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Optimal Planning of Electric Vehicle Charging Station along with Multiple Distributed Generator Units

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Abstract: Saving energy through the minimization of power losses in a distribution system is a key activity for efficient operation. Distributed Generation (DG) is one of the most efficient approaches to minimize losses. With increase in installation of Electric Vehicle Charging Stations (EVCSs) for Electrical Vehicles (EVs) in larger scale, optimal planning of EVCSs becomes a major challenge for distribution system operator. With increased EV load penetration in the electricity system, generation-demand mismatch and power losses increases. This results in poor voltage level, and deterioration in voltage stability margin. To mitigate the adverse impacts of increasing EV load penetration on Radial Distribution Systems (RDS), it is essential to integrate EVCSs at appropriate locations. The EVs integration into smart distribution systems involves Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) in charging and discharging modes of operation respectively for exchange of power with the grid thus resulting in energy management. The inappropriate planning of EVCSs causes a negative impact on the distribution system such as voltage deviation and an increase in power losses. In order to minimize this, DG units are integrated with EVCSs. The DGs assist in keeping the voltage profile within limitations, resulting in reduced power flows and losses, thereby enhancing power quality and reliability. Therefore, the DGs should be optimally allocated and sized along with the EVCS to avoid problems such as protection, voltage rise, and reverse power flow problems. This paper showcases a method to minimize losses using optimal location and sizing of multiple DGs and EVCS operating in G2V and V2G modes. The sizing and location of different types of DG units including renewables and non-renewables along with EV charging station is proposed in this study. This methodology overall reduces the power losses and also improves voltages of the network. The implementation is done by using the Simultaneous Particle Swarm Optimization technique (PSO) for IEEE 15, 33, 69 and 85 bus systems. The results indicate that the proposed optimization technique improves efficiency and performance of the system by optimal planning and operation of both DGs and EVs.

Index Terms: Distributed Generation, Particle Swarm Optimization (PSO), EV Charging Station, Smart Grid.

1. Introduction

Environmental pollution and soaring energy consumption with improvements in battery technology have started a new era in the electrification of the transportation sector. Electric Vehicles (EVs) are being considered as the best solution for road transportation system. Fossil fuel dependency, reduced emission of greenhouse gases and air pollutants which have a significant impact on global warming can be reduced with the usage of EVs. According to Business Intelligence and Strategy (BIS) research, the EV market is estimated to expand at Compound Annual Growth Rate (CAGR) of 43.13% between 2019 and 2030 [1]. However, the increasing number of EVs with rapid development and growth of EV markets in the transportation sector offers tremendous opportunities and challenges to the grid operators with increasing charging demand. Optimal planning and operation are key elements to minimize the operational risk of utilizing the existing distribution networks and deploy massive amount of EVs. Apart from lowering emissions, various researchers focus on investigating the advantages of the use of EVs at the grid level. EVs are connected to grid for the only purpose of battery charging. Nevertheless, the development and advancement of Smart Grids (SGs) have effectively transformed the traditional grid system. They have the ability to enable and promote the integration and utilization of renewable and sustainable energies into the distribution system [2]. The new SG technology is providing the flexibility of energy discharge to the grid and is technically named as Vehicle-to-Grid (V2G) operation [3]. In V2G mode, the energy in stationary EVs can be sent back into the grid to help supply energy at peak demand. EVs are considered as load when there is enough amount of active power and considered as power suppliers when there is lack of active power. With this facility, voltage fluctuations are suppressed and reserve supply is provided. The construction of Electric Vehicle Charging Stations (EVCSs) puts additional stress on the power network because the high charging rates of fast EVCS would degrade the distribution network's operational parameters. Massive installation of EVs will impact the aging infrastructure, power losses, aid voltage and harmonic distortions when penetrated for charging into the distribution network. In order to reduce adverse effects of EVs, proper site selection of EVCS is necessary. Distribution System Operators (DSOs) should carefully consider EV charging stations to prevent overburdening the network and to maximize operational flexibility. Hence to increase the penetration of EVs and to reduce impact of EVCSs on operational components of the distribution system like current, voltage and losses, Distributed Generation (DG) units are integrated.

Distributed generation is the need of the day of meeting the required demand from customers. DG has an immense effect on relieving the burden on distribution system which is embedded into it by using modular technology. It is in fact a small-scale power generator which experienced lot of developments in the past 10 to 15 years. It is essential to determine the proper capacity and position of DG sources in distribution networks in order to reap the full benefits of their potential [4]. The deployment of DG is one of the best strategies for reducing losses arising from the large development of EVs. Integration of EVCS with DG units helps to mitigate the charging effects of EVs. In order to prevent voltage increase, higher losses, reverse power flow problems, and to provide protection, the DGs need to be optimally allocated and sized along with EVCS. Optimal placement of DG and EVCS in the network is an important aspect to maximize the efficiency and to get maximum benefits with the placement of EVCS. The exploitation of future EVs capability is considered to be one of the possible solutions to promote the incorporation of renewable energies into energy systems.

The ultimate objective is therefore to ensure the optimum location and sizing of renewable and non-renewable DGs with EVCS by using an optimization strategy that minimizes total losses while sustaining the reliability and stability of the power system. The following are the primary contributions of this study, given in a step-by-step manner:

- Finding the optimal location of EVCS with objective function of loss reduction and voltage improvement.
- Simultaneously placing DGs and EVCS at best locations with proper sizing while EVCS acting as load by considering the system constraints to reduce losses.
- Similarly, simultaneously placing and sizing of DGs and EVCS at best locations while EVCS in V2G mode by considering the system constraints to reduce losses further.

