International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 7s
DOI: https://doi.org/10.17762/ijritcc.v11i7s.6999
***Article Received**: 30 March 2023 **Revised**: 16 May 2023 **Accepted**: 28 May 2023*

Reduction of Power Losses in the Distribution System by Controlling Tap Changing Transformer using the PSO Algorithm

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Abstract— Energy is an essential commodity for everyone, with electrical energy being the most preferred form. Unfortunately, non-renewable energy resources are gradually depleting, and renewable energy sources take several years to establish. To mitigate this problem, technology has shifted from non-renewable energy sources to electrical devices and machines, including household appliances like washing machines and air conditioners. However, the generation of electricity is still inadequate to meet the growing demand. This leads to two critical issues: Excessive power loss and inadequate voltage stability, making it difficult for power distribution companies to ensure a consistent and reliable power supply. The objective of this study is to tackle the issue of reduction and minimization of power dissipation By employing the PSO technique, adjusting the transformer tap settings. The proposed approach uses the 14-bus system as a reference and calculates losses for this system using the backward-forward sweeping technique.

Keywords- Addition of EV Charging Stations, Distribution System, Electric Vehicle Charging Station, Excesive Power Loss, Pentration of EVs, PSO Algorithm, Transformer Tap Settings.

I. INTRODUCTION

Due to the uncertainty of load, the process and regulation of a distribution arrangement is also complicated in particular fields. The actual density is very high, and the load varies from time to time. The power disappearance in a distribution grid is not the same; it varies due to loads. This changing of load causes a poor voltage profile. An average of 13% of generated power by the synchronous generator is approximately wasted in the distribution system in the form of losses. To tackle this challenge, there are several methods; one possible solution is to install shunt capacitors. Shunt capacitors play a major role; this leads to an improvement in the power factor of the distribution grid and voltage profile and reducing reactive power through compensation can lead to a decrease in power loss. [1]. However, it should be noted that the load demand varies during the day, and thus capacitors with different optimal sizes should be installed in the grid. The capacitor allocation is classified into six different approaches to clear the capacitor placing disarrangement in the distribution network. The authors have suggested the study uses the Particle Swarm Optimization (PSO) algorithm for optimization purposes to solve the capacitor appropriation trouble [2]. This study puts forth a proposal to two-stage methodology for determining the optimal site for installation and size of a capacitor. The methodology aims to minimize energy loss and improve

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voltage profiles [3]. In the first stage, the location for capacitors is determined, and in the second stage, the size of the capacitor. The capacitor allocation problem in the unbalanced network has been researched to minimize the Loss of energy in the distribution network [2, 3]. The shunt capacitor allocation problem in radial distribution systems is to compensate for the reactive power and is carried out by using the hybrid evolutionary method based on particle swarm optimization algorithms [5]. A new heuristic algorithm called the grasshopper optimization algorithm is employed to get the optimal site for installation problem of switchable capacitors in the spreading scheme.

II. PROPOSED METHODLY

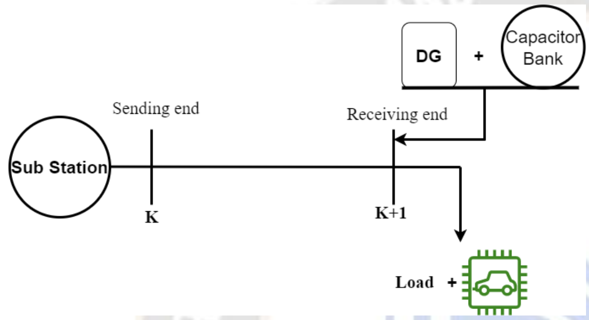

Fig. 1: Modified radial distribution system.

From the radial distribution system,
Radial distribution system power losses will be conveyed as:

$$P_{Loss(k,k+1)} = \frac{(P_{k+1}^2 + Q_{k+1}^2)}{|V_{k+1}|^2} * R \tag{1}$$

$$Q_{Loss(k,k+1)} = \frac{(P_{k+1}^2 + Q_{k+1}^2)}{|V_{k+1}|^2} * X \tag{2}$$

Forward/Backward Sweep Technique:

To ensure accurate measurement of the system's losses, an additional assessment is required. The Forward/Backward Sweep method is applied in this research to evaluate these losses.

