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Highlight

- ❖ Optimal distribution of reactive power in presence of DG units
- ❖ Genetic algorithm
- ❖ Minimize Power System Losses
- ❖ statistical-quality based Taguchi method

Graphical Abstract



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Optimizing Reactive Power for DG Units to Minimize Power System Losses Using Stochastic Modeling

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ABSTRACT

In recent decades, because of some main and principle world problems such as increasing the population, global warming, climate changes, and fossil fuel sources reduction, the using of renewable energies has impressively increased that can solve and reduce the caused problems by traditional power plants, and also can control power system the important indexes such as losses, voltage drop, transferring capacity. Reactive power has an important role in controlling and minimizing of losses, the optimal distribution of reactive power in presence of Distributed generation (DG) units in distribution networks is an important and key problem. In this paper, for uncertainties modelling of DG units and optimizing the reactive power, the statistical-quality based Taguchi method and Genetic algorithm are used, respectively. The simulation of this paper is checked and done in MATLAB and MINITAB using IEEE 57-bus standard network, and simulation results show 5.5 MW reduction of the distribution network losses.

1. Introduction

In addition to the active power, optimal reactive power distribution (ORPD) and voltage control are some of the most important issues in the power system that play a key role in the economic operation and loss control of the network, that means the set of the voltage of the generators, the position of the taps, and also the number of reactive compensators of the network, set at the best values then the amount of losses in the network reaches its minimum value [1]. In the normal and steady state of the network, determining the optimal state of these elements is sufficient to have the optimal answer. But when uncertainties are applied to the network, the state of uncertainty affects the final answer and the position of the network elements to the extent that this problem must be resolved again, taking into account the sources of uncertainty. This issue is non-convex and non-linear in nature. Hence, many classical methods such as the gradient method have been used [2]. In [2], reactive and active powers are separated and then the optimization problem is solved. Dynamic programming [3], Lagrange function and Cohen-Tucker conditions [4], linear programming [5], marine predators' algorithm (MPA) [6], modified

jellyfish search optimizer (MJSO) [7], African Vultures Optimization Algorithm (AVOA) [8] and modified version of Artificial Hummingbird Algorithm (MAHA) [9] for the ORPD problem are also presented. In addition, in [10] a multi-objective ORPD is proposed for an IEEE 69-bus distribution network, considering different load levels and the uncertainty of load models and demand. It introduces an optimization approach based on a modified grey wolf optimizer and multi-level Pareto analysis, demonstrating its effectiveness. In [11-13] the problem is done in the form of a programming mixed with integer and using GAMS software. Also, using the above software in [14,15], it has performed the two objectives of reactive power programming in order to reduce losses and voltage deviations and in [16], the voltage remains stable by active power control. In addition, uncertainties due to load and wind are considered in it. Also, in [17] a stochastic programming method is presented for coordinated operation of distributed energy resources in an unbalanced IEEE 34-bus three-phase active distribution network (ADN), effectively reducing system cost and co-optimizing active and reactive power. Allocation and sizing are also very important to reduce losses. In [18] a two-layer methodology that utilizes a two-stage stochastic programming algorithm is proposed for the allocation and sizing of Static Var Compensators (SVCs) in IEEE 33 and 69 radial distribution systems, effectively addressing uncertainties in PV and load powers and compares optimization algorithms such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) to demonstrate the effectiveness of the proposed methodology on the systems. In recent years, many papers based on evolutionary algorithms have been presented. The ability of evolutionary algorithms to solve nonlinear problems has been the main reason for all researchers to solve this problem with these algorithms [19]. An improved differential evolution algorithm is used in which discrete and continuous variables are considered with the aim of reducing losses [20]. Reactive power control programming is performed in distribution networks and includes wind generation uncertainties. Other references such as genetic algorithm [21], particle aggregation algorithm [19,22], evolutionary programming [23], differential evolution [24-26], metal annealing [27], search engine optimization algorithm [28, 29], propeller algorithm [30] The Gray Wolf Algorithm [31], the Teaching and Learning Algorithm [32] and the Combined Particle Swarm Algorithm [33], have solved the problem that none of the mentioned articles have examined the effect of uncertainties. However, recent studies have explored the application of various algorithms to address the issue of loss reduction in distribution networks, including the use of Cuckoo and Cultural Algorithms [37], the combination of Improved Taguchi Method and Dandelion Algorithm [38], and the correlation of Taguchi Method and Genetic Algorithm [39].