2. Relevant Background

Many studies have been conducted on the optimal placement and sizing of EVCS. Md. Mainul islam et al [5] presented a detailed study on various methods used to improve the placement and sizing problems of EVCS. Mondeep Mazumder and Sanjoy Debbarma [6] provided a detailed study on the viability of incorporating EVs into the existing distribution system, taking into account slow and fast charging. The study considered and compared both G2V (Grid-to-Vehicle) and V2G (Vehicle-to-Grid) technologies. Sanchari Deb et al [7] have been carried out research on the effect of the EVCS loads on voltage stability, power losses, reliability and economic losses. Yuttana Kongjeen and Krischonme Bhumkittipich [8] based on voltage-dependent control; they proposed the impact of EVs integrated into a power distribution system. This study showed the static voltage stability using the new load flow methodology. Galiveeti Hemakumar Reddy et al [9] analyzed the impact of EV connection on system reliability and proposed an energy index EENC for deciding the EVCS location and preventing from not charging due to the distribution system failures. Kang Miao Tan et al [10] reviewed the framework, advantages and constraints of V2G and outlined the major optimization techniques with multiple constraints. Mingsheng Zhang [11] proposed a model with minimized investment and charging cost for charging station placement. Priyanka Shinde, K.Shanti Swarup [12] analyzed the effect of EVCS load connected on the grid and proposed that optimization of reactive power of EVs can be used to increase the voltage profile in the system. M. Bagheri Tookanlou et al [13] designed a scheduling scheme that relies primarily on ensuring the incentives of both V2G and G2V operators. Xiangwu Yan et al [14] presented a multi-objective model for calculating the losses and investment costs using hierarchic genetic algorithm. Recently several heuristic optimization techniques have been used to solve the EVCS placement problems along with DGs. Hassan Fathabadi [15] analyzed different effects of EVs and PHEVs (Plug-in Hybrid EVs) with V2G connection capability and renewable energy sources used as DGs on a power distribution network. Leila Bagherzadeh [16] addresses a multi-objective optimization problem to ensure the optimal grid operating schedule, with EVs and DGs in the smart grid. The distribution approaches Beta and Weibull were used to resolve renewable resources uncertainties in the model. To solve the optimization problem, Cuckoo bird Optimization Algorithm was used. Mahnaz Moradijoz [17] implemented simultaneous placement of DGs and parking lots in the test system. Results show a significant reduction of losses with presence of DG units and parking lots. The results of the simulation show that changes to the charge rate and the numbers of EVs on the parking lot cause changes to the optimal location of the charging station and the DG. Zhipeng Liu [18] developed a model mathematically for the optimal sizing of EVCS with the minimization of total cost related with planning of EVCS as the objective function.

In light of the above works, this paper presents an effective method to minimize losses through optimal location and sizing of multiple types of DGs and optimal location of EVCS when operating as load in Grid-to-Vehicle (G2V) mode and DG itself when operating in Vehicle-to-Grid (V2G) mode, which overall reduces the power losses of the network. The optimization is performed using Simultaneous Particle Swarm Optimization (PSO) method. In the framework for power flow calculation, EV is considered as a static load and the EV charging with respect to time is not considered under balanced load conditions. By maintaining the initial size of the DG, the optimal location of EVCS load in both G2V and V2G modes in the system improves efficiency. Thus, this approach (allocation of DG and EV load) is indeed very beneficial for power utilities, which can reduce power losses by determining the appropriate locations for DG and EVCS. Four realistic frameworks are tested for effect i.e. 15, 33, 69 and 85 Bus IEEE RDS.

3. Method

In this paper, Simultaneous PSO methodology has been developed for optimal placement and sizing of DGs and EVCS in smart distribution systems. EVs acting in both G2V and V2G modes with and without DGs are performed to calculate the losses and voltage values. The V2G mode of EV is used to inject the energy to the system for restoration during the system failures. The various constraints of DG and EV are taken and maximum allowable capacities for both DG and EV are mentioned. DGs of different types operating with various power factors are considered and implementation is done for various bus systems. The placements of EVCS along with different types of DGs are performed with EV operating as load and DG itself. Thus, the proposed algorithm helps in reducing the power losses problem in the distribution network. The impact of the EVCS on the real power loss, reactive power loss and voltage magnitude are analyzed significantly in this work.

4. Modelling of Electric Vehicle Load

An EV load model is expressed as:

$$\mathrm{EV_{Power}} = \mathrm{S_0} \times \mathrm{k_p} \times \left(\frac{\mathrm{V_i}}{\mathrm{V_{i0}}}\right)^{\mathrm{n_{pi}}} \tag{1}$$

where S_0 indicates the apparent load power (kVA) at nominal voltage V_{i0}, n_{pi} is the exponential index value for EV load equals to 2.59, k_p is representing the load power factor (pf) given as k_p= 0.995 lagging taking into account the values from available EV chargers in market. EV load in this paper is considered as static load with real power injection. The total amount of load varies from normal values of 1226.4, 3715, 3802.2 and 2569.3 kW to 1544.09, 3926.41, 4093.04 and 2880.92 kW respectively for 15, 33, 69 and 85 Bus systems when load flow is applied. At this point, it can be said that the integration of EVs to the distribution system increases the overall load of the system and should be adequately planned to enhance technical and economic benefits and consequently to improve the inclusion rate of EV technologies.

The amount of power needed to charge an EV with the efficiency of the charger is as follows:

$$\mathrm{P_{Chrgng}} = \eta_{\mathrm{Chrgng}} \times \mathrm{P_{injected}^{rate}} \tag{2}$$

In this work, EV charger rating is considered as both power load and DG in G2V and V2G operations respectively. EVs with Li-ion batteries are considered for modeling the EVCS and assumed that it delivers only required real power to batteries of EV. In this paper, charging level of type 3 fast charging EVCS is considered which has the charging power of 50 kW for each EV and rated voltage/current of 480V/167A. In terms of actual and reactive power supply capabilities, DG units can be divided into four main categories according to their terminal features [19]:

- DGs of Type 1 are only capable of injecting active power
- DGs of Type 2 are only able to deliver reactive power
- DGs of Type 3 capable of injecting active as well as reactive power
- DGs of Type 4 capable of injecting active power but absorbs reactive power

5. Objective Function

The line losses are estimated as:

$$P_{Loss} = \sum_{i=1}^{nb} I_i^2 R_i \tag{3}$$

Hence, growing demand for load of a single bus would lead to net growth in the distribution network's total power losses. Minimization of the total power losses including both active and reactive power losses and enhanced voltage profile with EVs inclusion are the main objectives of this paper:

$$\mathrm{Minimization}\{\mathrm{P_{Loss}}\} \tag{4}$$

6. DG and EV Constraints

6.1. *Current limit*

$$\left|\mathrm{I_{ij}}\right| \le \mathrm{I_{maximum}} \tag{5}$$

Where I_{ij} is the capacity of line current flow between I and j, I_{max} is the maximum current carrying capacity of the power line.