Example:

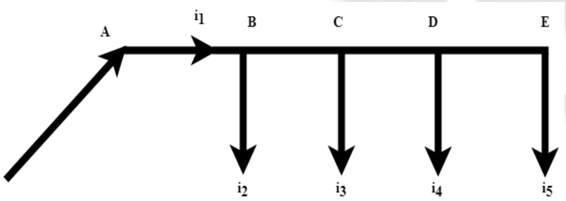

Fig. 2: Single-Line Representation of the RDS.

Backward Sweep

$$i_{de} = i_5 \tag{3}$$

$$i_{cd} = i_4 + i_5 \tag{4}$$

$$i_{bc} = i_{cd} + i_3 \tag{5}$$

$$i_{ab} = i_{bc} + i_2$$

Forward Sweep

$$V_{ab} = i_1 + R_{ab} \tag{6}$$

$$V_{bc} = i_{bc} + R_{bc} \tag{7}$$

$$V_{cd} = i_{cd} + R_{cd} \tag{8}$$

$$V_{de} = i_{de} + R_{de} \tag{9}$$

In the current investigation, DC type-2 and type-3 EV charging stations were installed in the RDS based on the voltage levels of the buses to ensure proper functioning. However, the charging stations caused uncertainty and increased power losses in the RDS, which disrupted the load demand curve. To mitigate this issue, a PV system (DG) and capacitor banks were introduced to provide real and reactive power compensation and improve the voltage profile in the RDS. The study also introduced voltage-dependent load modeling. The locations of the EV charging stations in the RDS, along with their types and ratings, are tabulated in Table 1. Table 2, on the other hand, presents information on the location of PV penetration levels and the CB percentage of compensation. Finally, equations (10)-(12) were used to determine the voltage at the receiving end and calculate active and reactive power losses after evaluating the DG and capacitor banks.

$$|V_{k+1}| = \frac{|V_k| + (|V_k|^2 - 4\left((P_{int}^2 + Q_{int}^2)^{1/2}\right)(R^2 + X^2)^{1/2}}{2} \tag{10}$$

$$P_{Loss(k,k+1)}^{DG} = \frac{((P_{k+1} - P_{int})^2 + (Q_{k+1} - Q_{int})^2)}{|V_{k+1}|^2} * R \tag{11}$$

$$Q_{Loss(k,k+1)}^{DG} = \frac{((P_{k+1} - P_{int})^2 + (Q_{k+1} - Q_{int})^2)}{|V_{k+1}|^2} * X \tag{12}$$

TABLE 1: EV CHARGING STATIONS [20], [26]

Level	Power (KW)	Supply Ratings	Bus Location
1	36	200-450V, 80A	-
2	96	200-450V, 210A	6,7
3	200	200-600V, 210A	8

TABLE 2: COMPENSATION & PENETRATION OF PV, CAPACITOR BANKS

DG/Capacitor	% Penetration / Compensation	Bus Location
PV	0-75	3
	0-25	6
	0-25	9
	0-25	12
Capacitor Bank	30	5
	50	6
	50	7
	20	8

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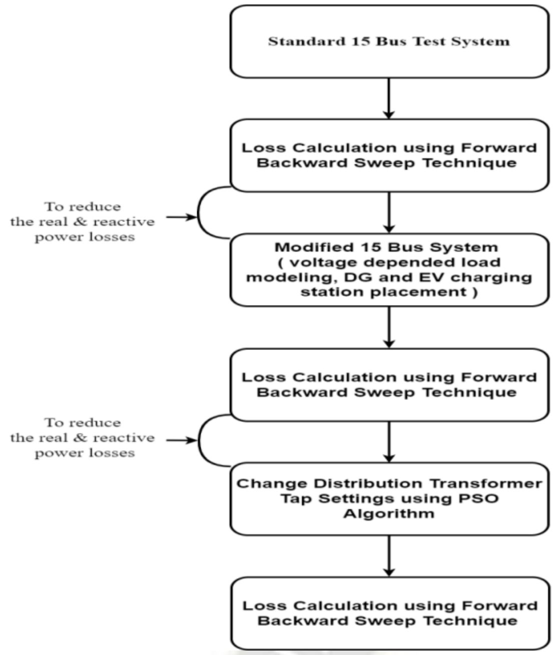

