimization problem.

Fitness Evaluation: The performance of each particle is assessed using a fitness function that measures its efficacy in solving the given optimization problem. The objective is typically to minimize or maximize this function. Position and Velocity Update: Particle movement is dynamic, with each particle adjusting its position and velocity based on its own historical best-known work and the best-known parts of its neighbors within the swarm.

Global and Local Best Positions: Every particle maintains a record of its best-known position and the best-known position within the entire swarm. These records guide the exploration of the search space.

Inertia Weight: The inertia weight parameter regulates the balance between exploration and exploitation during the optimization process. It influences how particles move through the search space.

PSO finds applications in various domains, including engineering design, data clustering, image processing, and machine learning. Its versatility and efficiency make it a popular choice for addressing complex, non-linear optimization challenges. Particle Swarm Optimization (PSO) is a nature- inspired optimization algorithm that draws inspiration from the collective behavior of bird flocks or fish schools. In PSO, a population of particles represents potential solutions to a problem, and these particles iteratively adjust their positions in the solution space based on their own experiences and the experiences of their neighbors. Each particle is influenced by its own historical best position and the global best position found

$$POF = b \times IP\ b \times IV\ b \times IQ \qquad (4)$$

The weight factors b1, b2, and b3, with relative values of 0.40, 0.30, and 0.30, indicate the amount of weight assigned to each variable system index based on priority [18].

The evaluations of the real and reactive loss with voltage deviation are, respectively, EPLOSS and EQLOSS with EV Deviation. The algorithm is characterized by its simplicity and efficiency in finding optimal solutions in complex search spaces. PSO operates on the principle of collaboration, where particles communicate and share information to collectively navigate the search space. Through this iterative process, the swarm converges towards a solution that optimizes the given objective function

One of the key strengths of PSO lies in its ability to handle non-linear and non-convex optimization problems. Its adaptability and ease of implementation make it a popular choice for various optimization tasks in fields such as engineering, finance, and machine learning. However, the performance of PSO can be influenced by parameter settings and may exhibit sensitivity to the problem at hand.

It continues to explore enhancements and variations of PSO to address its limitations and improve its applicability to diverse problem domains. Overall, PSO stands as a versatile and powerful optimization technique, leveraging principles from nature to efficiently search solution spaces and find

optimal or near-optimal solutions across a range of applications. Overall, PSO's simplicity and effectiveness make it a valuable tool for tackling optimization problems, particularly those characterized by high dimensionality and non-linearity. PSO, each swarm within its designated search area adheres to defined inertia and velocity (V) parameters across successive iterations. In AC to DC converters injection of the harmonic current and voltage of the consumer into the network increases the system integer multiples of the fundamental frequency appear in the power system that is made because of saturation of the core, non-linear converter, and in some cases, modulated converters (band width converters) however non- integer harmonics (hidden harmonics) can be found in the network in some condition. In a symmetrical network, even harmonics cannot be seen.

3. Result Discussions

The objectives of the topic "Optimization of Surface Two scenarios have been examined to ascertain the optimum arrangement and sizing of distributed generation for a specified load.

Case I: Without DG (Base Case) Case II: With DG

To evaluate the analysis of this approach, the study includes two case analyses. It uses the Dig Silent Power Factory an PSO methodologies to assess its effectiveness on an IEEE 69 bus distribution system. For case 1, various reliability parameters such as ASUI. The most recent Local Best position (ZL Best) of the swarm and the aggregate Global Best positions (ZG Best) in its vicinity are used to modify the movement's direction and speed. This trait directs the multitude toward areas of the search space that may provide fruit. PSO follows every person's every step throughout the search region, following a predetermined speed that is constantly adjusted depending on peer and local movement experiences [5]. The particle population is randomly given places during the initiation phase, and updates after that are dependent on both the best local knowledge and the best experience nearby. Newly computed velocities are essential in establishing the updated positions of the population at each iteration (m), as shown in (6).

C. Harmonics Analysis

Voltage and current surges in power systems usually deviate from the ideal sinusoidal wave. This perturbation or deviation from a pure sine wave can be made because of transformer core saturation or devices such as thyristor controllers and especially voltage disturbances. Usually, only the harmonics with the 0.02, ASAI as 0.97, ACCI as 10.81, AENS as 16.67, ASIFI as 70.17, SAIFI as 63.86, CAIFI as 63.86, ASIDI as 210.53, SAIDI as 191.59, ENS as 800.26 shown in Table-I . Total PLOSS is 0.23 MW, QLOSS is 0.10 MVAR, PG is 4.03 MW, and QG is 2.85 MVAR, as shown in Table II and graphical representation shows in Fig.2 and Fig.3, Moreover, the voltage profiles for all 69 buses were analysed (Fig.3), were conducted.