6.2. *Voltage limit*

$$\mathrm{V_{Bus\_min}} \le \mathrm{V_{Bus}} \le \mathrm{V_{Bus\_max}} \tag{6}$$

$$0.95\ \mathrm{pu} \le \mathrm{V_{Bus}} \le 1.05\ \mathrm{pu} \tag{7}$$

where V_{Bus} is the bus voltage, V_{Bus_min} is the minimum allowable bus voltage, and V_{Bus_max} is the maximum allowable bus voltage.

6.3. *EV battery SOC limit*

EV battery SOC (State of Charge) should be kept within the specified range to reduce battery degradation. In addition, the EV battery cannot completely be discharged because those energy quantities are allocated for use with the EV drive.

$$\mathrm{EV_{SOC\_min}} \le \mathrm{EV_{SOC}} \le \mathrm{EV_{SOC\_max}} \tag{8}$$

where EV_{SOC} is the state of charge for EV, EV_{SOC_min} is the minimum acceptable EV SOC and EV_{SOC_max} is the maximum acceptable EV SOC.

6.4. *Power distribution limit*

The electric energy supplied form the grid and DGs including the EVs connected to the grid should meet the demand for load and system losses with EVCS operating in either one of the two modes.

- In G2V mode

$$P_{Grid} + \sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} (P_{iLoad} + P_{iEVCS}) + P_{Losses} \tag{9}$$

- In V2G mode

$$P_{Grid} + \sum_{i=1}^{N} (P_{DGi} + P_{iEVCS}) = \sum_{i=1}^{N} P_{iLoad} + P_{Losses} \tag{10}$$

where P_{Grid} is the power generated from grid generator, P_{EVCS} is the power related to EVCS and P_{iLoad} is the load demand.

6.5. *DG sizing limit*

$$50 \le \mathrm{DG_{Sizing}} \le 3500 \tag{11}$$

Different types of DGs such as Type-1, Type-2, Type-3 and Type-4 DG are considered whose limits are in kW, kVAr, KVA and KVA respectively.

7. Particle Swarm Optimization (PSO) Methodology

Kennedy and Eberhart developed the early PSO technique as a stochastic optimization strategy based on swarming behavior. It offers solutions for complicated numerical maximization or minimization of constrained nonlinear problems. Due to a number of benefits compared to certain other heuristic optimization algorithms, PSO was preferred to mitigate the optimization problem in this article. The adaptive and exhaustive nature to the essence of the objective function with requirement of low memory size and computation time made this method more advantageous. A decreased reliance on the set of initial points also ensures that the convergence algorithm will be versatile and vigorous. Particles travel in a certain velocity through the multi-dimensional problem field in this method. Each particle in the swarm is in a position to interact. This helps them to change their moving speed in accordance with their own and other particle movement patterns. The particle swarm's spontaneous motion keeps the solution from being stuck at local minimum. Each particle maintains control of its own location in the problem space throughout the PSO iteration. For each iteration, the present position of each particle is evaluated if it can be found to be greater than all the values that have previously been found, and then these coordinates are stored as $P_{Best,i}$. A variable named $G_{Best,i}$ store the best value of the function. With prior experience, current velocity and the best perceptions of the neighbors, every particle decides about evolution based on its own experience as well as that of its neighbors. The particles position and velocity are updated with each iteration. If taken k number of iterations with i number of particles, for each particle the position(X) and velocity (V) can be reckoned by [20]:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{12}$$

$$V_i^{k+1} = \omega^k \times V_i^{k+1} + C_1 \times rand_1 \times \left(P_{Best,i}^k - X_i^k\right) + C_2 \times rand_2 \times \left(G_{Best,i}^k - X_i^k\right) \tag{13}$$

$$\omega^k = \omega_{max} - \left(\frac{\omega_{max}-\omega_{min}}{k_{max}}\right) \times k \tag{14}$$

where ω is the inertia weight factor, C_1andC_2 are acceleration coefficients, rand1 and rand2 are the random variables with a uniform distribution between 0 and 1, $P_{Best,i}$ is the local best of particle i and $G_{Best,i}$ is the global best of the group.

