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Optimal Location of Electric Vehicle Charging Station in Reconfigured Radial Distribution Network

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ABSTRACT-Electric vehicles are becoming increasingly popular because they are cleaner-burning and more efficient than combustion-engine automobiles. Due to the diminishing availability of fossil fuels and the carbon emissions produced by cars, electric vehicles (EV) have become a need for mobility in the near future. Electric car charging stations were established as a consequence of the increase in EVs. Electric car charging lowers voltage and increases real power loss in the radial distribution network. In order to mitigate real power loss and provide a stable voltage profile, the charging station has to be placed as efficiently as possible. The current research examines and elucidates the influence of electric vehicle charging stations (EVCS) on the balanced radial distribution network (BRDN) using particle swarm optimization (PSO). There are two steps involved in the planning process. The optimal placement for EVCS [1] in BRDN is identified in the first stage using PSO. The second stage uses reconfiguration to ensure higher EVCS stability. This two-step technique's main goal is to decrease the real power loss due to the placement of charging stations in the radial distribution network (RDN). The correctness of the suggested approach is expounded upon in four different cases. The second, third, and fourth cases use a two-step procedure, which is then compared to the base case. In the base case EVCS is ideally located in BRDN using PSO. The fourth case employs a concurrent two-step optimization approach and demonstrates superior performance compared to other cases. The suggested approach is implemented and evaluated on the IEEE 69 bus BRDN using the MATLAB software.

Keywords: Radial Distribution Network, Particle Swarm Optimization, Reconfiguration, Optimal Location, Electric Vehicles, Charging Stations, Real Power Losses.

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1. INTRODUCTION

The use of electric vehicles (EVs) is increasing therefore there is need to mitigate future greenhouse gas emissions resulting from transportation. But we also know that electric vehicles are only environmentally friendly if the electricity needed to power them originates from renewable energy sources rather than fossil fuels. There are several development hurdles that the infrastructure for charging electric vehicles must overcome. While there is still a long way to go before electric cars are a common form of transportation worldwide, the market for EVs has seen rising demand. Electric cars might revolutionize the global transportation industry. By 2028, the number of electric cars in all categories of two- and four-wheelers will keep rising.

With further study, EVs can perform on level with conventional cars, but EV charging infrastructure is a significant obstacle for the ecosystem of electric transportation. The impact of charging patterns on the distribution network might vary significantly depending on the location of the charging station[2], particularly in the context of a large fleet of electric vehicles. This phenomenon has the potential to lead to excessive load and power dissipation. The potential consequences might be mitigated from a system planning standpoint by the smart placement of charging stations throughout the distribution system. Reconfiguring the distribution network cuts down the system losses without the need for devices like DGs and capacitors to make up for them.

In EVs, the charging plan and the reconfiguring the RDN were optimized in two steps. The goal was to reduce real power losses as much as possible. Most of the research talked about how EVs affect the power grid and how reconfiguration can be used to lessen those effects. The literature doesn't talk about multi feeder distribution network like IEEE 69 bus systems, which would help us figure out where the EVCS should be placed best. The research proposes applying the heuristic algorithm Particle Swarm Optimization (PSO) to find the optimal location of EVCS[3] to minimize real power losses and to improve the voltage profile as well as reconfiguring the radial distribution network. The method is used on a standard IEEE 69 bus system in radial distribution network considering the four different cases explained in the upcoming sections.

2. PROBLEM FORMULATION

The increasing usage of EVs is closely correlated with the fast advancement of energy storage technology. Nevertheless, scientific research has yet to address the need to examine the consequences of adopting EVCS on the RDN[4]. This research investigates the effects of integrating EVCS into radial distribution networks and aims to reduce power losses via strategic system reconfiguration. The current research will employ distribution load flow analysis to analyze the mentioned impacts.