In Case 2, three DG units were optimally placed at buses 36th, 48th, and 61st of the IEEE 69 bus DN. I. The reliability parameters for Case 2 conclude ASUI as 0.015 ASAI as 0.71, ACCI as 6.86, AENS as 10.63, ASIFI as

43.98, SAIFI as 39.99, CAIFI as 39.99, ASIDI as 135.64, SAIDI as119.80, ENS as 600.40 are shown in Table-, PLOSS as 0.02 MW, QLOSS as 0.015 MVAR, PG as -2.62 MW, as 1.80 MVAR, PGEN 6.84 MW, QGEN 1.2 MVAR are shown in Table-II. The optimal placement of DG units significantly improved the system's reliability and reduced power losses.

TABLE I. RELIABILITY ANALYSIS

PARAMETERS	WITHOUT DG	WITH DG
ASUI	0.02	0.015
ASAI	0.97	0.71
ACCI	10.81	6.86
AENS	16.67	10.63
ASIFI	70.17	43.98
SAIFI	63.86	39.99
CAIFI	63.86	39.99
ASIDI	210.53	135.64
SAIDI	191.59	129.80
ENS	800.26	600.40

TABLE II. LOAD FLOW

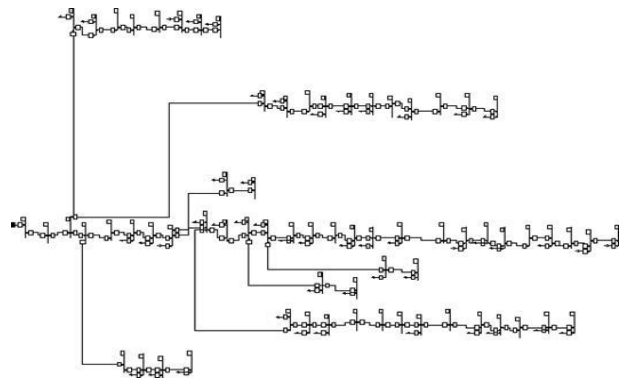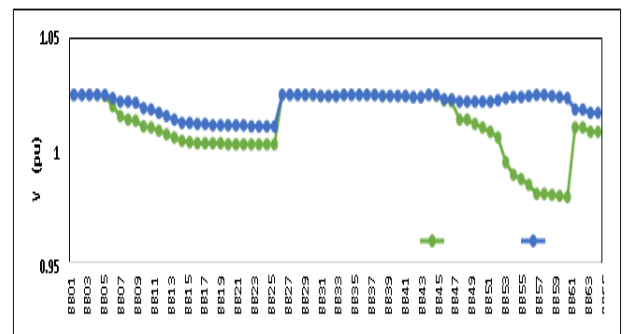| CASe	Total Power Losses		Grid Power		DG Generation	
	P LOSS (MW)	Q LOSS (MVAr)	PG (MW)	QG (MVAr)	PGEN (MW)	QGEN (MVAr)
1	0.23	0.10	4.03	2.85	-	-
2	0.02	0.015	-2.62	1.80	6.84	1.2

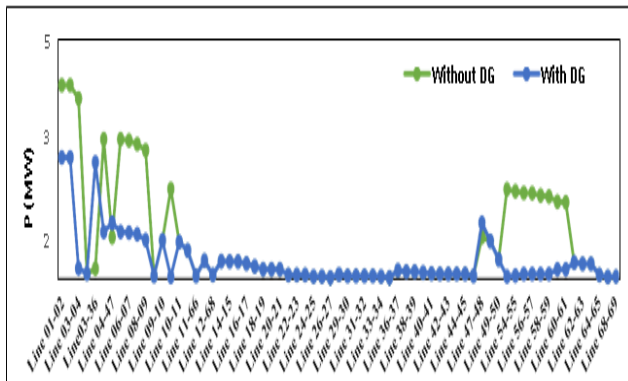Fig. 1. IEEE 69 Bus

Fig. 2. Voltage Profile
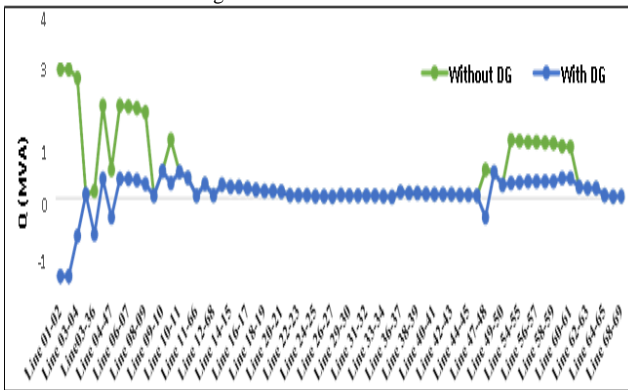
Fig. 3. Active Power Profile

Fig. 4. Reactive Power Profile

4, Conclusions:

Using the Dig Silent and the PSO approach, this paper presents optimal placement and sizing strategies for DGs within a realistic distribution system. Two scenarios, one with DGs and one without, were thoroughly investigated. In the context of a 33-bus RDS, DGs were strategically placed at bus numbers 36th, 48th, and 61th to minimize PLOSS and QLOSS while improving the voltage profile.

