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An Implementation of Optimization Algorithms to 22-Bus Practical Radial Distribution System by Multi-objective Optimization Approach

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Abstract— ***This paper introduces an approach for the efficient positioning of distributed generators within a radial distribution system, incorporating load models into consideration. The effectiveness of the proposed algorithms was evaluated through application to 22-bus radial distribution systems, and a comprehensive comparison of the results from all algorithms was conducted. It was found that all algorithms showed improved performance and yielded better results. Distribution systems are experiencing heavy loads due to population growth, which increases the risk of overloading distribution feeders and causing sudden voltage collapse. Therefore, steady state voltage stability analysis is a valuable tool for assessing the loading capacity of distribution systems. The proposed methods for determining the best location for distributed generators have been tested on a practical radial distribution system in APEPDCL, India. The findings suggest that incorporating distributed generators (DG) enhances the voltage profile and mitigates power loss within the system. The study also illustrates the analysis of voltage stability, underscoring the substantial influence of DG placement on the system's capacity to uphold stable voltage levels. This capability empowers the distribution system to accommodate increased loads without necessitating the construction of new infrastructure. While all the proposed methods performed well in achieving the objective of multi-objective optimization, the computation time is shorter for the IMO method.***

Index Terms— ***DFIG, MPP Tracking, renewable energy, wind.***

I. INTRODUCTION

In the context of conventional load flow analysis, the impact of various distributed generation (DG) types on DG placement is assessed. Active and reactive power loads are classified as constant power, constant current or constant impedance loads. In constant power loads, both real and reactive power remains constant with voltage changes. Constant current loads maintain a consistent current as voltage varies, while constant impedance loads retain a constant impedance throughout voltage changes. Power loss is a primary concern for short feeders, while voltage stability holds significance for long feeders. While modeling all loads as constant current provides a reasonable approximation for many circuits, adopting a conservative approach for voltage profile analysis involves modeling all loads as constant power.

Practical voltage-dependent load models, applicable to industrial, residential, and commercial loads, are static models employed to represent diverse customer classes (IEEE Task Force, 1993). The voltage-dependent load model, characterized by a static representation, expresses the power-voltage relationship through an exponential equation, outlined as follows.

$$P_i = P_0(V_i) \tag{1}$$

$$Q_i = Q_0(V_i)^{\beta} \tag{2}$$

Where P0 and Q0 denote the nominal real and reactive powers at the operating point, and Pi and Qi represent the real and reactive power at bus i. The term Vi represents the bus voltage, and α, β are the load exponents, which vary based on the load type as outlined in Table 1. These exponents are derived from a reference cited in [8]. Equations (1) and (2) do not incorporate the frequency dependence of the load within the distribution system. This is because the load is a pan-system phenomenon that cannot be locally controlled and remains consistent throughout the entire system.

In practical scenarios, the load at each bus may encompass industrial, residential, and commercial components, exhibiting seasonal variations. Furthermore, the load may fluctuate between day and night within a specific season. Hence, a seasonal mixed load model is employed to characterize the load at each bus, as illustrated below.

$$P_i = w_{ipi}P_{0i}\left(\frac{V_i}{V_{0i}}\right)^{\alpha_i} + w_{rpi}P_{0i}\left(\frac{V_i}{V_{0i}}\right)^{\alpha_r} + w_{cpi}P_{0i}\left(\frac{V_i}{V_{0i}}\right)^{\alpha_c}$$

$$Q_i = w_{iqi}Q_{0i}\left(\frac{V_i}{V_{0i}}\right)^{\beta_i} + w_{rqi}Q_{0i}\left(\frac{V_i}{V_{0i}}\right)^{\beta_r} + w_{cqi}Q_{0i}\left(\frac{V_i}{V_{0i}}\right)^{\beta_c}$$

Let αi and βi denote the active and reactive exponents, respectively, for the industrial load model. Similarly, αr and βr represent the active and reactive exponents for the residential load model, while αc and βc stand for the active and reactive exponents for the commercial load model. The pertinent factors for the active industrial, residential, and commercial load models at bus i are designated as wipi, wrpi, and wcpi, respectively. Correspondingly, the relevant factors for the reactive industrial, residential, and commercial load models at bus i are denoted by $wiqi$, $wrqi$, and $wcqi$.

