IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, February 2024

Harmonics and Short Circuit Analysis with Multiple DG Units

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Abstract: *This paper introduces a novel approach employing Particle Swarm Optimization (PSO) for the optimal allocation of Distributed Generators (DG) in distribution networks (DN). The primary objectives include reducing harmonics and conducting short circuit analysis, studying the impact of DG on enhancing the voltage profile and overall system reliability and minimizing both active and reactive power losses. The optimization process incorporates an objective function (OF) guiding load flow calculations for the DNMATLAB-DIgSILENT simulations performed on an IEEE 33 bus DN to assess the effects of DG. Investigations into harmonics and short circuits are conducted under both with-DG and without-DG conditions, revealing noteworthy enhancements in system performance metrics, such as voltage profile and harmonics, validating the effectiveness of the proposed PSO-based method. In this study, PSO methods are deployed to address network challenges arising from installing multiple DGs of different types. Comparative analyses between PSO methodologies with and without DG underscore the improved outcomes of the proposed approach. Application of the suggested method to the IEEE 33 bus system demonstrates substantial reductions in harmonics, enhancements in voltage profile, and significant decreases in active and reactive power losses..*

Keywords: Particle Swarm Optimizer (PSO),Radial Distribution System (RDS), Optimal Power Flow (OPS), Distribution Network (DN), Distributed Generator (DG)

I. INTRODUCTION

Distributed generation is becoming increasingly important due to its potential to enhance the efficiency and reliability of distribution systems [1]. H. Patel et al. focus on determining the optimal locations for installing DG units in the distribution network [2]. The reference is a valuable source for understanding distributed generation modelling within the building sector. Distributed generation, particularly in the context of buildings, has gained significant attention due to its potential for sustainable energy generation.[3] presented work Currently, available techniques for power system harmonic estimation are numerous. Because of its simplicity, the FFT has been used extensively for harmonic estimates since the 20th century presented in[4]. Comparably, over the same period, DFT gained popularity for harmonic estimates in PS, as has been well-documented in [5][6][7][8]. Nevertheless, these Fourier transform-based methods cannot guarantee optimal performance in the presence of many sounds due to specific leakage, aliasing, and picket fence effects while being simple to mimic. [9–10, 11–12, 13]. Furthermore, because the definitions of harmonic and transient waves differ, FFT is inappropriate for estimating transients, which are brief, abrupt deviations from the conventional sine wave.

To address these drawbacks, various modified versions of Fourier transform techniques have been proposed [14][15]. Notwithstanding their usefulness, these approaches can no longer satisfy utilities' increasing expectations for dynamic tracking of harmonic precision due to the quick development of power systems. The two main categories of harmonic estimating techniques in signal processing for power systems are parametric and non-parametric. [16]. Frequency identification has been a primary focus for accurate spectral analysis [17] [16].

DOI: 10.48175/568

II. SYSTEM MODELLING AND METHODOLOGY

A. Distributed Generator

This includes a formulation of the problem. Reducing power loss dependent on DG size and seating is the challenge. Two case studies will be used as examples to minimize losses as much as possible. In addition to lowering actual P_L, using real power loss as an objective function will reduce reactive power losses and enhance the system's voltage profile. PSO approach should be used to tackle this issue.

The formula is used to determine all losses on the line segment joining buses iand(i + 1).

$$Losses = \frac{|V_i - V_{i+1}|^2}{R_i - j\,X_i} \qquad (1)$$

$$P_{Loss(i,i+1)} = Real|Losses| \qquad (2)$$

$$Q_{Loss(i,i+1)} = Imag|Losses| \qquad (3)$$

Where,

V_i is the voltage on bus i.,R_i is the resistance of the line segment between busses i and i + 1. X_i is the reactance of the line segment between busses i and i + 1.

$P_{Loss(i,i+1)}$ is the true power loss from bus i to bus i + 1.

$Q_{Loss(i,i+1)}$ is the reactive power loss from bus i to i + 1.

1. Constraints

following are the issue inequality constraints: 1) The voltage on each bus should be kept within certain limits:

$$V_{min} \le |Vi| \le V_{max} (4)$$

Where V_{max} denotes the maximum bus voltage. The minimum bus voltage is $V_{min.}$

2) Each line's current should be kept within certain limits:

$$|Ii,i+1| \le |Ii_{,i+1,max}| \qquad (5)$$

Where$Ii_{,i+1}$represents the current in the line segment between buses i and i+1. The current maximum limit of the line connecting buses i and i+1 is$I_{i,i+1\max}$.

