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Genetic Algorithm-Based Optimization for AVR and DG Placement in Distribution Networks

Abstract: - Distributed Generation (DG) penetration in distribution networks has increased dramatically in recent years as power markets have improved. Aside from serving loads locally, the installation of DG has a number of technical advantages, including improved voltage profile and lower network loss. Using an Automatic Voltage Regulator (AVR) in conjunction with DGs maximizes technological benefits. This study investigates the influence of DG and AVR placement with the purpose of decreasing network losses. The Genetic Algorithm (GA) solves the optimization problem. The effectiveness of the proposed approach is proven with a standard IEEE 69-bus distribution network.

Keywords: Distributed Generation, Automatic Voltage Regulator, Genetic Algorithm.

1 INTRODUCTION

Industrial growth, rapid urbanization, and increased electric gadget affordability are all contributing to a lack of energy generation to meet expanding demand. To maximize economic gains while also conserving energy, generated electricity must be used efficiently. Power losses at the distribution level are mostly caused by low voltages, high currents, and overload conditions. Energy conservation through network reconfiguration, capacitor allocation, and reconductoring is becoming more significant. However, its effectiveness is limited because it only injects reactive power into the network. The usage of Distributed Generation (DG) for loss reduction has risen in popularity as a result of the restructuring of the electric power system [1].

Various analytical and meta-heuristic strategies have been used by researchers to solve the problem of DG and capacitor allocation. Prasad optimally selects conductors and places capacitors to minimize system costs using the Harmony Search Algorithm, analysing both annual energy loss and investment costs. Implemented on an 85-bus system, this approach effectively reduces losses, lowers costs, and improves the voltage profile [2]. Renewable distributed generation (RDG) deployment has increased due to environmental concerns, offering benefits like loss reduction, improved voltage profile, and reduced line loading [3]. Meta-heuristic techniques, including the Artificial Bee Colony (ABC) algorithm [4], Harmony search algorithm (HSA) [5], Flower pollination algorithm [6], Grey Wolf Optimizer [7], and improved teaching learning-based optimization algorithm [8], were used to solve the DG allocation problem and reduce active power loss. Das [9] employed the Fuzzy-GA approach and Plant Growth Simulation program to tackle the shunt capacitor allocation problem. Bhattacharya and Goswami [10] employed a Fuzzy approach to detect locations and Simulated Annealing to optimize capacitor sizes, reducing both loss and capacitor costs. A few authors investigated the influence of DG location and capacitors in distribution systems.

The goal of this research is to use GA to determine the ideal sizes and positions for DGs, as well as the optimal tap settings and placements for AVRs in a radial distribution network. Ravindra proposes an improved Pareto

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multi-objective backtracking search algorithm for optimal DG and AVR allocation in distribution systems [11]. The optimal allocation problem is solved within the restrictions of maximum DG penetration limit, thermal limit of branches, tap position of AVRs, injected active and reactive power limits of distributed generators, and allowable bus voltage limits [12-13]. Finally, it suggests using NSGA-II optimization for DG, capacitor, and AVR allocation to improve voltage, minimize losses, and enhance network reliability, with testing on IEEE 33 and 69-bus systems [14]. Here the proposed approach is applied to find out optimal placement of DG and AVR for different scenarios for minimizing the objective functions power loss and voltage deviation.

2 PROBLEM FORMULATION

The primary objective of this project is to reduce active power losses directly contributes to an improvement in bus voltage levels. By optimizing the power flow across branches, we aim to achieve a significant reduction in network power loss.

To accomplish this, the strategic placement of Distributed Generators (DGs) and Automatic Voltage Regulators (AVRs) is a key focus. DGs help to decentralize power generation, thereby reducing the distance power must travel, which in turn minimizes losses. Meanwhile, AVRs work to maintain voltage levels within optimal ranges, ensuring consistent and efficient power delivery. This coordinated approach not only minimizes active power loss but also contributes to reduce voltage deviation in distribution network.

2.1 Objective function

The primary objective of this study is to achieve loss reduction in the power distribution network. This goal is quantified using a target function, which is defined as the ratio of the network's power loss with the integration of Distributed Generators (DGs) and/or Automatic Voltage Regulators (AVRs) to the power loss in a base case scenario.