Through the application of optimization techniques and a comprehensive analysis of all scenarios, the most favourable outcome was identified in case II, where all three DGs were simultaneously located at the specified buses.

Results from case 2 indicate substantial improvements in computation, convergence, techno-economic benefits, and significant reductions in PLOSS (85.23%) and QLOSS (76.85%). This research suggests potential extensions, such as identifying optimal charging stations for electric vehicles and further modifications to the DSTATCOM renewable Wind-DG system

References:

[1] Rohouma, W., Balog, R. S., Peerzada, A. A., & Begovic, M. M. (2020). D-STATCOM for harmonic mitigation in low voltage distribution network with high penetration of nonlinear loads. Renewable energy, 145, 1449-1464. Zare, F., Soltani, H., Kumar, D., Davari, P., Delpino, H. A. M., & Blaabjerg, F. (2017). Harmonic emissions of three-phase diode rectifiers in distribution networks. Ieee Access, 5, 2819-2833.

[2] Wei, Mingjie, Fang Shi, Hengxu Zhang, Zongshuai Jin, Vladimir Terzija, Jian Zhou, and Hailong Bao. "High impedance arc fault detection based on the harmonic randomness and waveform distortion in the distribution system." IEEE Transactions on Power Delivery 35, no.2 (2019): 837-850.

[3] Saeed, Muhammad Hammad, Wang Fangzong, Basheer Ahmed Kalwar, and Sajid Iqbal. "A review on microgrids' challenges & perspectives." IEEE Access 9 (2021): 166502-166517.

[4] Archana, A. N., and T. Rajeev. "A novel reliability index based approach for EV charging station allocation in distribution system." IEEE Transactions on Industry Applications 57, no. 6 (2021): 6385-6394.

[5] Khan, Hannan Ahmad, Mohd Zuhaib, and Mohd Rihan. "Analysis of varying PV penetration level on harmonic content of active distribution system with a utility-scale grid integrated solar farm." Australian Journal of Electrical and Electronics Engineering 19, no. 3 (2022): 283-293.

[6] Xu, Jun, and Quanfu Yu. "Harmonic transform-based non-parametric density estimation method for forward uncertainty propagation and reliability analysis." Structural Safety 103 (2023): 102331.

[7] Li, Yahui, Yuanyuan Sun, Qingyan Wang, Kaiqi Sun, Ke-Jun Li, and Yan Zhang. "Probabilistic harmonic forecasting of the distribution system considering time-varying uncertainties of the distributed energy resources and electrical loads." Applied Energy 329 (2023): 120298.

[8] Shaheen, A.M.; Elsayed, A.M.; Ginidi, A.R.; Elattar, E.E.; El-Sehiemy,

[9] R.A. Effective Automation of Distribution Systems With Joint Integration of DGs/SVCs Considering Reconfiguration Capability by Jellyfish Search Algorithm. IEEE Access 2021, 9, 92053–92069

[10] Shaheen, A.M.; Elsayed, A.M.; Ginidi, A.R.; El-Sehiemy, R.A.; Elattar,

[11] E.E. Improved Heap-Based Optimizer for DG Allocation in Reconfigured Radial Feeder Distribution Systems. IEEE Syst. J. 2022, 10, 1–10

[12] El-Hassanin, Doaa, Sahar Kaddah, and Magdi El-Saadawi. "Short Circuit Analysis of Power Distribution Network Including Distributed Generations." Port-Said Engineering Research Journal 17, no. 1 (2013): 122-130.

[13] Rahimipour Behbahani, Milad, and Alireza Jalilian. "Reconfiguration of harmonic polluted distribution network using modified discrete particle swarm optimization equipped with smart radial method." IET Generation, Transmission & Distribution (2023), 17:2563–2575

[14] Sultanov, M. M., E. G. Zenina, V. G. Kul'Kov, A. V. Strizhichenko, and O. I. Zhelyaskova. "Assessment of the reliability of electrical equipment in the presence of higher current and voltage harmonics." Russian Electrical Engineering

93, no. 1 (2022): 53-58.

[15] Deb, Sanchari, Karuna Kalita, and Pinakeshwar Mahanta. "Impact of electric vehicle charging stations on reliability of distribution network." 2017 International Conference on Technological Advancements in Power and Energy (TAP Energy). IEEE, 2017.

[16] Li, Shenghui, Xue Bai, Xiaotong Zhang, Cailian Gu, and Zixuan Chen. "Reliability analysis of distribution network with distributed power supply." In Journal of Physics: Conference Series, vol. 1518, no. 1, p. 012010. IOP Publishing, 2020.

[17] Abbas, Ahmed S., Ragab A. El-Sehiemy, Adel Abou El-Ela, Eman Salah Ali, Karar Mahmoud, Matti Lehtonen, and Mohamed MF Darwish. "Optimal harmonic mitigation in distribution systems with inverter based distributed generation." Applied Sciences 11, no. 2 (2021): 774.