2.1 Distribution Load Flow Analysis

Load flow analysis[5] is a computational technique used to ascertain the voltage magnitude and phase angle at every bus within a power system. In the manuscript the load flow is generalized with the 6 bus system. The forward/backward load flow is generally used majority of the literature due to its efficiency. Additionally, it enables the determination of power flow in each branch of the system, power injection from each generating source, and the quantification of system losses. The analysis of radial distribution systems involves the use of forward and backward sweep load flow techniques.

In the load flow analysis, the bus voltages are first set to a flat voltage profile or 1.0 per unit (p.u.) in the forward direction. The computation of the initial branch current can be obtained by considering the previous branch current and accounting for the existing loads on each bus. Consequently, this analysis of load flow is sometimes referred to as forward/backward load flow. Let V_{bus} represent the voltage of the bus and I_{bus} denote the current of the bus in per unit (p.u.) values. The calculation of bus current involves the utilization of bus voltage, real power, and reactive power. The determination of branch current, denoted as I_{branch}, is derived by employing the bus incidence matrix and I_{bus}. Similarly, the voltage drop is determined by utilizing the I_{branch} and the impedance Z.

A detailed evaluation of the radial distribution network (RDN) [6]using the proposed approach is briefly outlined employing a limited sample radial distribution network, as seen in *figure 1*.

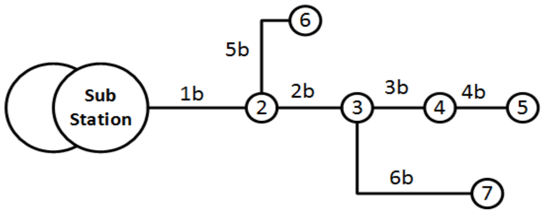

Figure 1: Line diagram of RDN

Table 1: Data pertaining to line characteristics, load characteristics, and the computed losses for the given sample radial distribution system (RDS) at different bus locations

Branch No	Bus No	Sending end bus	Receiving end bus	Resistance (Ω)	Reactance (Ω)	Real Power Load (kW)	Reactive Power Load (kVAR)	Simulation outputs		
								Bus Voltage (p.u)	Branch Current (p.u)	Losses (kVA)
1	1	1	2	0.2	0.03	12	10	1.00	1.00	8.16+j 1.83 *Individual losses*
2	2	2	3	0.4	0.04	3	6	0.905	0.90	
3	3	3	4	0.15	0.01	5	8	0.855	0.88	
4	4	4	5	0.32	0.05	10	7	0.882	0.87	
5	5	2	6	0.43	0.02	6	4	0.875	0.90	
6	6	3	7	0.52	0.01	8	5	0.902	0.88	
-	7	-	-	-	-	-	-	0.881	-	

Table 1 displays the line data and bus data of the sample distribution system. The assumed values for the actual power and reactive power of the load at the bus are shown in *table 1*. These values are used in the calculation of the branch currents, starting from the last branch and progressing towards the first branch.

$$I_{bus} = S^{*}_{bus} / V_{bus} \quad (1)$$

$$I_{branch} = [K]\, I_{bus} \quad (2)$$

Where, [K] is bus incidence matrix [X].

$$\Delta V = Z \times I_{branch} \quad (3)$$

$$V_{bus\_u} = V_{bus} - \Delta V \quad (4)$$

The calculation of bus currents is performed using the voltage provided in equation (4), which has been updated. The aforementioned procedure is iterated until the discrepancy betweenVbus and Vbus_u reaches the predetermined error tolerance threshold of 0.0001.

The calculation of losses at the m^{th} branch, situated between the i^{th} and j^{th} branches, is derived as follows:

$$\text{Losses at the } m^{th} \text{ branch} = \{V(i) - V(j)\}^2 \times Z^{-1} \quad (5)$$

The objective function for the given problem is minimization of losses of the radial distribution system.