In this paper, the ORPD problem and voltage control using GA are done in a situation where the effect of uncertainty caused by WTs is considered. Obviously, conventional unloading methods can no longer be used when uncertainty arises. Therefore, to solve this problem, the probabilistic optimal power flow (POPF) method is used.

The significant advantages of this paper are summarized as blow:

- 1) Solving ORPD problem considering uncertainties of DG units and Time-varying load.

2) Applying the Taguchi method for modeling load, solar irradiance, and wind speed uncertainties.

3) Comparing the result of the Taguchi method with the POPF method such as: Scenario-Based, LHS, and 2PEM for answering the problem.

2. Expression of the ORPD

The objective function is expressed in Equation (1) [34].

$$\min P_L = \sum_{l=1}^{nl} P_{Loss,l} \quad (1)$$

Where P_L is the total network loss. This optimization problem has some constraints. Equations (2) and (3) show equal limits in the network. Equations (4) and (5) express unequal constraints.

$$V_i \sum_{j=1}^N V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) + P_{Di} - P_{Gi} - P_{wi} = 0 \quad (2)$$

$$V_i \sum_{j=1}^N V_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) + Q_{Di} - Q_{Gi} - Q_{ci} = 0 \quad (3)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (4)$$

$$|T_i| \leq T_i^{max} \quad (5)$$

2.1. Load demand uncertainty Modeling

Generally, the uncertainty or in other words (random variable) RVs of load demand can be modelled using the normal or Gaussian probability density functions (PDFs) Equations (6):

$$PDF_L(S_L) = \frac{1}{\sqrt{2\pi}\sigma_L} \exp\left(-\frac{(S_L - \mu_L)^2}{2\sigma_L^2}\right) \quad (6)$$

2.2. Wind energy uncertainty modelling

The Weibull PDF is usually to define speed distribution by Equations (7) that is shown in Figure 1:

$$PDF_V(v) = \frac{\beta}{\alpha} \left(\frac{v}{\alpha}\right)^{\beta-1} \exp\left(-\left(\frac{v}{\alpha}\right)^\beta\right) \quad (7)$$

Further, the output power from a wind power plant is expressed by Equations (8):

$$P_W(V) = \left\{ \begin{array}{ll} 0 & V \leq V_i \text{ and } V_o \leq V \\ \left(\frac{V^3 - V_i^3}{V_r^3 - V_i^3}\right) P_r & V_i \leq V \leq V_r \\ P_r & V_r \leq V \leq V_o \end{array} \right\} \quad (8)$$

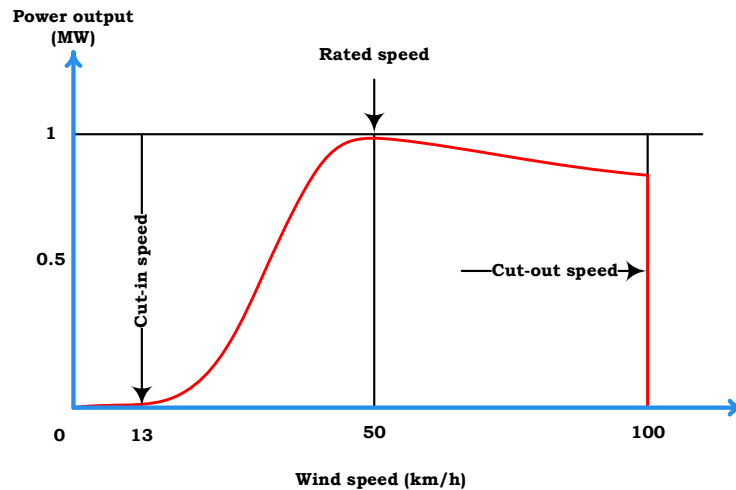


Figure 1. Wind turbine production capacity [28].

3. Orthogonal Arrays

An orthogonal array (OA) is a type of fractional factorial matrix in which the rows reflect the levels of random variables (RVs) in each experiment, while the columns indicate specific factors. Historically, the concept of OA was referred to as magic squares. The term "orthogonal" is used to describe OAs due to the independent examination of each column. The orthogonal array (OA) is comprised of a matrix, as depicted in Table 1, whereby numerical values are organized systematically in both horizontal rows and vertical columns. Each row within the matrix represents an individual experiment, while each column corresponds to a random variable (RV). Therefore, the dimensions of the matrix may be expressed as (" N " " \times " " N ") multiplied by N . The symbol " L " represents the level assigned to the i^{th} variable in the " j^{th} " experiment [26, 36].