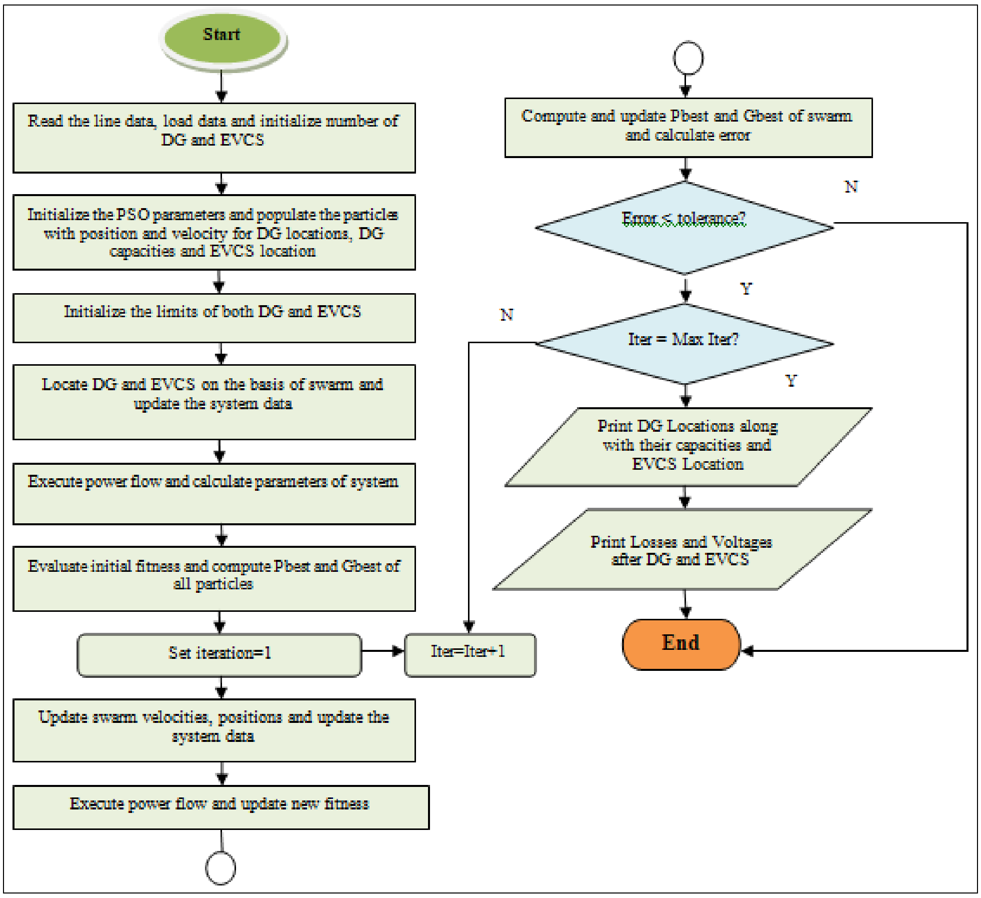

Fig.1. Flowchart for simultaneous placement of DG and EVCS using PSO methodology

The complete structure of the work to solve the optimal multiple DGs and EVCS placement along with the sizing of four different types of DGs operating at different power factors using PSO is shown in Fig.1. The following are the steps involved in applying the PSO algorithm to solve the problem of optimal EVCS and DG allocation:

Step 1: Initialize the bus data, number of DGs and EVCSs subjected to equality and inequality constraints

Step 2: Initialize the parameters corresponding to upper and lower limits of DG sizes in kW, EVCSs, PSO parameters and maximum number of iterations

Step 3: Initialize population of particles having positions X and velocities V

Step 4: Set iteration =1

Step 5: Using forward-backward load flow, evaluate the initial population and objective function values (3) and find the index of the best particle

Step 6: Select P_{best} and G_{best}

Step 7: Update positions and velocities of particles using (12) and (13)

Step 8: Evaluate fitness and find the index of the best particle for both DGs and EVCS

Step 9: Update P_{best} and G_{best} of total population and calculate error

Step 10: If iteration is equal to maximum iterations, then increment iteration by 1 and go to step 6 instead go to step 11

Step 11: Print G_{best} as the optimal solution and stop.

8. Results

DGs of types 1, 2, 3 and 4 are considered in which type-3 DG with power factors of 0.707, 0.9 and upf are taken as Type-3A, Type-3B and Type-3C respectively and their DG capacities are in kW, kVAr, KVA and KVA respectively.

8.1. IEEE 15-bus system

Using Load flow, without placing any DG unit and EVCS, the real and reactive power losses are 61.7944 kW and 57.2977 kVAr respectively with a minimum voltage of 0.9445p.u. In this system, EVCS is with capacity of 500kW such that 10 EVs can be charged at a time.

Table 1. Optimal Locations and Sizing of DGs and EVCS for 15-Bus system

15-BUS SYSTEM						
DG Type	EVCS as Load			EVCS as DG		
	DG Loc	EVCS Loc	DG Cap	DG Loc	EVCS Loc	DG Cap
No DG	**	9	**	**	4	**
Type-1	4 6 11	6	1677.1	6 12 9	4	722.40
Type-2		9	1211.9	11 4 6	4	1182.32
Type-3A		4	2004.6	4 6 12	3	1329.80
Type-3B		4	2002	4 6 12	3	1164.23
Type-3C		6	1677.1	6 12 9	4	722.40
Type-4	3 6 13	3	1187.7	12 15 6	15	483.07

Table 1 shows different DG and EVCS locations and their capacities in both modes of operation. Without any DG the optimal location for EVCS placement is obtained at bus 9 when it is modeled as load and at bus 4 when modelled as DG.

Table 2. Percentage reduction of Losses and Voltage magnitudes with EVCS as Load for 15-Bus system

15-BUS SYSTEM -EVCS LOAD								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	61.7944	87.7281	57.2977	80.3977	0.9445	0.9382	-41.97	-40.32
Type-1	96.0733	31.3598	86.24	28.7789	0.9381	0.9712	67.36	66.63
Type-2	87.7281	54.838	80.3977	49.785	0.9382	0.9639	37.49	38.08
Type-3A	97.96	5.8344	92.3882	4.9996	0.9326	0.994	94.04	94.59
Type-3B	97.96	5.1167	92.3882	4.0461	0.9326	0.9921	94.78	95.62
Type-3C	96.0733	31.3598	86.24	28.7789	0.9381	0.9712	67.36	66.63
Type-4	92.1708	13.8692	86.8338	12.5299	0.9328	0.9923	84.95	85.57

From Table 2 it is identified that with no DG and EVCS as load, active power losses are raised by 41.97% and voltage magnitude is reduced to 0.9382 from 0.9445 p.u. After the implementation of DGs losses are significantly reduced. Type-3B DG operating at 0.9 pf can reduce the losses to maximum level.