The following condition must be satisfied for all buses, except buses without load (BWL) and the slack bus.

$w_{ipi} + w_{rpi} + w_{cpi} = 1, for i = 1\ to NB, but i\ G\ BWL \quad (5)$

$w_{iqi} + w_{rqi} + w_{cqi} = 1, for i = 1\ to NB, but i\ G\ BWL \quad (6)$

The voltage exponents for the active and reactive components of the summer day, summer night, winter day, and winter night load models are detailed in Table 1, as documented by Qian et al. (2011). Hypothetical relevant factors for each load model at every bus are generated, with the assumption that wip is equal to wiq, wrp is equal to wrq, and wcp is equal to wcq.

In real-world scenarios, loads comprise a mix of various types depending on the supplied area. Consequently, it is imperative to examine a combination of residential, commercial, and industrial loans at each bus in the system. It is assumed that all loads are individual spot loads. The integration of distributed generators into distribution systems raises several pertinent issues that necessitate careful consideration.

Table 1. Load Type and Exponent Value

Load Type	Load Exponents	
	α	β
Constant power	0.0	0.0
Constant current	1.0	1.0
Constant impedance	2.0	2.0
Industrial	0.18	6.00
Residential	0.72	2.96
Commercial	1.25	3.50

A. Implementation of Optimization Approaches for Optimal Allocation of DGs in a Radial System with Various Load Models:-

In this segment, the GBMO, IMO, and LSA methodologies are applied to assess the optimal positioning of multiple distributed generators (DGs) within a 33-bus radial distribution system. The primary goal is to minimize real power loss and enhance the voltage profile. It is presumed that the system's structure and topology are constant, with full knowledge of all branches between the buses. The assessments of the objective function are contingent solely on the placement and magnitude of the DG. These algorithms are designed to optimize the location and size of DGs, addressing specific objectives within a radial distribution system, while accommodating various operational constraints.

B. Computational procedure for optimal placement of DGs using GBMO, IMO and LSA algorithms:

Step 1: Read the system data, algorithm parameters and constraint limits etc.

Sep 2: Generate initial solution randomly and calculate the objective function.

Step 3: Store the best solution so far that gives minimum value of objective function.

Step 4: Start evolution procedure for the new solution (Evolution procedure depends on optimization algorithm chosen).

Step 5: Please evaluate the objective function and compare the current solution with the previous best solution.

Sep 6: Repeat the steps 4 and 5 until the best solution reached (checking for stopping criterion).

Step 7: Print the results.

C. Assumptions for DG placement:

a) DG is considered as a subtractive load.
b) DG contributes both active and reactive power injections.
c) The DG's capacity should be either equal to or less than the total system load demand (with the limitation of 70% of the total losses considered in the investigations).
d) The DG is positioned at the node where the load is connected.
e) The source node is excluded as a potential location for DG placement. The modeling of real and reactive power loads incorporates voltage dependency.

II. RESULTS AND DISCUSSIONS

A. 22- Bus Practical Radial Distribution System

The 22-bus system discussed here is a segment of the radial distribution system managed by the Andhra Pradesh Eastern Power Distribution Company Limited (APEPDCL) in India. Operating at base values of 11 kV and 100 MVA [90], this system comprises 22 buses and 21 branches. The overall active power load in the system is 0.66231 MW, with a reactive power load of 0.65740 MVAR. In the absence of any compensation, the system incurs active power losses of 17.69 kW and reactive power losses of 8.06 kVAR. For detailed data regarding this practical 22-bus system.

B. Implementation of Optimization Algorithms to 22-Bus Practical Radial Distribution System by Multi-Objective Optimization Approach:-

In this section, the efficacy of previously proposed methodologies, namely LSA, IMO, and GBMO, was evaluated on a practical 22-bus radial distribution system. The judicious selection of control parameters plays a crucial role in the success and performance of these algorithms. The parameter selection for LSA, IMO, and GBMO aligns with the practices outlined in the preceding chapters. It is assumed that the maximum DG size falls within the range of 0-70% of the total load, with a constraint limiting the maximum number of DGs to three for this particular system. The study focuses on optimizing the location and size of Type-1 and Type-3 DGs with the objective of minimizing power loss.