In this context, "base case power loss" represents the power loss within the network when no DGs or AVRs are utilized. By comparing the modified network's performance against this baseline, the study can effectively assess the impact of DG and AVR placement on reducing power loss, thereby highlighting the improvements in voltage deviation.

$$f_p = \left(\sum_{i}^{Nbr} PL_i^{with\_DG/AVR}\right) / \left(\sum_{i}^{Nbr} PL_i^{base}\right) \quad . \tag{1}$$

The optimization problem is solved using the following constraints:

(i) Voltage Constraint

$$V_{\min} \le V_i^{with\_DG/AVR} \le V_{\max} \tag{2}$$

(ii) Branch current limits (Thermal limits)

$$I_i \le I_{cap} \tag{3}$$

(iii) DG power capacity constraint

$$P_{DG\_\min} \le P_{DGi} \le P_{DG\_\max} \tag{4}$$

(iv) Tap settings Constraint for AVR

$$T_{\min} \le T \le T_{\max} \tag{5}$$

where $PL_i^{with\_DG/AVR}$ represents the total real power loss with DG and/or AVR, PL_i^{base} corresponds to the total real power loss with base case, $V_{\min}$ is the Minimum voltage, $V_{\max}$ is the Maximum voltage, $P_{DG\_\min}$ is the Minimum DG power capacity, $P_{DG\_\max}$ is the Maximum DG power capacity, $T_{\min}$ is the Minimum tap setting, $T_{\max}$ is the Maximum allowable tap setting.

2.2 Automatic Voltage Regulator (AVR) model

To assess the influence of Automatic Voltage Regulators (AVRs) on the distribution network, a detailed model is developed [9]. An AVR operates as an autotransformer equipped with a tap-setting control mechanism on its windings, enabling precise regulation of voltages across the distribution network. Positioned strategically between buses A and B, the AVR is initially set with a tap setting denoted as ‘t’ and an internal admittance represented by ‘Y’, as illustrated in Fig. 1.

In this model, the AVR is depicted as a combination of series and parallel admittances, as shown in Fig. 2. This configuration allows for accurate simulation of the AVR’s impact on the network’s voltage profile and power flow. By adjusting the tap setting, the AVR can dynamically maintain voltage levels within desired limits, thereby improving the voltage deviation at each bus in the network.

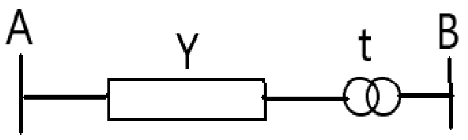

Fig. 1 AVR model in branch

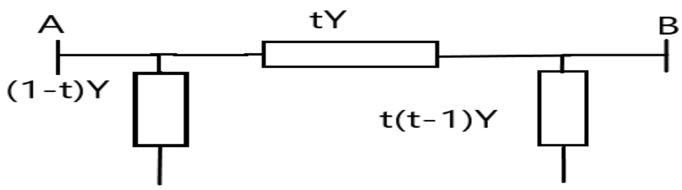

Fig.2 π model representation of AVR

When the tap setting of the autotransformer is adjusted from its initial value t by an increment Δt, the AVR model requires modification, as depicted in Fig. 3. To represent this variation in tap position, an alternative modeling approach involves adjusting the configuration in Fig. 3 by introducing imaginary injection currents, I_A and I_B as shown in Fig. 4.

These fictitious injected currents, defined by equations (6) and (7), enable an accurate simulation of the effects of tap changes on the network without physically altering the transformer setup. By incorporating these injection currents into the model, we can replicate the impact of varying tap positions on the voltage profile and power flow, allowing for a precise analysis of AVR performance in maintaining optimal network conditions.