2.2 EVCS Modelling

The primary assumption behind the modelling of Electric Vehicle Charging Stations (EVCS)[2] is that they provide the EV battery with precisely the necessary amount of actual current. There are three types of charging station for EVs which are three phase AC charging station, DC slow charging station and DC fast charging station[7]. In this case fast charging station is considered which is modelled as an extra load to the system. The size of the EVCS is varying as per the size of the real load of the system. When an Electric Vehicle Charging Station (EVCS) is linked to a bus, it results in an increase in the actual power of that bus.

The type of EV charging station is considered as the fast-charging station since the load is consider as fixed load which is not time varying. Hence, in order to mitigate the branch currents within the system, it is essential to strategically position the Electric Vehicle Charging Stations (EVCS) at an appropriate location. This will result in an enhanced overall performance of the system.

2.3 Reconfiguring the Existing Radial Distribution Network

Reconfiguration is an act of rearranging the design of a distribution network in a manner that does not disturb its radial nature[8]. This approach is a very efficient and economical method for reducing system losses, without the need for additional compensating devices inside the system. The primary concern in this situation is to the determination of the appropriate quantity of tie line switches to be used, a decision dependent upon the number of RDS loops. This article examines the optimal methodology for determining the appropriate number of main switches and tie line switches. The objective of the optimization process is to minimize system losses by accurately reconfiguring the system. In this article, a heuristic technique is used to minimize system losses by determining the optimal times for opening and closing switches.

3. OPTIMAL LOCATION OF EVCS IN RECONFIGURED RDN USING PSO

The physical significance of the EVCS location is that the selection of low sensitive voltage bus which is nearer to the substation. The physical significance of EVCS is that every system can able bear 150 % of its rated load capacity hence the size of the EVCS is also the 50% excess of the load of the respective system. Particle swarm optimization (PSO)[9] has been identified by previous studies as a computational approach that offers a straightforward methodology for locating the closest possible optimum solution. The dimension of the particle swarm optimization depends on the number of unknowns in the objective functions to be optimized. In this case the unknowns are varied in two optimization problem. These methods are during reconfiguration of radial distribution system which depends on the number of tie-line switches, location of EVCS to be placed in the radial distribution system and both reconfiguration and placement of EVCS in radial distribution system. However, the impact of incorporating EVCS[4] into the RDN with regard to of voltage profile, actual power losses, and reactive power losses has not been extensively discussed by researchers. The convergence process of the optimization method that the losses of the system must be as less as possible with the proceeding of every iteration. The losses of the system calculated using forward/backward load flow with the placement of EVCS and reconfiguration switches at every iteration for finding least losses among them. This research presents a suggested technique for the selection of the most suitable bus for integrating EVCS into an established BRDN. The network constraints during optimization is for bus voltage which is between 0.95 p.u and 1.05 p.u. In order to validate the idea, an examination of the operation of the BRDN is conducted in several cases utilizing the Particle Swarm Optimization (PSO) technique.

Case-1: BRDN with EVCS Integration and without Reconfiguration.
Case-2: EVCS Integration before the reconfiguration of established BRDN
Case-3: EVCS Integration after the reconfiguration of established BRDN
Case-4: EVCS Integration along with reconfiguration simultaneously in established BRDN.

The above cases are validated through simulation by implementing on IEEE 69 bus BRDN shown in *figure 2*.

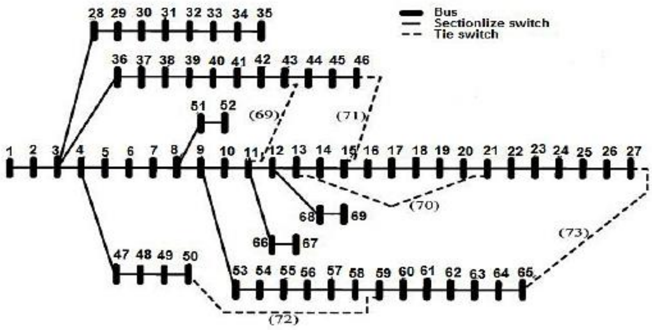

Figure 2: Line diagram of IEEE 69 bus BRDN

Case-1: BRDN with EVCS Integration and without Reconfiguration

Particle Swarm Optimization (PSO) factors [10] including particle number, starting velocity, ultimate velocity, minimum inertia, maximum inertia, and maximum generation number are initialized before optimization which are shown in *table 2*.