The performance results, such as optimal locations, sizes, loss reduction, and computation time, are provided in Tables 2 and 3. From these tables, it is evident that the LSA algorithm has produced the best solution for the 22-bus system. The loss reduction achieved is 91.0678%, and the minimum bus voltage is 0.9978 p.u. when Type-3 DGs are placed. With Type-1 DGs, the loss reduction is similar for all algorithms, approximately 51.9%. Additionally, Figure 1 and Figure 3 demonstrate that the LSA algorithm has successfully achieved the objective with less iteration compared to other algorithms.

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Based on the results obtained, it is clear that the developed methods LSA, IMO, and GBMO can be applied to real-time systems. Among these methods, LSA has performed particularly well in achieving the desired objectives. Table 4 provides a detailed numerical analysis of real power line loss for the system under the IMO method. The values obtained from Table 4 closely match the original values of the system, demonstrating the effectiveness of the developed methods in meeting the predetermined objectives.

Table 2. Results for 22-bus system using Type – 1 DGs with LSA, IMO and GBMO algorithms

Method	Optimal Location	PDG	QDG	PLOSS WODG	PLOSS WDG	Percentage PLOSS Reduction	Vmin WODGp.u	Vmin WODGp.u	Comp Time (S)
		MW	MVar	kW	kW				
LSA	14	0.344	0.00	17.7215	8.509	51.9	0.972	0.990	6.43
	20	0.178	0.00						
IMO	20	0.183	0.00		8.530	51.8		0.990	4.81
	14	0.312	0.00						
GBMO	20	0.183	0.00		8.530	51.8		0.990	5.67
	14	0.312	0.00						

Table 3. Results for 22-bus system using Type – 3 DGs with LSA, IMO and GBMO algorithms

Method	Optimal Location	PDG	QDG	PLOSS WODG	PLOSS WDG	Percentage PLOSS Reduction	Vmin WODG p.u	Vmin WODGp.u	Comp Time (S)
		MW	MVar	kW	kW				
LSA	21	0.203	0.117	17.7215	1.582	91.0	0.972	0.997	6.90
	14	0.400	0.231						
IMO	11	0.100	0.057		1.660	90.6		0.997	5.48
	17	0.504	0.291						
GBMO	20	0.100	0.057		1.734	90.2		0.997	5.36
	16	0.464	0.267						