4. POPF with TM

In POPF, the relationship between input and output RVs is according to Equation (9):

$$Y_{in} = f(X_{out}) \quad (9)$$

The input and output RVs vectors are Y_{in} and X_{out} , respectively, and f is a nonlinear function. In POPF, the factors are called as RVs. In the POPF the whole details of Taguchi method are shown in Figure2 and explained in [39].

5. Simulation Results

The utilization of the 57-bus IEEE standard network is used to attain the efficacy of the Taguchi method. The system under consideration is equipped with a total of seven generators and eighty transmission lines, out of which seventeen lines are equipped with a tap changer. Additionally, three pieces of reactive power compensating equipment have been placed at bases 15, 25, and 53 for the purpose of compensation. The network experiences an initial loss of 33 MW in the absence of wind turbines. The performance range of the variables is shown in Table 1, while additional network information may be found in reference [19].

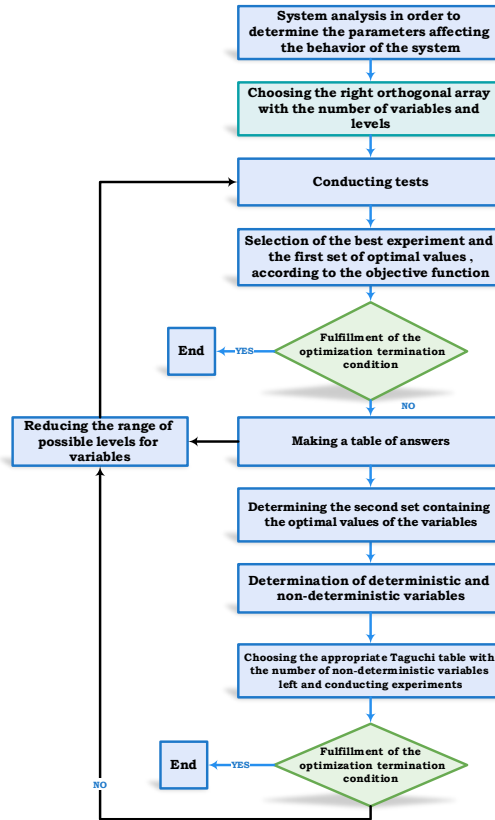


Figure 2. Taguchi and POPF flowchart [39].

Table 1. Orthogonal array $OA_{N_{exp}} (N_L)^N$.

Experiment number	Level of each variable			
	RV ₁	RV ₂	...	RV _N
1	L ₁₁	L ₁₂	...	L _{1N}
2	L ₂₁	L ₂₂	...	L _{2N}
...
N_{exp}	LN_{exp1}	LN_{exp2}	...	LN_{expN}

The methodology is executed using the MATLAB and MINITAB software platforms. The present scenario entails the existence of a wind farm located in bus 38, possessing a nominal capacity of 100 MW. In order to replicate the operations of this wind farm, wind velocity data obtained from the North Dakota site and the Watford area have been employed [25]. The mean wind velocity within this region is recorded as 8.5 meters per second, with a corresponding standard deviation of 5.55. Figure 2 displays the distribution of wind speeds over a one-year period, revealing a noticeable right skewness in the data. Table 2 presents the outcomes according to the control variables. The findings presented in Table 3 indicate that the observed values for the variables fall within the acceptable range. Figures 2 to 9 provide diagrams illustrating the changes in several factors, such as generator voltage, tap position, and control equipment production. These diagrams offer improved control over the condition of the variables. The findings indicate the allowable range of values for all variables throughout the 500 iterations of the algorithm. It is evident that initially, there is significant variability among all variables.

However, as the number of repetitions increases, there is a progressive attainment of relative convergence among all variables. Additionally, Figure 9 presents the output voltage of all the buses, illustrating the permissible range of values for their output voltage. Table 4 presents several approaches for predicting postoperative pancreatic fistula (POPF), including point estimate, Taguchi, Scenario-based, and Latin hypercube sampling, along with their respective outcomes.

Table 2. Limitations of control variables.