Table 3. Percentage reduction of Losses and Voltage magnitudes with EVCS as DG for 15-Bus system

15-BUS SYSTEM -EVCS DG								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	61.7944	42.8084	57.2977	38.6701	0.9445	0.9559	30.72	32.51
Type-1		30.9455		28.4814		0.9736	49.92	50.29
Type-2		12.8076		10.7047		0.9805	79.27	81.32
Type-3A		5.0515		4.3186		0.9946	91.83	92.46
Type-3B		14.0034		12.8091		0.9908	77.34	77.64
Type-3C		30.9455		28.4814		0.9736	49.92	50.29
Type-4		6.112		4.444		0.9923	90.11	92.24

From Table 3, at condition with EVCS as the only DG losses are reduced by 30.72% providing a reserve capacity of active power in peak load conditions. Type-3A DG operating at 0.707 pf reduces the losses to maximum value.

8.2. IEEE 33-bus system

Using Load flow, without placing any DG unit and EVCS, the real and reactive power losses are 210.9983 kW and 142.5335 kVAr respectively with a minimum voltage of 0.9038p.u. In this system, EVCS is with capacity of 1000kW such that 20 EVs can be charged at a time.

Table 4. Optimal Locations and Sizing of DGs and EVCS for 33-Bus system

33-BUS SYSTEM						
DG Type	EVCS as Load			EVCS as DG		
	DG Loc	EVCS Loc	DG Cap	DG Loc	EVCS Loc	DG Cap
No DG	**	19	**	**	12	**
Type-1	13 24 30	24	3946.7	14 24 31	6	2255.8
Type-2		19	1969.5	13 24 30	12	1928.2
Type-3A		19	3441.8	14 24 30	7	2911.5
Type-3B		30	4333.4	7 14 30	24	2676.4
Type-3C		24	3946.7	14 24 31	6	2255.8
Type-4	6 15 33	19	2040.7	3 15 31	7	2132.6

Table 4 shows different DG and EVCS locations and their capacities in both modes of operation. Without any DG the optimal location for EVCS placement is obtained at bus 19 when it is modelled as load and at bus 12 when modelled as DG.

Table 5. Percentage reduction of Losses and Voltage magnitudes with EVCS as Load for 33-Bus system

33-BUS SYSTEM EVCS LOAD								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	210.9983	218.1959	142.5335	147.0347	0.9038	0.9031	-3.41	-3.16
Type-1	269.5939	72.7861	178.6682	50.6527	0.8995	0.9687	73.00	71.65
Type-2	218.1959	145.2607	147.0347	98.6042	0.9031	0.9311	33.43	32.94
Type-3A	218.1959	23.1122	147.0347	17.7977	0.9031	0.9897	89.41	87.90
Type-3B	378.2896	11.7599	255.7761	9.7692	0.8783	0.9921	96.89	96.18
Type-3C	269.5939	72.7861	178.6682	50.6527	0.8995	0.9687	73.00	71.65
Type-4	210.9983	20.1196	142.5335	16.5257	0.9038	0.9863	90.46	88.41

From Table 5 it is identified that with no DG and EVCS as load, active power losses are raised by 3.41 % and voltage magnitude is reduced to 0.9031 from 0.9038 p.u. After the implementation of DGs losses are significantly reduced. Type-3B DG operating at 0.9 pf can reduce the losses to maximum level.

Table 6. Percentage reduction of Losses and Voltage magnitudes with EVCS as DG for 33-Bus system

33-BUS SYSTEM EVCS DG								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	210.9983	129.9652	142.5335	86.0748	0.9038	0.9319	38.40	39.61
Type-1		67.6703		47.2133		0.9703	67.93	66.88
Type-2		63.4575		42.463		0.9612	69.93	70.21
Type-3A		11.2445		9.6237		0.9941	94.67	93.25
Type-3B		17.6343		13.6154		0.9926	91.64	90.45
Type-3C		67.6703		47.2133		0.9703	67.93	66.88
Type-4		20.1196		16.5257		0.9863	90.46	88.41

From Table 6, at condition with EVCS as the only DG losses are reduced by 38.40% providing a reserve capacity of active power in peak load conditions. Type-3A DG operating at 0.707 pf reduces the losses to maximum value.

8.3. IEEE 69 bus system

Using Load flow, without placing any DG unit and EVCS, the real and reactive power losses are 224.9846 kW and 102.1937 kVAr respectively with a minimum voltage of 0.9092p.u. In this system, EVCS is with capacity of 1000kW such that 20 EVs can be charged at a time.

Table 7. Optimal Locations and Sizing of DGs and EVCS for 69-Bus system

69-BUS SYSTEM						
DG Type	EVCS as Load			EVCS as DG		
	DG Loc	EVCS Loc	DG Cap	DG Loc	EVCS Loc	DG Cap
No DG	**	3	**	**	62	**
Type-1	11 18 61	3	2626.7	11 18 61	49	2624.7
Type-2	18 61 66	3	1844.8	18 61 69	61	1711.7
Type-3A	11 21 61	3	3081.7	18 50 61	53	3382.1
Type-3B	18 61 69	61	3811.8	18 61 66	49	3038.7
Type-3C	11 18 61	3	2626.7	11 18 61	49	2624.7
Type-4	19 62 69	3	2001.1	2 19 62	9	2754.3

Table 7 shows different DG and EVCS locations and their capacities in both modes of operation. Without any DG the optimal location for EVCS placement is obtained at bus 3 when it is modelled as load and at bus 62 when modelled as DG.

Table 8. Percentage reduction of Losses and Voltage magnitudes with EVCS as Load for 69-Bus system

69-BUS SYSTEM EVCS LOAD								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	224.9846	225.0444	102.1937	102.3291	0.9092	0.9092	-0.03	-0.13
Type-1	225.0444	69.4332	102.3291	35.0195	0.9092	0.979	69.15	65.78
Type-2	225.0444	145.3454	102.3291	67.8842	0.9092	0.9314	35.41	33.66
Type-3A	225.0444	9.634	102.3291	9.1352	0.9092	0.992	95.72	91.07
Type-3B	450.2212	5.6522	197.1544	7.3497	0.8663	0.9943	98.74	96.27
Type-3C	225.0444	69.4332	102.3291	35.0195	0.9092	0.979	69.15	65.78
Type-4	225.0444	13.3506	102.3291	10.8993	0.9092	0.9917	94.07	89.35

From Table 8 it is identified that with no DG and EVCS as load, active power losses are raised slightly by 0.03%. After the implementation of DGs losses are significantly reduced. Type-3B DG operating at 0.9 pf can reduce the losses to maximum level.