Fig. 3: Proposed Approach to Minimize the Losses.

Nonpartisan activity:

Here the single detached objective to abbreviate the power losses, i.e., real & reactive power losses. The objective function is characterized as follows

$$\min F(x) = \frac{1}{f(x)}; f(x) \neq 0$$

In this study, design variables include the edge presence, integrated service, and transformer tap settings. The tap settings have minimum and maximum limitations of 0.9 and 1.10 per unit (PU), respectively. Which is declared as VarLow = 0.9 and VarHigh = 1.1.

Table 3: Optimization Parameters for Transformer Tap Setting Adjustment.

S. No.	Parameter	Value
1	VarLow	0.9
2	VarHigh	1.1
3	Cognitive (C1)	1.5
4	Social (C2)	2.5
5	Inertia	0.3
6	Damping Ratio	0.95
7	Size of the Swarm	50
8	Max. iterations/Generations	100

III. RESULTS & DISCUSSION

To minimize power loss, an initial analysis was conducted on the 15-bus RDS using voltage load modeling. The results were then compared to those obtained using constant power modeling, as depicted in Figure 4.

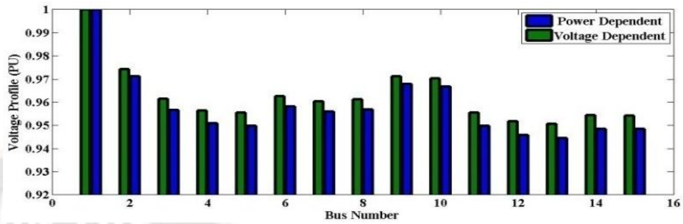

Fig. 4: Comparison between the power constraint and voltage load descriptions of the voltage profile.

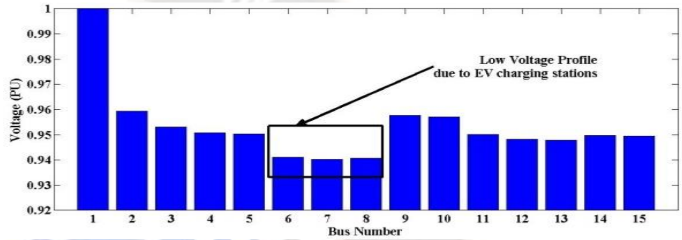

Fig.5: Comparison of the voltage profile of the distribution system before and after the deployment of EV charging stations.

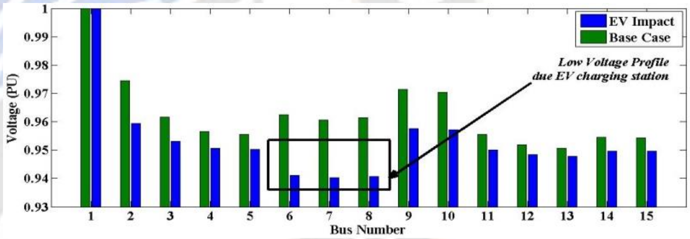

Fig. 6: Comparison of the voltage profile of the distribution system before and after the placement of EV charging terminals.

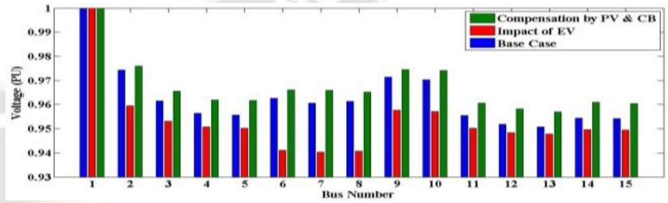

Fig.7: Impact of compensation on the voltage profile of the distribution system.