Variable	Max[p.u.]	Min [p.u.]	Step
VG	1.06	0.94	---
V	1.06	0.94	---
T	1.1	0.9	0.01
QC ₁₈	1.0	0	---
QC ₂₅	0.059	0	---
QC ₅₃	0.063	0	---

Table 3. Results for system variables.

VG ₉	VG ₈	VG ₆	VG ₃	VG ₂	VG ₁
1.037	1.055	1.035	1.044	1.058	1.06
T ₃₄₋₃₂	T ₇₋₂₉	T ₂₄₋₂₆	T ₂₄₋₂₅	T ₂₄₋₂₅	T ₂₁₋₂₀
4	8	12	8	5	12
T ₁₄₋₄₆	T ₁₅₋₄₅	T ₁₁₋₄₁	T ₄₋₁₈	T ₄₋₁₈	VG ₁₂
7	8	1	1.058	1.06	1.033
T ₉₋₅₅	T ₃₉₋₅₇	T ₄₀₋₅₆	T ₁₁₋₄₃	T ₁₃₋₄₉	T ₁₀₋₅₁
4	8	12	8	5	12
-	-	-	QC ₅₃	QC ₂₅	QC ₁₈
-	-	-	7	8	1

Table 4. Values of μ and σ using other alternative techniques approaches.

Entire losses	TM	Scenario	LHS	2PEM
μ [MW]	27.5	40.8	48.36	36.1
σ	9.10	19.17	28.42	13.2

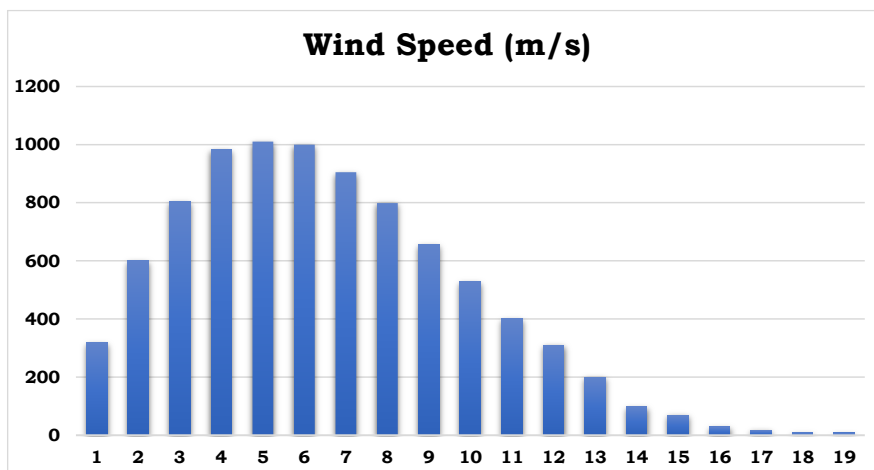


Figure 3. Wind speed frequency diagram [40].

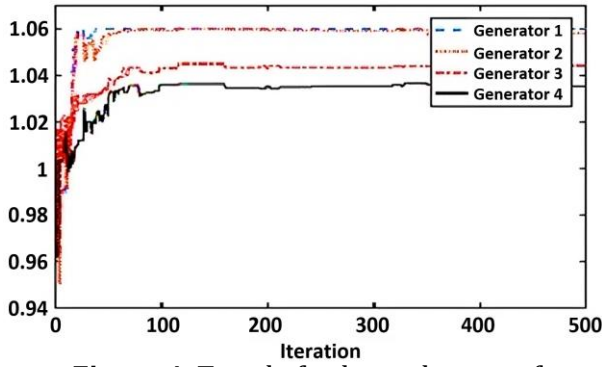


Figure 4. Trend of voltage changes of generators 1 to 4

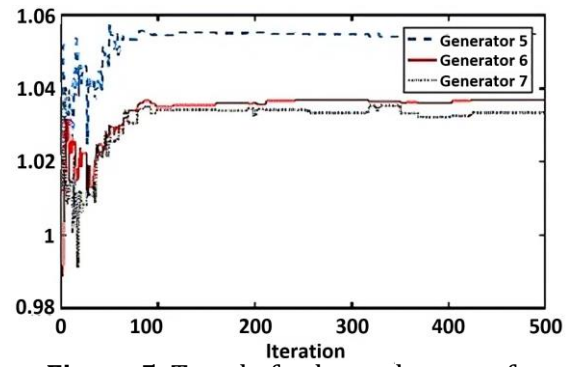


Figure 5. Trend of voltage changes of generators 5 to 7.