From Table 9, at condition with EVCS as the only DG losses are reduced by 50.29% providing a reserve capacity of active power in peak load conditions. Type-3A DG operating at 0.707 pf reduces the losses to maximum value.

Table 9. Percentage reduction of Losses and Voltage magnitudes with EVCS as DG for 69-Bus system

69-BUS SYSTEM EVCS DG								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	224.9846	111.836	102.1937	53.4916	0.9092	0.9485	50.29	47.66
Type-1		68.0119		31.5495		0.979	69.77	69.13
Type-2		41.6506		23.3525		0.9683	81.49	77.15
Type-3A		7.008		3.2411		0.9938	96.89	96.83
Type-3B		8.3502		5.7068		0.9967	96.29	94.42
Type-3C		68.0119		31.5495		0.979	69.77	69.13
Type-4		11.0168		9.4495		0.9933	95.10	90.75

8.4. *IEEE 85 bus system*

Using Load flow, without placing any DG unit and EVCS, the real and reactive power losses are 314.6786 kW and 198.2695 kVAr respectively with a minimum voltage of 0.8715p.u. In this system, EVCS is with capacity of 1000kW such that 20 EVs can be charged at a time.

Table 10. Optimal Locations and Sizing of DGs and EVCS for 85-Bus system

85-BUS SYSTEM						
DG Type	EVCS as Load			EVCS as DG		
	DG Loc	EVCS Loc	DG Cap	DG Loc	EVCS Loc	DG Cap
No DG	**	16	**	**	27	**
Type-1	9 34 67	67	3791.5	22 35 68	8	1086.63
Type-2	32 64 85	3	2073.3	34 64 80	27	2019.20
Type-3A	9 34 67	3	3178.4	34 64 80	3	2735.70
Type-3B	32 64 85	32	4058.3	34 64 80	3	2578.20
Type-3C	9 34 67	67	3791.5	22 35 68	8	1086.63
Type-4	2 32 60	3	3341.5	2 32 60	3	1841.18

Table 10 shows different DG and EVCS locations and their capacities in both modes of operation. Without any DG the optimal location for EVCS placement is obtained at bus 16 when it is modeled as load and at bus 27 when modelled as DG.

From Table 11 it is identified that with no DG and EVCS as load, active power losses are raised by 8.15 and voltage magnitude is reduced to 0.8699 from 0.8715 p.u. After the implementation of DGs losses are significantly reduced. Type-3B DG operating at 0.9 pf can reduce the losses to maximum level.

Table 11. Percentage reduction of Losses and Voltage magnitudes with EVCS as Load for 85-Bus system

85-BUS SYSTEM EVCS LOAD								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	PL%	QL%	After	PL%	QL%
No DG	314.6786	340.3334	198.2695	211.6632	0.8715	0.8699	-8.15	-6.76
Type-1	788.8099	147.7525	476.0793	92.446	0.7933	0.9524	81.27	80.58
Type-2	342.1544	178.6736	216.5288	112.252	0.8675	0.9146	47.78	48.16
Type-3A	342.1544	22.1964	216.5288	12.9519	0.8675	0.9883	93.51	94.02
Type-3B	836.9211	24.7653	498.3282	12.3179	0.7697	0.9861	97.04	97.53
Type-3C	788.8099	147.7525	476.0793	92.446	0.7933	0.9524	81.27	80.58
Type-4	342.1544	33.3163	216.5288	17.6098	0.8675	0.9804	90.26	91.87

From Table 12, at condition with EVCS as the only DG losses are reduced by 40.99% providing a reserve capacity of active power in peak load conditions. Type-3A DG operating at 0.707 pf reduces the losses to maximum value.

The graphical representations of active power losses and minimum voltage profile for all the bus systems with and without installation of DG units and EV charging station are represented from Fig.2 to Fig.5.

The active power losses obtained with the placement of EVCS load in both G2V and V2G modes before and after installation of DGs are plotted in Fig.2 and Fig.3 respectively. From Fig.2 and Fig.3, it is observed that in comparison with other types of DG, the percentage of loss reduction and minimum voltage level is more with Type-3A DG which operates at power factor of 0.707. This is because of the locally available reactive power for the loads, thus reducing the available reactive power from the substation.

Table 12. Percentage reduction of Losses and Voltage magnitudes with EVCS as DG for 85-Bus system

85-BUS SYSTEM EVCS DG								
DG Type	P_L (kW)		Q_L (kVAR)		V_{min} (p.u)		Loss Reduction	
	Before	After	Before	After	Before	After	PL%	QL%
No DG	314.6786	185.6974	198.2695	112.0164	0.8715	0.9257	40.99	43.50
Type-1		148.2011		92.688		0.9542	52.90	53.25
Type-2		45.584		23.3275		0.9662	85.51	88.23
Type-3A		18.0639		9.2457		0.9924	94.26	95.34
Type-3B		48.0635		28.5621		0.9891	84.73	85.59
Type-3C		148.2011		92.688		0.9542	52.90	53.25
Type-4		27.3096		13.8864		0.9825	91.32	93.00