$$I_A = (1-(t+\Delta t)) * Y * V_B \tag{6}$$

$$I_A = (1-(t+\Delta t)) * Y * V_B + ((t+\Delta t)^2 * Y * V_B) \tag{7}$$

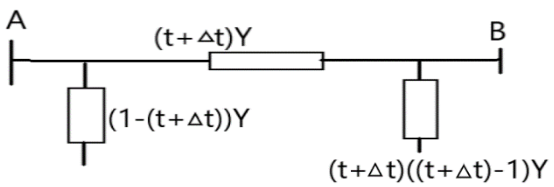

Fig. 3 AVR model including tap position variation

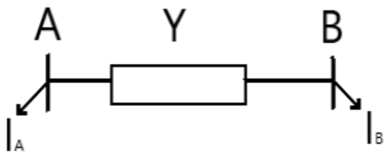

Fig. 4 AVR equivalent with fictitious current injections

2.3 Genetic Algorithm

A Genetic Algorithm (GA) is an optimization technique inspired by natural evolution. It finds solutions for complex problems by simulating the process of natural selection. Here's the step-by-step process:
STEP 1: Generate an initial population of potential solutions (chromosomes) randomly or based on heuristics.
Define parameters such as population size, crossover rate, mutation rate, and the maximum number of generations.
STEP 2: Evaluate each individual using a fitness function that quantifies how well the solution addresses the problem.
STEP 3: Choose individuals as parents for reproduction based on their fitness. Tournament-Select the best from a subset of individuals.
STEP 4: Crossover: Combine genetic material from selected parents to produce offspring.
STEP 5: Mutation: Introduce small, random changes in offspring genes to explore new solutions and maintain genetic diversity.
STEP 6: Form the next generation by replacing less-fit individuals with offspring.
STEP 7: Termination: Repeat steps 2–6 until a stopping condition is met, such as a satisfactory fitness or maximum generations.

2.4 Proposed Approach

Step 1: Define loss as objective function, DG sizes and locations, Tap changers and locations as decision variables. Initialize GA parameters and specify the IEEE 69-bus test system line and load data, constraints.
Step 2: Initialize the chromosomes with solution vectors (DG sizes and locations, Tap changers and locations).

$$SV = [DG_1^1\ \mathrm{DG}_2^1 \ldots. DG_N^1\ \ \mathrm{L}_1^1\ \mathrm{L}_2^1\ \mathrm{L}_3^1 \ldots. L_N^1\ \mathrm{T}_1^1\ \mathrm{T}_2^1\ \mathrm{T}_3^1 \ldots. T_N^1\ \ \mathrm{TL}_1^1\ \mathrm{TL}_2^1\ \mathrm{TL}_3^1 \ldots. TL_N^1\,] \quad (11)$$

Each solution vector in chromosomes is evaluated by finding the objective function value by running a load flow. Backward -Forward Sweep method is used determine load flows. Sort the solution vectors in chromosomes based on their ascending order of functional values.
Step 3: Determine the best solution from the solution vector.
Step 4: Generate a fresh set of solutions
Step 5: Check the termination criteria and stop.

3 RESULTS

To verify the efficacy of the proposed approach, it is tested on a IEEE 69-bus system which is a 12.66 kV system whose data is taken from [15].
Four scenarios are simulated in this work.
Scenario I: System without DGs and AVRs (Base case)
Scenario II: System with AVRs only
Scenario III: System with DGs only
Scenario IV: System with DGs and AVRs (Proposed approach)
Bus voltage deviations of the system is computed as given in (12)

$$Vdev = sum\sum_{i=2}^{nbus}(V_i\ \text{-}1)^2 \qquad \mathrm{i} = 1,2,3,4\ldots..\mathrm{nbus} \quad (13)$$

where *nbus* represents total number of nodes and V_i is the i^{th} bus voltage.

Table 1. Results of IEEE 69-bus Test System

Planning Cases	DGs placement and rating		AVR locations and Tap ratio				Total Real Power loss (kW)	Minimum bus voltage (p.u)	Voltage deviation
	Bus No.	Ratings (MVA)	Branch no.	Tap ratio	Branch no.	Tap ratio			
Scenario-I	----	----	----	----	----	----	224.98	0.9091	0.0993
Scenario-II	----	----	56 59 61 62	0.9000 1.0875 0.9125 0.9625	----	----	196.82	0.9141	0.0897
Scenario-III	65 26 60 62 61	0.56 0.40 0.59 0.51 0.27	----	----	----	----	14.94	0.9884	0.0036
Scenario-IV (AGA) [16]	21 61 62 63 64	0.441 0.572 0.348 0.539 0.428	5 6 7 8 9 10 11 44	1.0989 1.0938 1.0984 0.9014 1.0906 1.0983 1.0958 1.0509	48 49 55 57 59 66 68	1.0637 1.098 0.9237 1.063 0.9098 0.9305 0.9092	11.87	0.9953	0.00076
Scenario-IV HSA[17]	61 60 62 65 23	0.76 0.38 0.48 0.32 0.38	13 25 10 35	1.0813 0.9125 0.9188 0.9813	----	----	10.44	0.9904	0.0026
Scenario-IV GA	62 17 61	0.70 0.38 1.18	66 50 51	0.9740 0.9601 1.0282	----	---	13.16	0.9864	0.0047

In this study, DG penetration is limited to 50%, with all DG units operating at a power factor of 0.85 lagging. The results for four scenarios are summarized in Table 1. The total real power loss in the network for Scenario I is 224.98 kW. For Scenario II, the losses reduce to 196.821 kW, while they further decrease to 14.94 kW in Scenario III and 11.87 kW in Scenario IV when solved using the Adaptive Genetic Algorithm (AGA) [13]. Using the proposed GA in Scenario IV, the losses are minimized to 10.44 kW. A comparison of Scenario IV results shows that the proposed GA achieves greater power loss mitigation than AGA. While the proposed Genetic Algorithm (GA) approach outperforms AGA in voltage deviation, it is less effective compared to GA.