Table 2: The parameters of PSO

S.No	Parameter	Value
1	Number of Particle Swarms(N)	50
2	Maximum number of iterations	100
3	Maximum Inertia (wmax)	0.9
	Minimum Inertia (wmin)	0.2
4	Initial Velocity (v1)	2
5	Final Velocity (v2)	2

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The particle-matrix dimension equals the number of elements in the desired function, each with lower and upper limits. Here, tie line switches represent system parts. After each generation, inertia updates initialized particles. The minimum target function value is computed in each generation, and the lowest desired function value is found throughout all generations. The present challenge involves EVCS quantity.

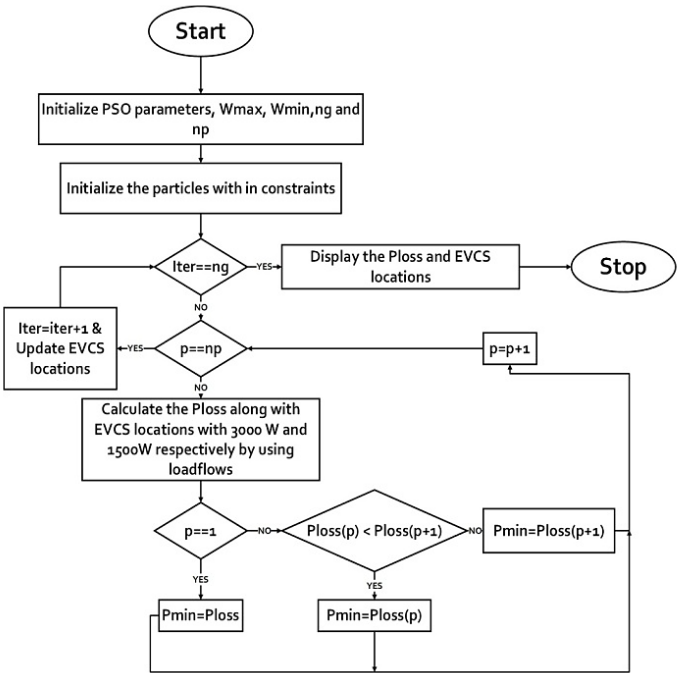

Figure 3. Flow chart for BRDN with EVCS Integration and without Reconfiguration

Case-2: EVCS Integration before the reconfiguration of established BRDN

The appropriately located EVCS adds load to the electrical system during EV charging, increasing branch current. Increased branch current increases voltage-drop and overall battery losses. It uses more grid current, lowering performance. Thus, adding the EVCS and other compensating devices should enhance the voltage profile and reduce losses. After optimizing the EVCS location, radial distribution networks are inspected and reconfigured to decrease losses. The mentioned process flowchart is in *Figure 4*.