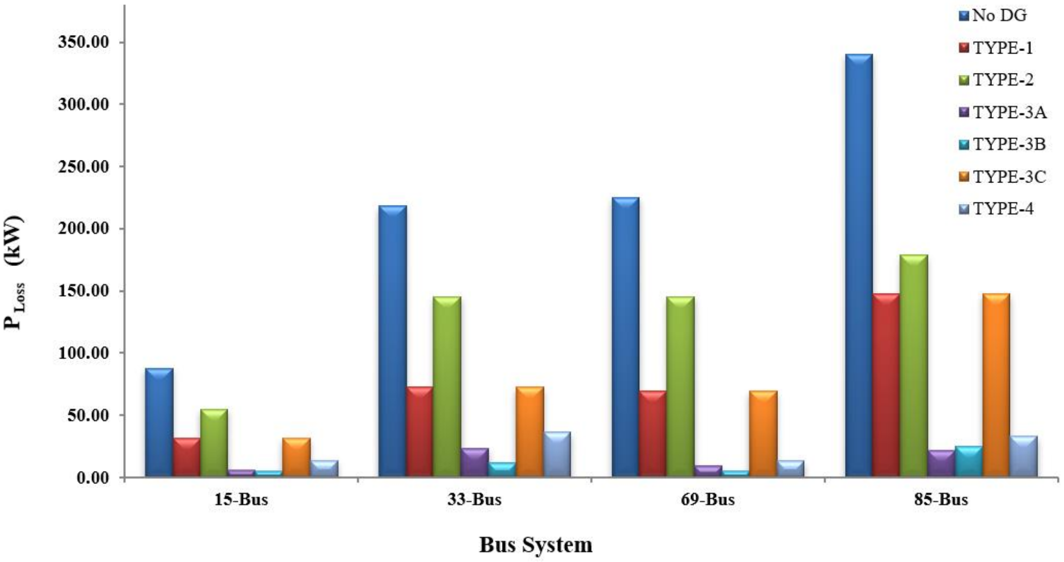

Fig.2. Comparison of Active losses when EVCS acting as load (G2V) mode

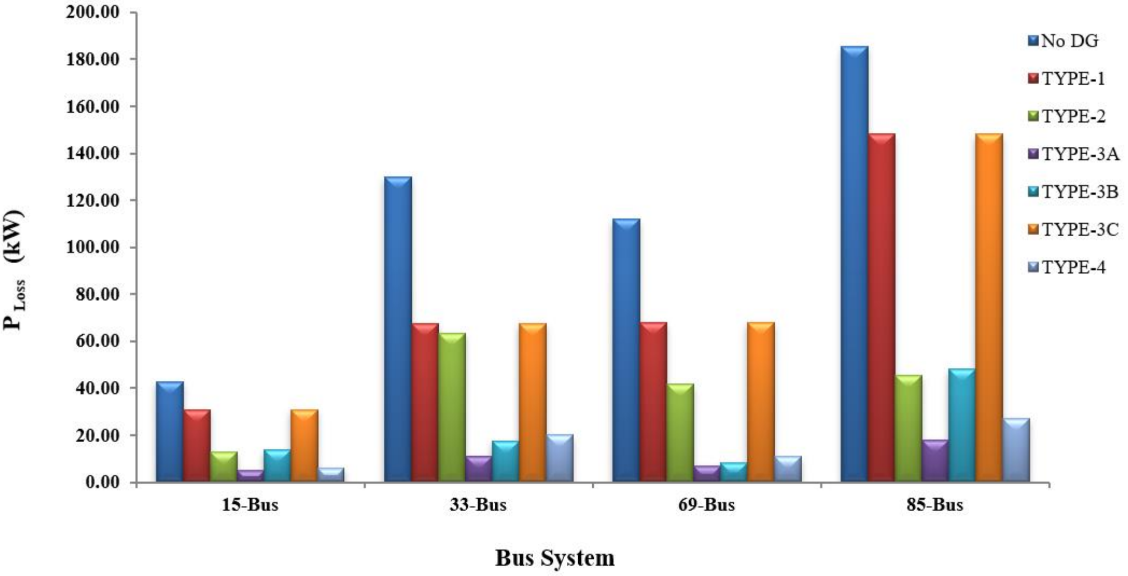

Fig.3. Comparison of Active losses when EVCS acting as DG (V2G) mode

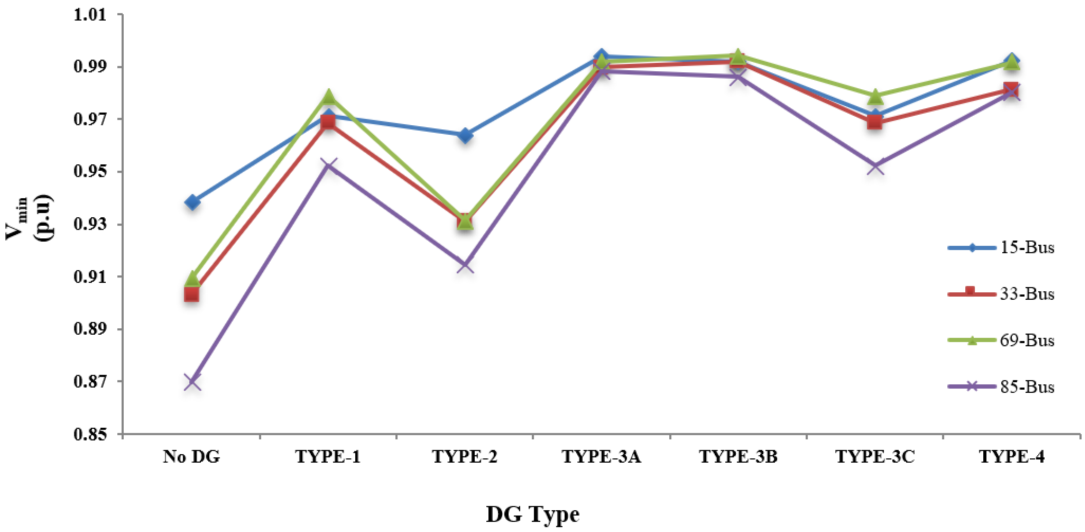

Fig.4. Vmin profile when EVCS as load

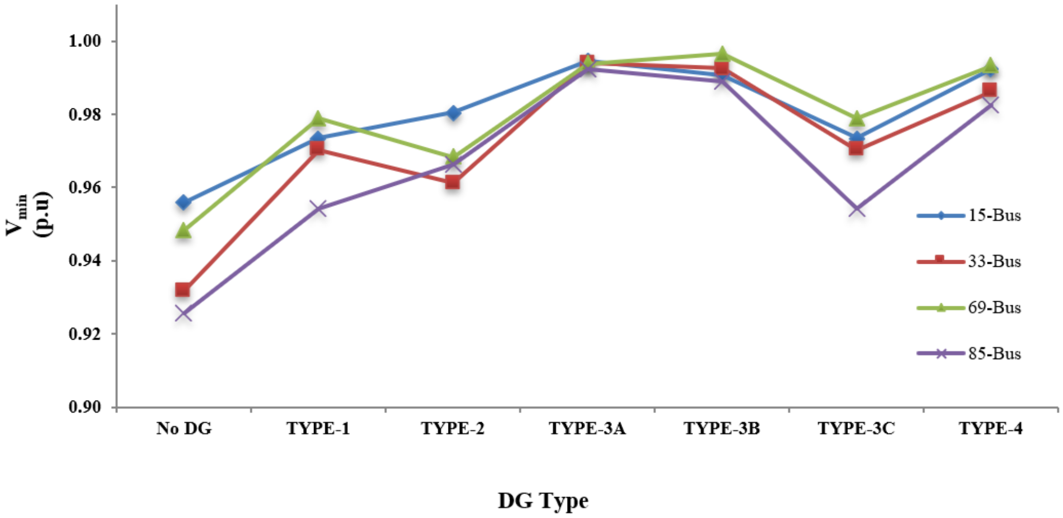

Fig.5. Vmin profile when EVCS as DG

The minimum voltage profiles of all the bus systems with EVCS as load and DG are shown in Fig.4 and Fig.5. The V_{min} values are very low without any DG and they are enhanced to higher values after installation of DGs thus increasing the stability of the system.

9. Discussions

Greenhouse gas emissions are reduced at a great extent by using EVs and they have positive effect on the environment. Nevertheless, the negative impact of the EV charging station load on the electricity distribution network cannot be ignored. In certain aspects, the charging load of large-scale electric vehicles would eventually impact the operation safety of distribution network in many ways. Installation of charging stations to increase accessibility for everyone is a requirement to use electric vehicles at large scale. A vital part of the process is the location and capacity of charging station installations. To facilitate electric vehicle users experience, planning of charging facilities is important to improve and accelerate the promotion and development of electric vehicles. Concurrently connected EVs to the grid can cause more losses and large voltage deviation at distinct buses from different sources. Therefore, this work presented a method of optimally locating the EVCS along with DGs to reduce losses and emissions. The Simulation results illustrate the importance of optimal concurrent placement of both EVCSs and DGs in the distribution system. The present simultaneous method provides the best locations along with their capacities which reduces the computational time, memory and gives more effective results. The proposed algorithm in this paper helps to reduce the power losses problem in the distribution network. Another advantage of using this algorithm is that the computation time needs a smaller number of load flow analysis in the process. Algorithm works fine even with and without DGs present in the distribution network. This is a new approach for simultaneous placement. The below simulated results are achieved in the four bus systems showcases these items:

- Utilizing DGs in a grid decreases the total losses and also improves the voltage profile of the grid.
- Utilizing EVCSs as load in G2V mode increases the power losses. The losses are significantly high if they are not placed optimally.
- Utilizing EVCSs with V2G in a grid significantly decreases the power losses and improves the voltage magnitudes.
- Utilizing both DGs of different types and EVCSs in a grid effectively decreases the power losses, and significantly improves the voltage profile. The amount of loss reduction is higher when EVCS also act as DG source.