Table 1 reveals that in Scenario IV (AGA), deploying 5 DGs and 15 AVRs results in a power loss of 11.87 kW. In contrast, Scenario IV (GA), which uses 5 DGs and only 4 AVRs, reduces the loss further to 10.44 kW. Meanwhile, Scenario IV (GA) achieves a power loss of 13.16 kW with 3 DGs and 3 AVRs. These results indicate that the proposed GA-based method is more efficient than the AGA-based approach. Additionally, the proposed approach achieves the highest percentage of loss reduction at 94.53% compared to other scenarios. Figure 5 further demonstrates that the voltage profile of the network significantly improves due to the simultaneous placement of AVRs alongside DGs in Scenario IV.

4 CONCLUSION

In this study, the simultaneous placement of Automatic Voltage Regulators (AVRs) and Distributed Generators (DGs) was carried out on the IEEE 69-bus system. The primary objective of this work is to minimize energy losses in the distribution network. The optimization process is divided into three distinct scenarios: optimal DG allocation, optimal AVR allocation, and the combined allocation of both DGs and AVRs. Each scenario addresses specific challenges in enhancing the performance of the power system.

To achieve the desired outcomes, the Genetic Algorithm (GA) was employed as the optimization tool. This evolutionary algorithm effectively determined the optimal locations and capacities for both DGs and AVRs, ensuring a comprehensive and efficient solution. Among the various scenarios analyzed, the proposed approach—referred to as Scenario-IV—demonstrated the highest power loss reduction. This result indicates the superiority of simultaneously deploying DGs and AVRs compared to individual placements, as considered in Scenarios I, II, and III.

Additionally, the voltage profile of the network showed significant improvement under Scenario-IV. The simultaneous integration of DGs and AVRs not only reduced energy losses but also enhanced the voltage stability of the power distribution system.

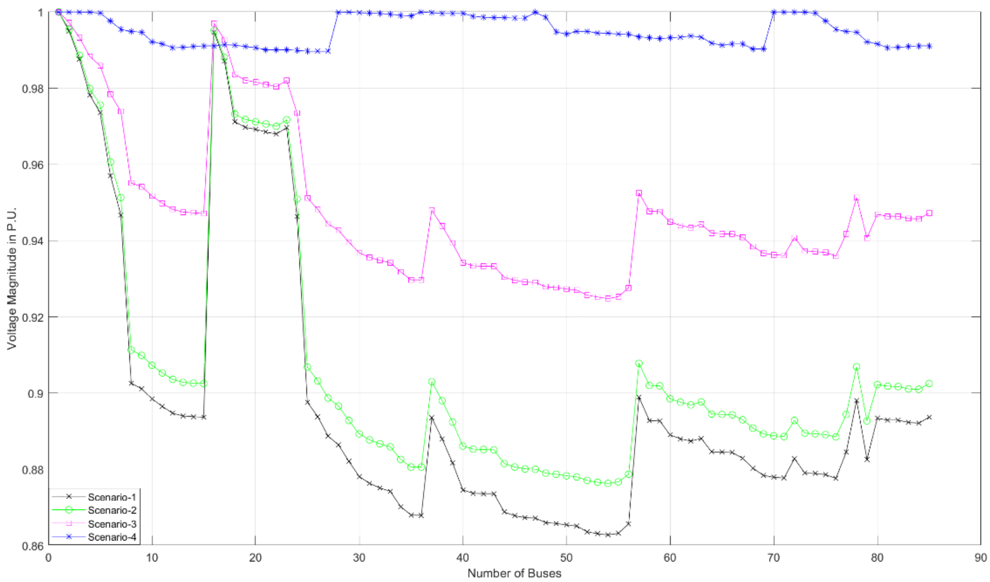

Fig. 5 Voltage profile of 69-bus system

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