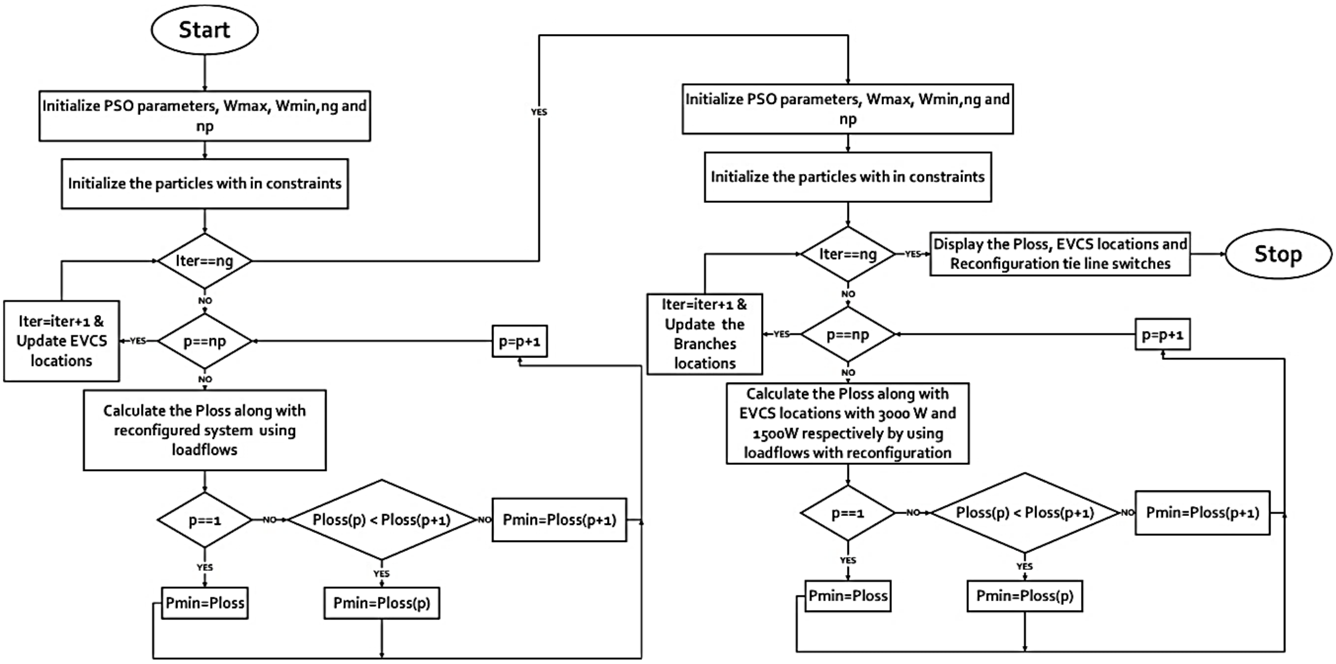

Figure 4. Flow chart for EVCS Integration before the reconfiguration of established BRDN

Case-3: EVCS Integration after the reconfiguration of established BRDN

One potential approach to enhancing system performance is through reconfiguration, which offers a cost-effective option without the need for supplementary devices such as distributed generator (DG). This approach enhances the utilization of the existing resources. An examination of a distribution system's functioning is conducted thoroughly in this case. *Figure 5* depicts the flowchart representing the mentioned process.