All of the results presented here indicate that as the penetration of EVs in the distribution system increases, power losses will increase, and higher voltage drops in the system will occur. However, after optimum installation of the DGs, losses can be minimized and the voltage profile can be improved simultaneously. The conclusion can provide guidelines on the future design of the EV charging station and power system planning for PEVs.

10. Conclusions

The EV charging station load effect on the distribution network power loss is presented and the results tested on various systems are reported in this article. Placement of various renewable and non-renewable DG types and EVCS are done simultaneously in the test systems. Proposed technique is tested on 15, 33, 69, and 85-bus test systems without DG and with multiple DGs along with EVCS acting as load and DG simultaneously. Four types of DGs with Type-3 DG operating at different power factors are considered for the simulations. The EV charger load is modeled as a fast EV charger consuming 50 kW power. Test Systems results indicate that charging impacts of EVCSs on voltage quality and operation performance of distribution networks can be mitigated by optimal placement. With charging station operating in bidirectional operation ((i.e., G2V and V2G services), more EVs can be facilitated without distribution transformer overloading. In both G2V and V2G operation, incorrect allocation of EVCS locations increases losses and have bad effect on voltage profile. Thus, optimal integration of DGs into distribution feeder increases the EVs penetration while reducing real and reactive power losses and eventually improving voltage profiles in the distribution system. The main findings of the simulation are summarized as follows:

- Relative to those without the charging stations, the power losses after the placement of the charging stations were high.
- Minimum power losses can be obtained in the system with EVCS placed far from the substation with the presence of DG units.
- The optimum placement and sizing of the 3 Type-3 DGs led to significant reduction in power losses and to voltage enhancement.

The current state of EVs stations installation is gaining traction all over the world. By utilizing the method in this paper will improve the overall system where power losses can be reduced. There are several intriguing research directions to pursue in the future. One is to examine the impact of EV charging on the power grid by location and time of day using charging demand modelling and second is multiple coordinated charging station development in unbalanced systems.

11. Abbreviations

BIS: Business Intelligence and Strategy; CAGR: Compound Annual Growth Rate; DG: Distributed Generation; EV: Electric Vehicle; EVCS: Electric Vehicle Charging Station; G2V: Grid-to-Vehicle; PHEV: Plug-in Hybrid Electric Vehicle; PSO: Particle Swarm Optimization; RDS: Radial Distribution System; SG: Smart Grid; SOC: State of Charge; V2G: Vehicle-to-Grid.

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