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N Sirisha [1a,*],

Kurra Venkateswara Rao[a],

M P Subba Raju[a], Sana Vani[a] ,

A M S V Sushma[c],

B Rajani[a],

Chitturi Ramprasad[b] ,

J M Kanthi Thilaka[d],
Tallada Padma Praveen[d]

Greedy Algorithm for Optimized AVR and DG Positioning 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 Greedy 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, Greedy 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.

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[1] aDepartment of Electrical and Electronics Engineering, Aditya University Surampalem, 533 437,India
b Department of Mechanical Engineering, Aditya University Surampalem, 533 437,India
c Department of Electrical and Electronics Engineering, S R K R Engineering College Bhimavaram 534204,India
d Department of Humanities and Basic Sciences , Aditya University Surampalem, 533 437,India

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 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.

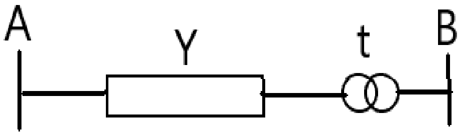

Fig. 1 AVR model in branch

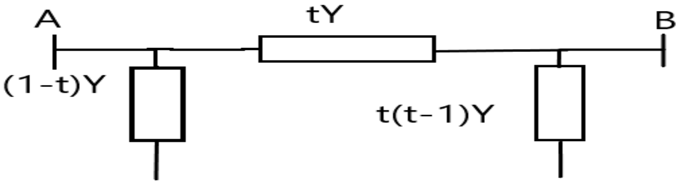

Fig.2 π model representation of AVR

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.

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

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

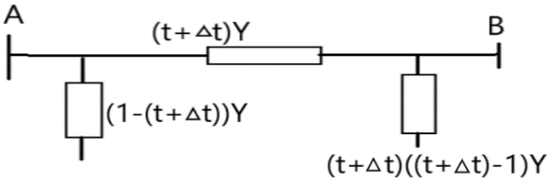

Fig. 3 AVR model including tap position variation

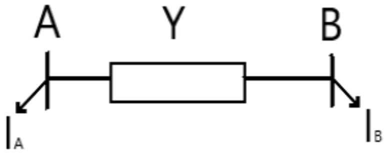

Fig. 4 AVR equivalent with fictitious current injections

2.3 Greedy Algorithm

The Greedy Algorithm is an optimization technique that builds a solution iteratively by making the locally optimal choice at each step. The process can be outlined as follows:

STEP 1: Clearly identify the problem to solve and the objective function to optimize. Understand the constraints and conditions for a feasible solution.

STEP 2: Preprocess the input to make greedy choices straightforward, such as sorting items by value, cost, or efficiency.

STEP 3: Start with an empty or partial solution and set relevant variables (e.g., total value or cost) to their initial state.

STEP 4: At each step, select the best available option based on the problem's criteria. Check if adding the selected option keeps the solution feasible within constraints.

STEP 5: Add the chosen option to the solution and update variables accordingly.

STEP 6: Stop when the solution is complete or no further options can be selected without violating constraints.

2.4 Proposed Approach

Step 1: Define loss as objective function, DG sizes and locations, Tap changers and locations as decision variables. Initialize MWCA parameters and specify the IEEE 69-bus test system line and load data, constraints.

Step 2: Initialize the RM with solution vectors (DG sizes and locations, Tap changers and locations).

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

Each solution vector in RM 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 *RM* based on their ascending order of functional values.

Step 3: Determine the best solution from the raindrops.

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)

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

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	15 62 60	0.0034 0.0124 0.0063	40 20 41	1.0323 0.9449 1.0304	----	----	16.13	0.9839	0.0060

In this work, DG penetration is restricted to 50%, with all DG units operating at a lagging power factor of 0.85. The results for the four scenarios are summarized in Table 1. The total real power loss in the network is 224.98 kW for Scenario I, which decreases to 196.821 kW in Scenario II. In Scenario III, the loss is reduced further to 14.94 kW. For Scenario IV, the loss is 11.87 kW when solved using the Adaptive Genetic Algorithm (AGA) [13], and 10.44 kW with the proposed GA. A comparison of Scenario IV solutions shows that GA achieves superior power loss mitigation compared to AGA. While the proposed Greedy Algorithm (GA) offers better voltage deviation performance than AGA, it is less effective than GA in minimizing power loss.

Table 1 shows that in Scenario IV (AGA), deploying 5 DGs and 15 AVRs results in a power loss of 11.87 kW. In Scenario IV (GA), the loss is further reduced to 10.44 kW with 5 DGs and 4 AVRs. Meanwhile, Scenario IV using the Greedy Algorithm (GA) achieves a power loss of 16.13 kW with 3 DGs and 3 AVRs. These results demonstrate that the proposed GA-based method outperforms the AGA-based approach. Additionally, the proposed method achieves the highest percentage of loss reduction at 93.36% among all scenarios. Figure 5 highlights significant improvements in the network's voltage profile, attributed to the simultaneous placement of AVRs and DGs in Scenario IV.

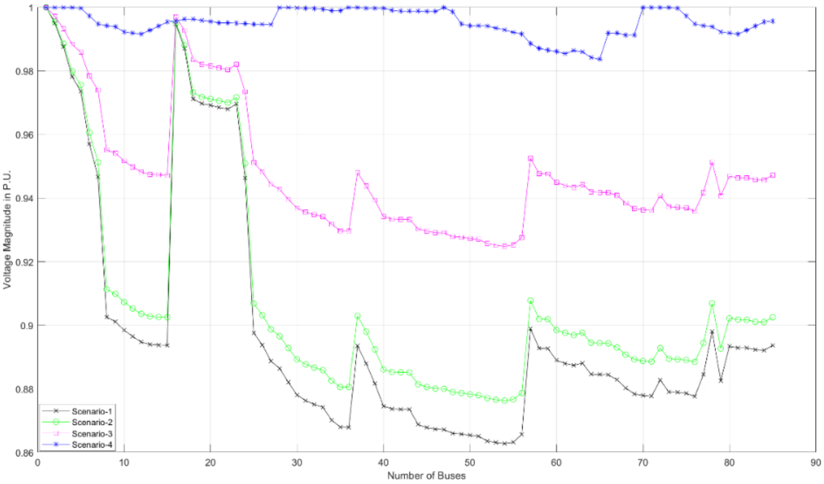

Fig. 5 Voltage profile of 69-bus system

4 CONCLUSION

This study investigates the simultaneous placement of Automatic Voltage Regulators (AVRs) and Distributed Generators (DGs) in the IEEE 69-bus system, with the aim of minimizing energy losses in the distribution network. The optimization process is categorized into three scenarios: Scenario-I, focusing on optimal DG allocation; Scenario-II, emphasizing optimal AVR allocation; and Scenario-III, addressing the combined placement of DGs and AVRs. Each scenario targets specific challenges to improve the efficiency and reliability of the power system.

The Greedy Algorithm was employed as the optimization tool to achieve these objectives. This method efficiently identified the optimal locations and capacities for DGs and AVRs, providing a practical and effective solution. Among all the scenarios examined, Scenario-IV, which involves the simultaneous placement of DGs and AVRs using the Greedy Algorithm, achieved the most significant reduction in power losses. This result underscores the superiority of an integrated deployment approach compared to standalone strategies, as demonstrated in Scenarios I, II, and III.

Moreover, Scenario-IV resulted in a marked improvement in the network's voltage profile. The coordinated placement of DGs and AVRs not only reduced energy losses but also enhanced voltage stability and overall system reliability. These findings highlight the critical importance of simultaneous resource integration in optimizing the performance of modern power distribution systems.

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