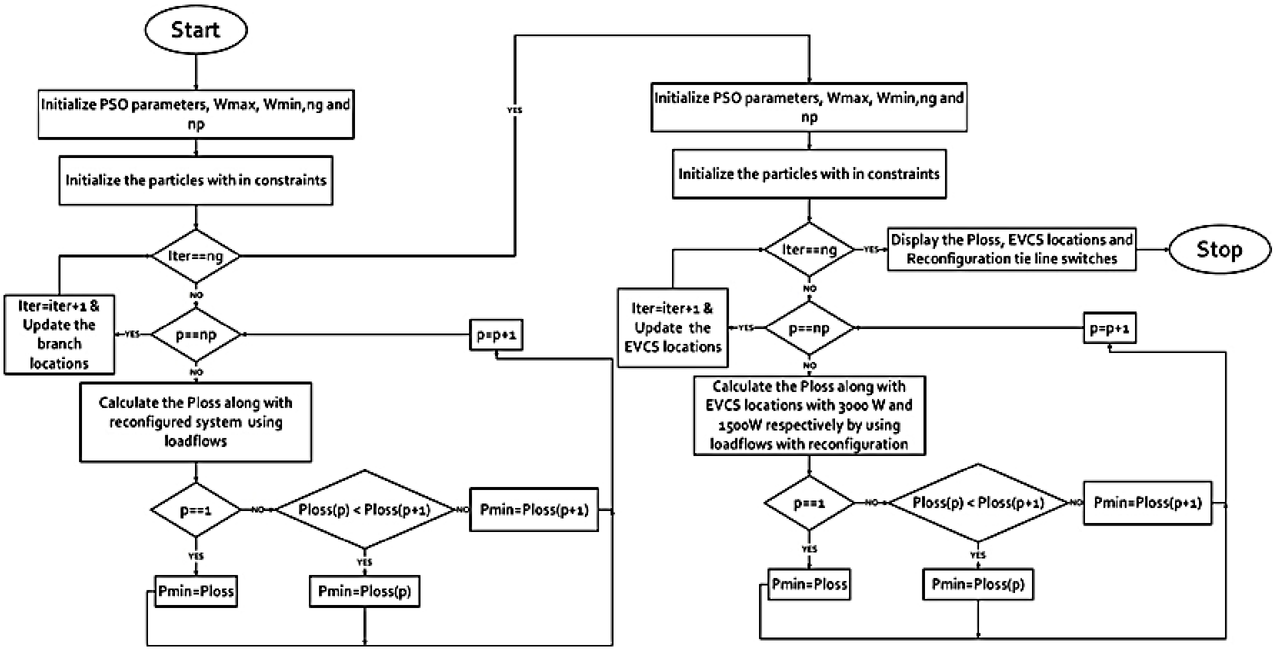

Figure 5. Flow chart for EVCS Integration after the reconfiguration of established BRDN

Case-4: EVCS Integration along with reconfiguration simultaneously in established BRDN

In order to analyze the effectiveness of the Radial Distribution Network (RDN), this research focuses on the tactical location EVCS in conjunction with the process of reconfiguration. *Figure 6* illustrates the flowchart representing the mentioned process.

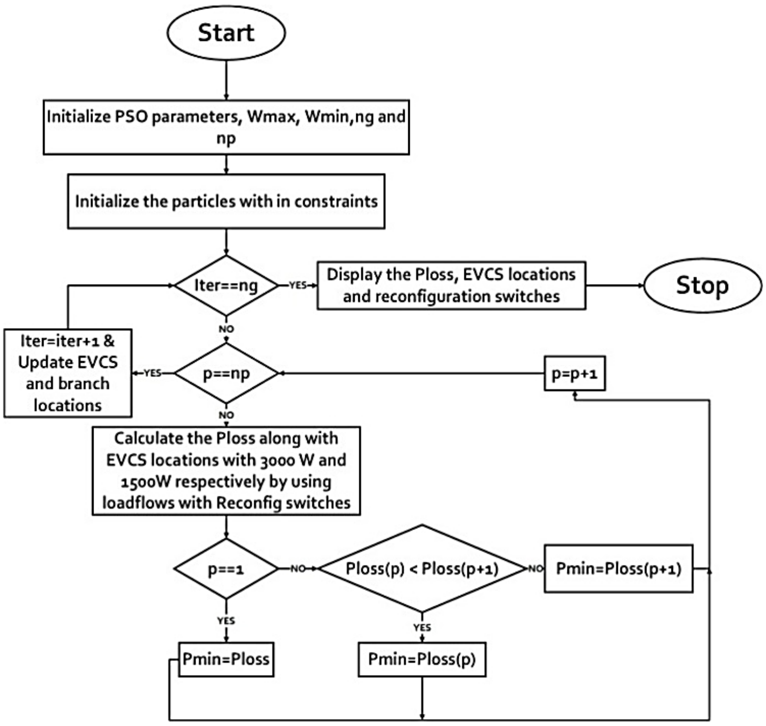

Figure 6. Flow chart for EVCS Integration along with reconfiguration simultaneously in established BRDN