The EV charging station is installed in the 15-bus tree-like power distribution network (PDN) based on the voltage profile of the buses The presence of a 296 kW electric vehicle charging load leads to unpredictable load behavior and substantial power losses in the system. In particular, buses with EV charging stations have poor voltage profiles, which cause losses in both real and reactive powers. Fig. 5 depicts the drop in voltage profiles of buses, while Fig. 6 illustrates

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the voltage drop percentage at the buses with installed EV charging stations. According to Table 4, the increased losses in real and reactive power are 151.609% and 189.5%, respectively.

The combination of a distributed generation (DG) system and a capacitor bank enables adjustments in real and reactive power to restore the voltage profile of buses in the RDS, particularly when the presence of EV charging stations significantly affects them. The voltage profile in the RDS has improved, as seen in Fig. 6. The rectangular box in Figure 7 depicts the effect of the correction intended to counteract the effects of the EV charging stations at Bus Numbers 2 and 6. Fig. 8 illustrates how changing the transformer tap settings reduced power loss in the RDS.

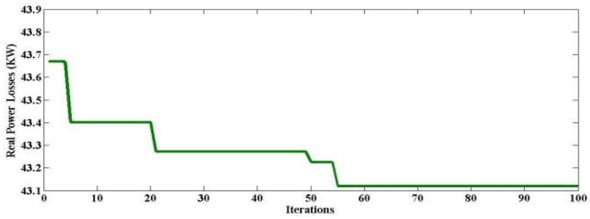

Fig.8: Reduction in active power loss achieved through PSO-based tap settings in the RDS.

TABLE 4: COMPARISON OF POWER LOSSES & VOLTAGE ELEVATION IN THE DISTRIBUTION POSITION

	Immutable Voltage Modeling (Base Case)	EV Charging Station employment	EV Charging Station & undefined DG with circuit breaker	PSO-based Distribution Transformer Tap Settings
Real Power loss (KW)	56.0682	140.95	46.4112	**43.2111**
Reactive Power loss (KVAr)	44.5854	129.02	32.0099	**32.1123**
Max. Voltage (P.U.)	0.97160 @ 2^{nd} Bus	0.9622 @ 2^{nd} Bus	0.9797 @ 2^{nd} Bus	**0.99247 @ 2^{nd} Bus**
Min. Voltage (P.U.)	0.94622 @13^{th} Bus	0.9400 @ 7^{th} Bus	0.9499 @13^{th} Bus	**0.96624 @13^{th} Bus**

Table 4 presents the results of the PSO-based transformer tap settings, which demonstrate a reduction in power loss and an improvement in the voltage profile of the distribution system. The impact of the EV charging station on the voltage profile was particularly significant at bus number 7 in the IEEE 15 bus system, as can be seen in Table 4 which demonstrates the reduction in power loss and improvement in voltage profile achieved through PSO-based transformer tap settings. However, by utilizing compensation and a PSO-based transformer tap settings strategy, the voltage profiles were improved, even at bus numbers 13 and 7. Moreover, the maximum voltage levels were also enhanced, along with the voltage profiles at those bus numbers.

IV. CONCLUSION

The research findings indicate that the implementation of PSO algorithm can be a viable solution to address power loss and voltage profile problems in radial distribution systems impacted by the addition of EV charging stations. The results show that the proposed method of locating and sizing capacitor banks along with PSO-based transformer tap settings can significantly reduce real power loss and improve voltage profiles in the distribution network. The research emphasizes the significance of adequate compensation for mitigating the effect of electric vehicle charging stations on the distribution network. The findings of this study can be useful for power distribution companies in designing and optimizing distribution systems to accommodate the increasing penetration of EVs. Further research can be done to investigate the effectiveness of other optimization techniques and the impact of different types of EV charging stations on distribution networks.

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