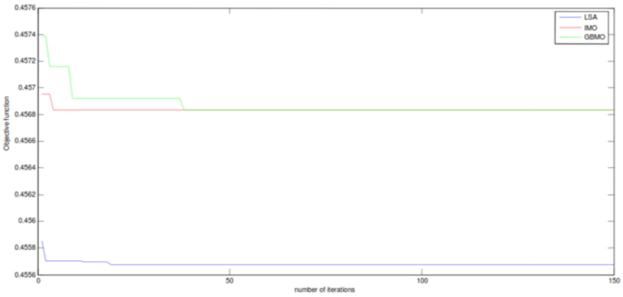

Figure 1. Convergence characteristics of 22-bus system with Type-1 DGs

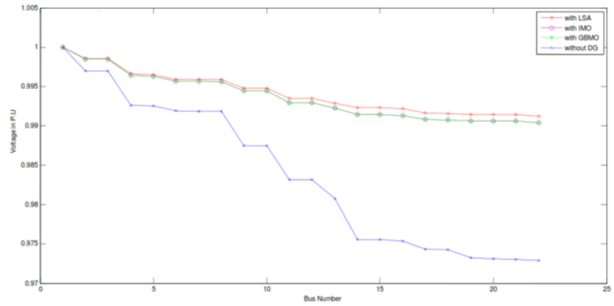

Figure 2. Voltage profile correction with Type-1 DGs for 22-bus system

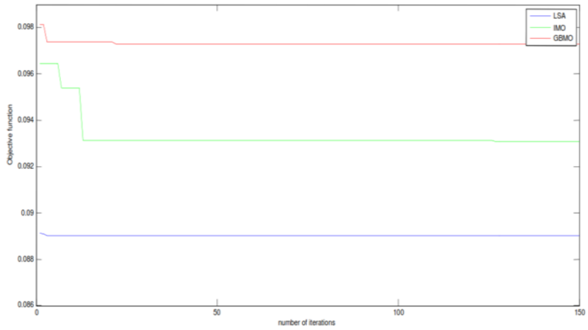

Figure 3. Convergence characteristics of 22-bus system with Type-3 DGs

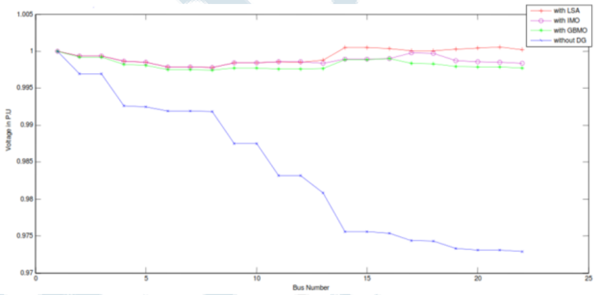

Figure 4. Voltage profile correction with Type-3 DGs for 22-bus system

Table 4. Numerical analysis for 22-bus system

Branch. No.	From Bus No.	To Bus No.	PLoss (kW) Original	QLoss (kvar) Original	PLoss (kW) DLF	QLoss (kvar) DLF	PLoss (kW) Type3 DGs	QLoss (kvar) Type-3 DGs
1	1	2	2.7427	1.3525	2.7427	1.3526	1.3792	0.2129
2	2	3	0.0003	0.0002	0.0003	0.0002	0.0003	0.0003
3	2	4	3.6120	1.8600	3.6120	1.8600	1.7637	0.2279
4	4	5	0.0075	0.0046	0.0090	0.0046	0.0090	0.0089
5	5	6	0.0327	0.0175	0.0342	0.0176	0.0340	0.0338
6	6	7	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
7	6	8	0.0013	0.0007	0.0013	0.0007	0.0013	0.0013
8	4	9	3.6687	1.8883	3.6687	1.8894	1.6978	0.1828
9	9	10	0.0003	0.0001	0.0003	0.0001	0.0003	0.0002
10	9	11	2.8585	1.4800	2.8700	1.4801	1.2929	0.1627
11	11	12	0.0003	0.0002	0.0003	0.0002	0.0003	0.0003
12	11	13	1.4444	0.7444	1.4455	0.7444	0.6455	0.1136
13	13	14	2.6619	1.3718	2.6634	1.3719	1.2680	0.2096
14	14	15	0.0004	0.0002	0.0004	0.0002	0.0004	0.0004
15	14	16	0.0946	0.0495	0.0961	0.0495	0.0436	0.0043

16	16	17	0.3270	0.1691	0.3285	0.1692	0.1577	0.0353
17	17	18	0.0024	0.0020	0.0039	0.0020	0.0038	0.0037
18	17	19	0.2086	0.1083	0.2101	0.1083	0.2034	0.1997
19	19	20	0.0226	0.0123	0.0241	0.0123	0.0234	0.0229
20	20	21	0.0005	0.0011	0.0020	0.0011	0.0020	0.0019
21	20	22	0.0070	0.0043	0.0085	0.0044	0.0082	0.0081

C. Voltage Stability Analysis for 22-bus Practical Radial Distribution System:

In this section, we examine the influence of optimal Distributed Generation (DG) placement on the voltage stability of a practical agricultural radial distribution system comprising 22 buses. The system is exclusively radial, with all loads categorized as agricultural. Table 5 provides a concise overview of the sensitive bus analysis for the 22-bus system incorporating Type-1 and Type-3 DG. The data in Table 4 indicates a noteworthy enhancement in the voltage stability of the system due to the presence of DG. Figures 5 and 6 visually represent the fluctuation of the critical bus stability index value with increasing system load. The observations from both figures reveal that as the system load rises, the critical bus index value decreases and approaches zero at the critical loading point of the system. This underscores the positive impact of DG on voltage stability, as illustrated by the decreasing critical bus index value under varying system load conditions.