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4. RESULTS AND DISCUSSION

The appropriateness of the proposed approach is demonstrated by its implementation on the standard IEEE 69 bus radial distribution network [11]. Base apparent power is 10 MVA and nominal voltage is 12.66 kV for the 69-bus distribution system. As illustrated in Figure 2, this system contains 69 nodes, 73 branches, and tie-lines 69-73. All five of these tie-lines remain open during normal conditions of operation and connected to these buses and actual and reactive power demands. The system's voltage profile, real and reactive power losses are assessed. This research analyses a 3.8 MW charging station with 10 kW charging devices. Four different cases are used to verify the system where EVCS capacity being constant. The Results of Case-1 and Case-2 are shown in *figure 7* and *figure 8*. The Results of Case-3 and Case-4 are shown in *figure 9* and *figure10*.

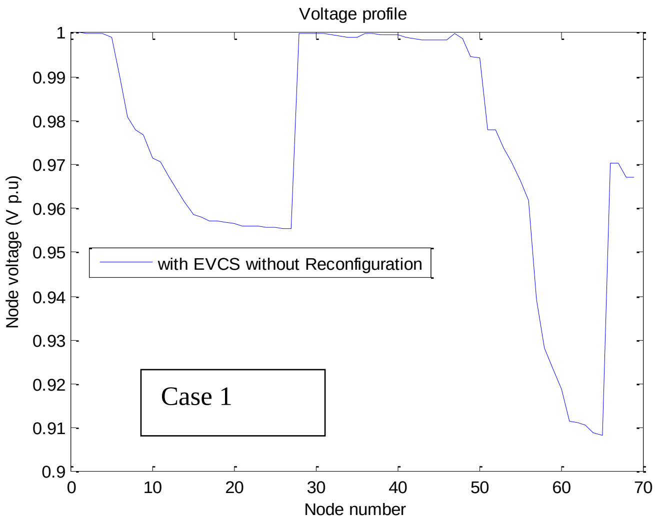

Figure 7: Voltage profile during EVCS Integration into an established BRDN

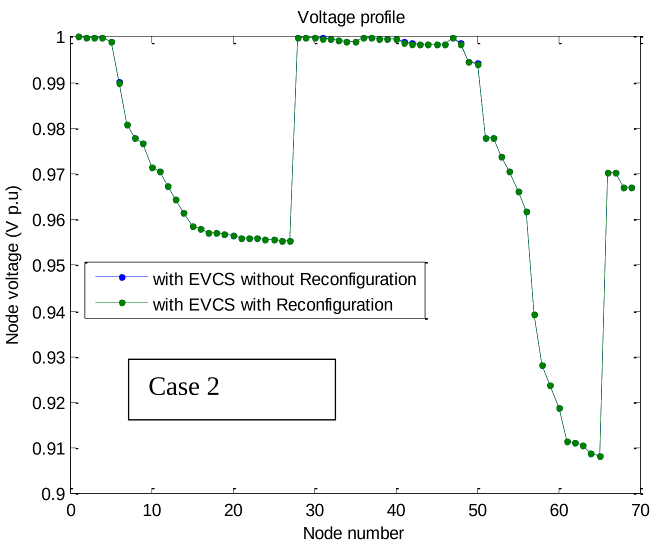

Figure 8: Voltage profile during EVCS Integration before Reconfiguration of an established BRDN

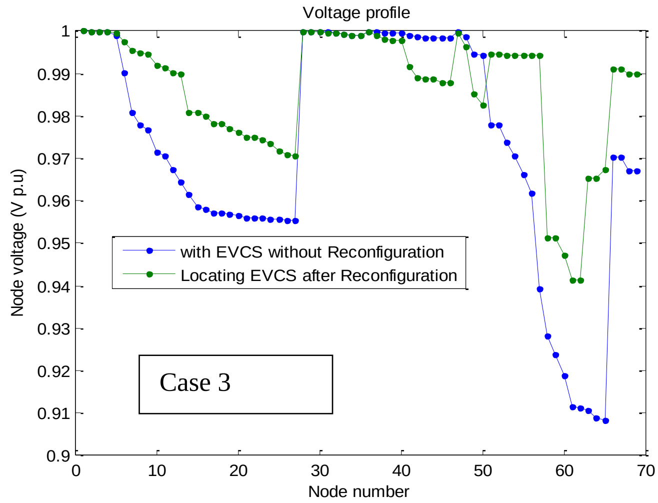

Figure 9: Voltage profile during EVCS Integration after Reconfiguration of an established BRDN