3) The total produced power at each bus should be less than the entire load plus total losses:

$$\sum_{i=1}^{n} P_{Di} \le \sum_{i=1}^{n} (P_i + P_{Loss(i,i+1)}) \qquad (6)$$

B. OPTIMIZATION TECHNIQUES

Optimization approaches, namely PSO DG sizing, and DG siting problems, all tackled concurrently. This approach mitigates the drawbacks associated with employing sensitivity analysis for determining the optimal DG unit placement and underscores the benefits of addressing this challenge simultaneously. Mathematical Model of PSO

$$\boxed{v_i^{t+1} = \underbrace{v_i^t}_{\text{Inertia}} + \underbrace{c_1 r_1 (pbest_i^t - p_i^t)}_{\text{Personal influence}} + \underbrace{c_2 r_2 (gbest^t - p_i^t)}_{\text{Social influence}}} \qquad (7)$$

The variables 'k','s_1', and's_2' indicate the weighting factors, 'r_1' and 'r_2' are random values between 0 and 1, and 'W' stands for the weighting function in this formula. The velocity of particle 'i' at iteration 'k' is represented by 'V_i' (k), while the updated velocity of particle 'i' is indicated by 'V_i' (k + 1). The particle 'i' position at iteration 'k' is shown by 'Yi' (k), while the revised position of particle 'i' is indicated by 'Y_i' (k + 1). For particle 'i', 'Pi' (k) denotes the particle that is personally best; 'G' (k) denotes the particle that is globally best.

C. HARMONICS ANALYSIS

Harmonics refer to sinusoidal voltages or currents characterized by frequencies that are integer multiples of the fundamental frequency at which the supply system is intended to operate.Harmonic distortion refers to the occurrence of harmonics in power systems due to the presence of nonlinear devices within the distribution system. A nonlinear device is characterized by a current that is not directly proportional to the supplied voltage.

Harmonic distortion can be expressed as a Fourier series due to its characteristics of periodic distortion, which is given by

$$x(t) = a_0 + \sum [a_n \cos(n\omega t) + b_n \sin(n\omega t)] \quad (8)$$

$$a_0 = \frac{1}{2\pi} \int_{-\pi}^{\pi} f(x)\omega t \; d\omega t \quad (9)$$

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x)\omega t \cos(n\omega t) \; d\omega t \quad (10)$$

$$b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x)\omega t \sin(n\omega t) \; d\omega t \quad (11)$$

D. SHORT CIRCUIT ANALYSIS

The repercussions of a short circuit can be severe, contingent on the system's capability to sustain short circuit current and the duration it persists. At the point of the short circuit, local consequences may include electrical arcs causing insulation damage, conductor welding, and fire. Electrodynamic forces on the faulty circuit can result in bus bar and cable deformation, while excessive temperature rise may harm insulation. Short-circuit events also affect other circuits within the network or nearby networks. Voltage drops occur in neighboring networks during short circuits, and network segments may shut down, impacting even "healthy" portions depending on the overall network design.

III. RESULT AND DISCUSSION

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

The study encompasses two case analyses to assess this approach's analysis. It employs the PSO and DIgSILENT Power Factory techniques to evaluate its performance on an IEEE 33 bus distribution system. TheActive Power loss is 0.21 MW, and the Reactive Power loss is 0.14 MVAr,The Grid active power is 3.92 MW, and the Grid Reactive power is 2.44 MVAr,as shown in Table 1, respectively. The graphical Representation ofthe Active Power profile, Reactive power profile,voltage profile, for both cases, are shown in Fig 4,Fig 5, Fig6respectively.

The three DG are best arranged at buses 16th, 24th, and 30th of IEEE 33 bus DN in the second scenario that is being suggested. Once these DG are installed. Real power is 0.1 MW, reactive power loss is 0.1 MVAr,Gridactive power is 0.85MW, and Grid Reactive power is 0.53MVArDG active power Generation is 2.88 MW and reactive power Generation is 1.78MVar from Table I, Active Power Loss, Reactive Power Loss which are reduced by 95.23%, 92.85%, respectively

IEEE 33-Bus Test SystemThe optimal configuration and sizing of distributed generation for a specified load were investigated under two scenarios:

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

The study employed the DIgSILENT Power Factory and Particle Swarm Optimization (PSO) methodologies to assess the effectiveness of the proposed approach on an IEEE 33 bus distribution system. The graphical representations in Fig. 1 depict the Total Harmonic Distortion (THD %) with and without DG, as well as the % HRV with and without DG (Fig. 2), Frequency Deviation with and without DG (Fig.3).