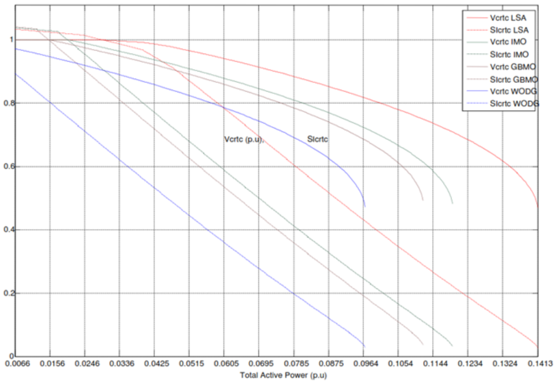

Figure 5. Variation of stability index and critical bus voltage magnitude with increasing load power with type1 DGs for 22-bus practical RDS

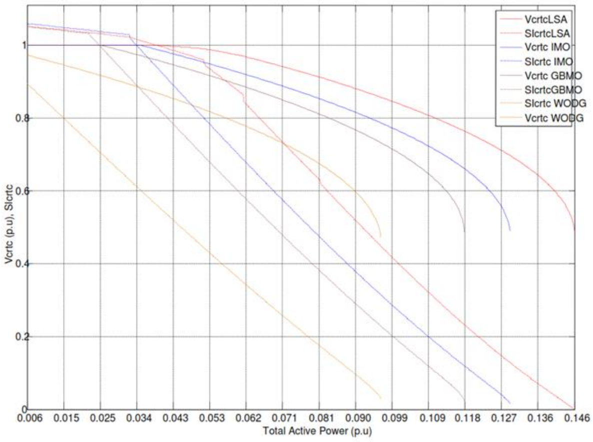

Figure 6. Variation of stability index and critical bus voltage magnitude with increasing load power with type3 DGs for 22-bus practical RDS

Table 5. Summary of critical bus and its stability index for 22-bus RDS

Type-1 DG			
Method	Critical Bus	Voltage (p.u)	Stability Index (SI)
Without DG	22	0.9759	0.8951
LSA	22	0.9913	1.0530

IMO	22	0.9904	1.0521
GBMO	22	0.9904	1.0449
Type-3 DG			
Method	Critical Bus	Voltage (p.u)	Stability Index (SI)
Without DG	22	0.9759	0.8951
LSA	07	0.9978	1.0511
IMO	08	0.9978	1.0498
GBMO	08	0.9974	1.0449

It is crucial to emphasize that the introduction of Distributed Generation (DG) into the system contributes to an enhancement in the stability index. The degree of improvement in the stability index is contingent upon the judicious placement and sizing of DG. Illustrated in Figure 6.15 and Figure 6.16 is the variation of the critical bus voltage magnitude with an increasing system load. These figures also depict the diverse outcomes achieved through different methods developed in prior chapters, contingent on the type of DGs considered. The observed voltage increase ranges between 0.97 p.u. and 1.02 p.u., while the stability index value spans from 0.8 to 1.2. Notably, Bus number 22 emerges as the critical bus. From the analysis of Figure 6.15 and 6.16, it becomes apparent that DG optimally enhances the critical loading point of the system. However, beyond this threshold, even a marginal increase in load results in a voltage collapse.

III. CONCLUSIONS

An investigation was carried out to determine the optimal placement of distributed generators in a radial distribution system, considering load models. The proposed algorithms were implemented on a 33-bus radial distribution system, and the outcomes derived from each algorithm were subjected to comprehensive comparison. It was found that all algorithms showed improved performance and yielded better results. Distribution systems are experiencing heavy loads due to population growth, which increases the risk of overloading and voltage collapse. Therefore, steady state voltage stability analysis is an important tool for assessing the loading capacity of distribution systems. The methods proposed for the optimal placement of distributed generators were tested on a practical radial distribution system in APEPDCL, India. The results indicate that DG can enhance the voltage profile and reduce power loss in the system. Voltage stability analysis is conducted to assess the impact of DG placement on voltage stability support. This enables the distribution system to handle higher load conditions and delay the need for new infrastructure construction or upgrades. While all proposed methods in the multi-objective optimization approach achieved the objective effectively, the computation time is shorter for IMO. The results indicate that the proposed algorithms are simple and can quickly solve the optimal placement of DGs with minimal computation time. These methods have been proven to effectively improve voltage profiles and reduce losses. These algorithms are capable of addressing the optimal placement of distributed generators in distribution systems, whether load models are considered or not. Hence, it can be inferred that these algorithms are dependable tools for effectively solving such problems.

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