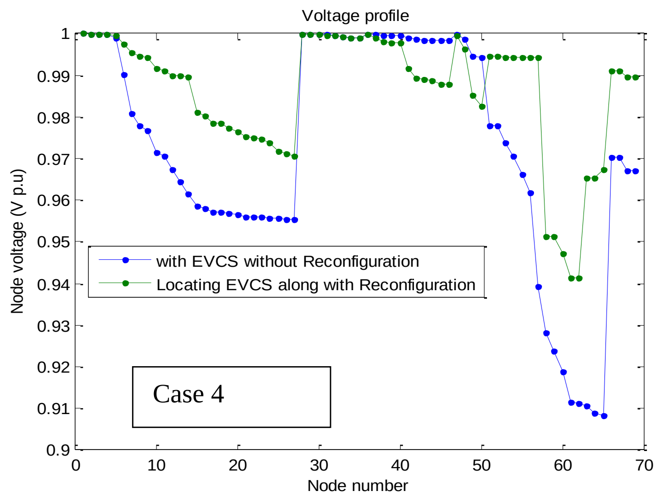

Figure 10: Voltage profile during EVCS Integration along with Reconfiguration simultaneously in an established BRDN

Table 3: Comparison of real power losses of IEEE 69 bus RDN

Cases	Switches opened for reconfiguring existing RDN	Real power losses (kw)	Minimum voltage (p.u) & (bus number)	Optimal location of EVCS
Case-1	-	225.4	0.9083 & (65)	2
Case-2	14,58,61,69,70	225.6	0.9083 & (65)	2
Case-3	13,57,62,69,70	101	0.9414 & (61,62)	2
Case-4	14,57,62,69,70	100.9	0.9414 & (61,62)	2

The results obtained from the research are compared in *table 3*, and we can observe that in IEEE 69 bus RDN the optimal location for EVCS placement is at bus 2 and the real power losses are less during the case-4 *i.e.*, EVCS Integration along with reconfiguration.

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5. CONCLUSION

Electric Vehicle Charging Stations (EVCS) serve as the crucial link between the electrical grid and the transportation network. The working performance of electric vehicles (EVs) will exert a substantial influence on infrastructures in a concurrent manner. Therefore, the optimal location of EVCS within the BRDN is of utmost importance. This research presents a comprehensive analysis of the optimal placement and reconfiguration of EVCS within the IEEE 69 bus BRDN. The primary objective is to minimize real power losses and enhance the stability and security of the power system network. Four scenarios were presented, demonstrating the reduction of actual power losses by reconfiguration through the utilization of PSO technique. The results of these scenarios were afterwards compared to validate the effectiveness of the method of planning.

The results obtained from the research indicate that in IEEE 69 bus RDN the optimal location for EVCS placement is at bus 2 and the real power losses are less during the case-4 i.e., EVCS Integration along with reconfiguration. The research shows the proposed approach has beneficial impact on minimizing real power losses and improving the stability of the power system network. Thus, without external compensators, the proposed method shows optimize solution for problems of electric transportation infrastructure.

The future research directions are when the EVCS are near to the consumer premises and that location is far from the distribution grid then the impact of these EVCS on distribution grid is even worse. Therefore, Integrating DG units with EVCSs may further reduce the system real power losses. These DGs reduces real power losses, improves voltage profile and which have capability of enhancing the power quality and reliability of the system.

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