TABLE 1 Load Flow Calculations For Ieee 33

Case	Total Power Losses		Grid Power		DG Generation	
	P_{LOSS}(Mw)	Q_{LOSS} (Mvar)	P(Mw)	Q(Mvar)	P(Mw)	Q(Mvar)
1	0.21	0.14	3.92	2.44	-	-
2	0.01	0.01	0.85	0.53	2.88	1.78

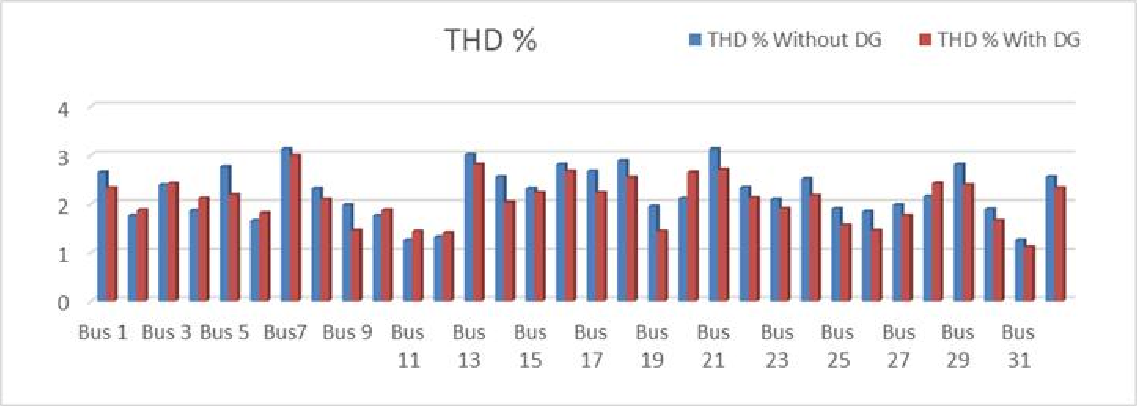

Fig. 1 THD %

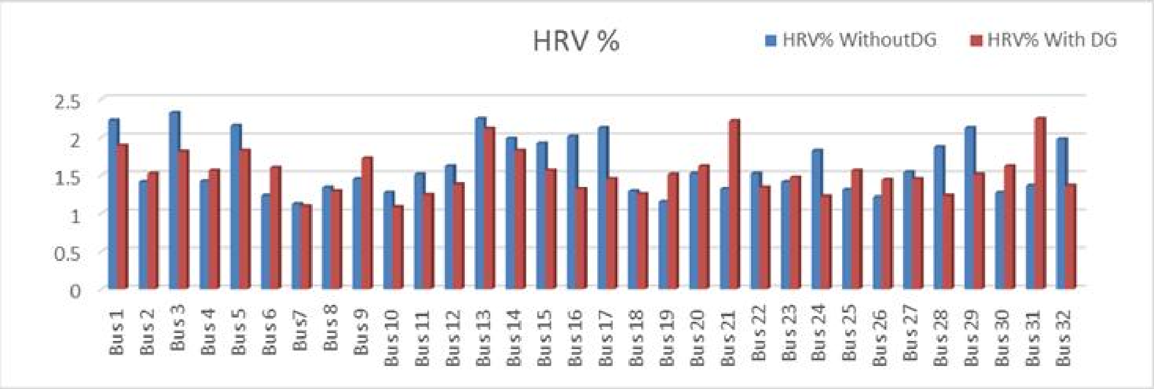

Fig. 2 HRV %

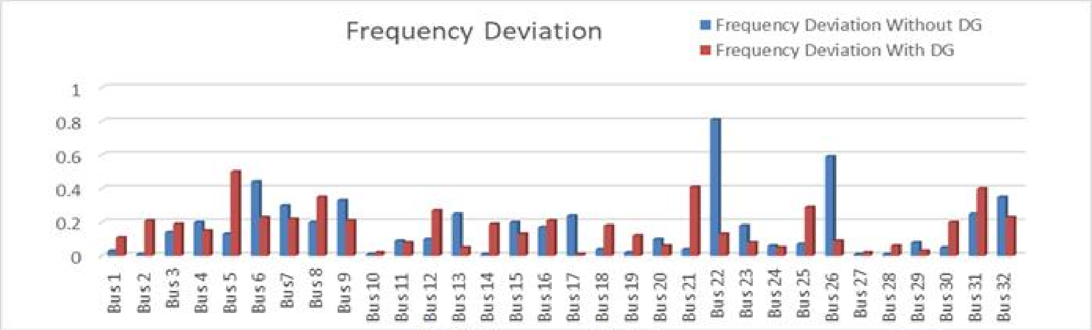

Fig.3 Frequency Deviation

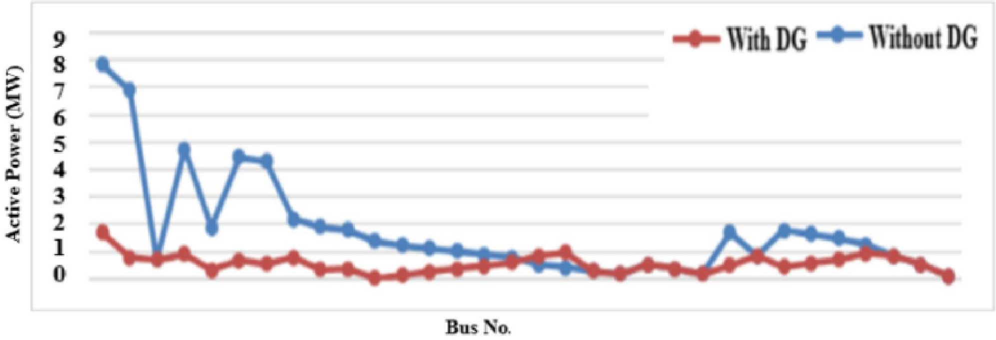

Fig. 4 Active Power

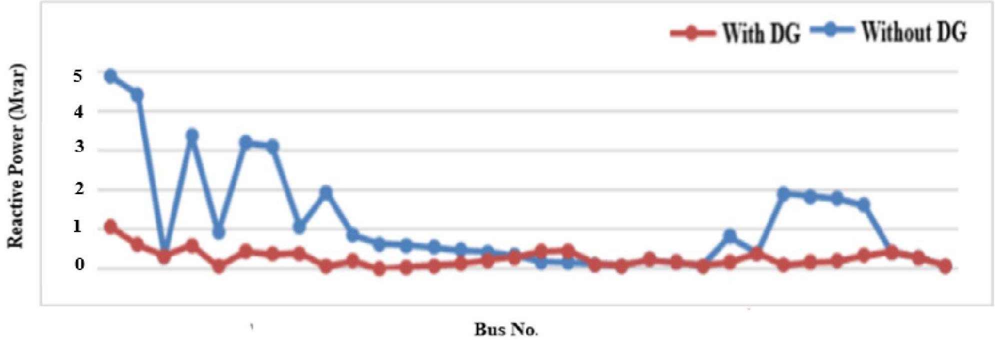

Fig.5 Reactive Power

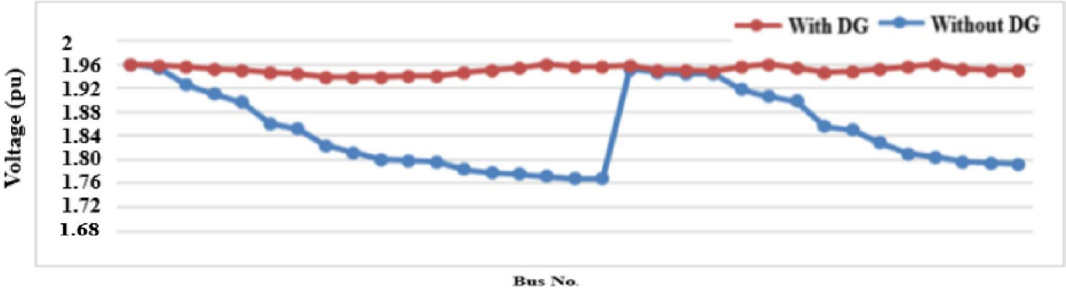

Fig. 6 Voltage Profile in IEEE 33 Bus

IV. CONCLUSION

This research focuses on developing an observer for harmonic analysis in power distribution networks. Implementing an iterative observer has proven successful in accurately estimating and identifying harmonic injections within a power distribution network. The obtained estimation results exhibit a high level of accuracy when compared to the actual values. Additionally, the research investigates harmonic estimation in a real-time environment and explores various short-circuit parameters with and without Distributed Generation (DG).

Utilizing the DIgSILENT software and the Particle Swarm Optimization (PSO) approach, this thesis introduces optimal placement and sizing strategies for DGs within a practical distribution system. The study thoroughly examines two scenarios: one incorporating DGs and another without DGs. In the case of a 33-bus Radial Distribution System (RDS), DGs were strategically placed at bus numbers 16th,24thand 30th to minimize power loss (P_{LOSS}) and reactive power loss (Q_{Loss}) while enhancing the voltage profile. By employing optimization techniques and conducting a comprehensive analysis of all scenarios, the most favourable outcome is identified in case II, where all three DGs are concurrently located at the specified buses. Results from case II demonstrate significant improvements in computational efficiency, convergence, techno-economic benefits, and substantial reductions in PLOSS (95.23%) and QLOSS (92.85%).

Further research is essential to advance the development of the harmonic analysis method for power distribution networks. In the context of harmonic state estimation, potential areas for investigation include the incorporation of large-scale wind farms and Solar Photovoltaic systems as harmonic sources in the distribution network. Additionally, there is a need to estimate harmonics in physical systems to explore time delays in Hardware-in-the-Loop (HIL) setups. Modifying the observer gain to handle various types of time delays can be a crucial aspect of this research.

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