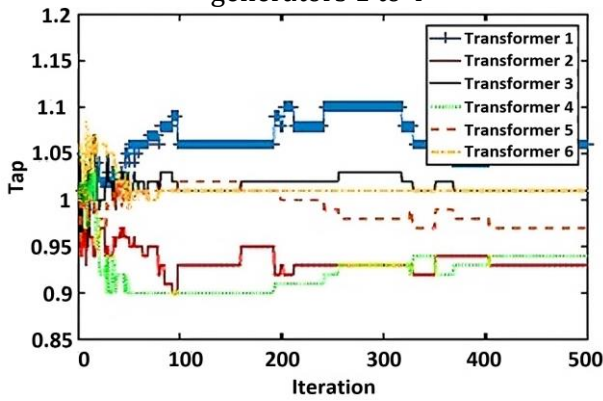


Figure 6. Trend of transformers 1 to 6 transformers.

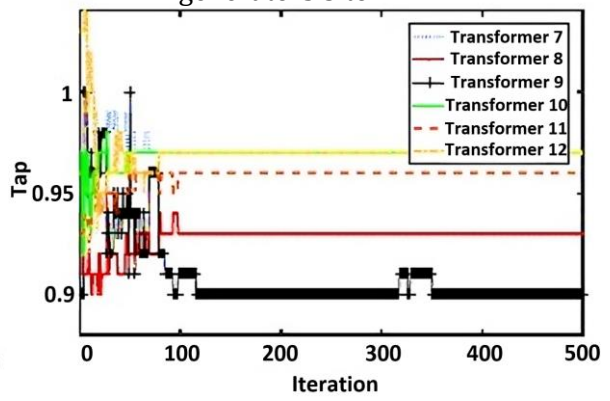


Figure 7. Trend of transformers 7 to 12 transformers.

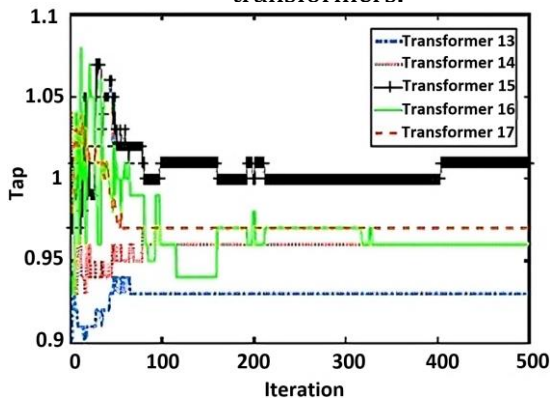


Figure 8. The process of changing the Taps of transformers 13 to 17.

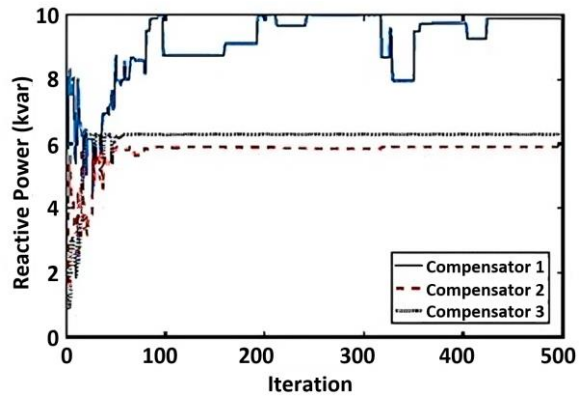


Figure 9. Trend of compensating equipment changes.

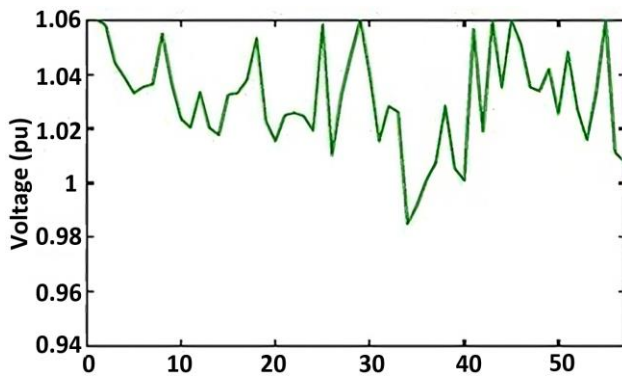


Figure 10. Voltage profile of all buses.

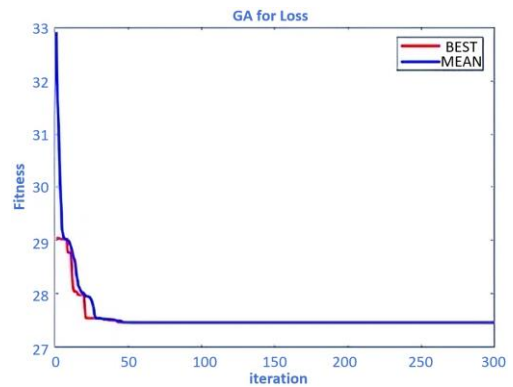


Figure 11. Convergence of loss optimization by GA.

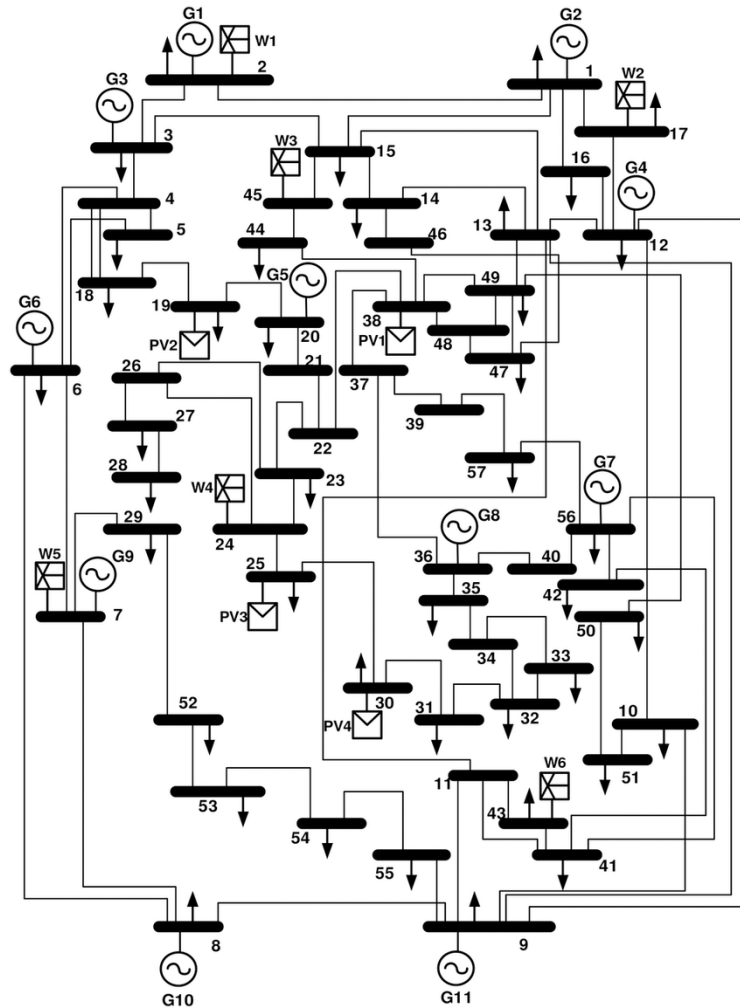


Figure 12: IEEE Standard 57-bus Network.

6. Conclusion

This article discusses the issues of reactive power distribution and voltage management in the presence of distributed generator units using an evolutionary genetic algorithm and statistical quality based on orthogonal arrays. It has been shown that this approach can solve the OPRD problem when used to the IEEE 57-bus standard network. The findings indicate that when DG unit output capacity is uncertain, there is a reduction in overall network losses as opposed to when it is not. In addition, all control variables remain inside their permitted range both during the issue solving process and at the conclusion of the method. The value of the system losses from the test, 27.5 MW, is the optimal load flow that can be acquired from the Taguchi method test using the genetic algorithm. The levels set by the TM are also obtained; however, the answer obtained for losses of the same system from the normal OPF by the Newton-Raphson load flow method is 33 MW. This suggests that the TM modifies the POPF of factor levels so that the system experiences the fewest losses possible and minimizes the difference between 33 and 27.5, which is equal to 5.5 MW, a noteworthy amount.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, have been completely observed by the authors.

Credit Authorship Contribution Statement

Majid Najjarpour: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Roles/Writing - original draft. **Behrouz Tousi:** Supervision. **Amirhossein Karamali:** Writing-review & editing.

Bibliography



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