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INTELLIGENT LOCATING AND SIZING OF DISTRIBUTED ENERGY RESOURCES IN DISTRIBUTION SYSTEM IN THE PRESENCE OF ELECTRIC VEHICLES

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Abstract- This paper proposes the intelligent locating and sizing of Distributed Energy Resources (DERs) in distribution network in the presence of electric vehicles. Different objectives are considered for DER placement including: loss reduction and reduction in power purchased from the market. By introducing the smart grids, customers are now more active in the electricity market; one way is through the electric vehicles. However it changes the way that the distribution network used to perform. Therefore in this paper, the DER placement problem is solved in the presence of electric vehicles. The Imperialist Competitive Algorithm (ICA) as one of the newest and most powerful optimization tools is employed in this study to solve this complicated optimization problem. The effectiveness of the proposed method is demonstrated using IEEE 30-bus radial distribution test system and the results are discussed in detail. Two case studies are carried out in this paper. The first one deals with the DER placement problem when electric vehicles are not present in the network. The second case solve the same problem in the presence of electric vehicles. The obtained results of these two cases are compared. The comparison illustrates the necessity of consideration of electrical vehicles in the planning problem of DER placement.

Keywords: Distributed Energy Resources (DERs), Electric Vehicles, Imperialist Competitive Algorithm, Loss Reduction.

I. INTRODUCTION

With the advent of smart grids along with the desire for reduction in greenhouse gas emissions and the need for increasing the social welfare through reducing the planning and operation cost of power systems, an augmented interest in Distributed Energy Resources (DERs) have been experienced [1-2].

By optimal placement and sizing of DERs many benefits could be achieved; optimal placement demands special attentions as well as consideration of all factors in the planning stage. Many studies investigated the benefits of DER placement. The most important benefits of DER are modeled in [3] in form of economic terms to ease the evaluation of DER placement problem while [4] proposed a set of indices in order to model and quantify the technical benefits of DERs.

The aim of the optimal DER placement is to determine the best locations and size of DER units to optimize the costs and quality of the delivered electric power to the customers. Several models and methods have been suggested for the solving this complicated optimization problem. An overview of the state of the art models and methods applied to the DER placement problem is proposed in [5], in which the applied approaches are analyzed and the current and future research trends are classified.

Several benefits could be achieved by optimal placement of DER units in the distribution systems. Two multi-objective formulations based on the GA and an ε-constrained method as optimization method for the placement and sizing of DER in distribution networks were proposed in [6]. The same problem was solved using a classic optimization method, GA, and an innovative approach for a sub-transmission network in [7].

The Smart Grid is a set of software and hardware tools capable of routing power more proficiently, and therefore reducing the need for excess capacity and upgrade of the existing system. The main difference between the current grid and the smart grid is that the last is a transformed electricity and distribution network which uses two-way communications, advanced intelligent technologies to enhance the efficiency and reliability of power supply. Being equipped with ICT-based (Information and Communication Technologies) optimization technology, smart grids are capable of communicating with demand side loads that offer a variety of options to make the grid load and production more predictable and adaptable [8].

The focuses of Vehicle-to-Grid (V2G) researchers have mainly been on interconnection of energy storage of vehicles and grid [9-13]. Their aim is to educate about the environmental and economic benefits of V2G and improvement of the power market. However, success of V2G technology mainly depends on the efficient scheduling of Gridable Vehicles (GVs) considered restricted number of parking lots. Ideally speaking, gridable vehicles for V2G technology should be charged from renewable sources. A gridable vehicle can be considered as a small portable power plant [14].

In this paper, we focus on applying the Imperialist Competitive Algorithm (ICA), to find the optimal location and size of the DER units in the presence of electric vehicles. The objectives for DER placement include: loss reduction, expansion cost minimization and reduction of power purchased from electricity power market. ICA as one the newest and most powerful optimization tools is employed in this study to solve the optimization problem. The potential of ICA regarding other evolutionary techniques in solving the complicated optimization problems in the realm of power system has been demonstrated in [1], [15-16].

The contribution of this paper is consideration the impact of EV integration in the distribution network on the DER placement. With the emergence of EV, their presence is inevitable in the distribution network and therefore they will affect the operation and planning of these systems. This impact should be identified and investigated in DER placement and sizing as one of the most important planning studies in distribution network. As a result, this paper deals with this problem and aims at identifying the impact of EVs integration on DER planning problem.

The rest of the paper is organized as follows. Section II gives an overview of vehicle to grids. Imperialist Competitive Algorithm is briefly described in section III. Proposed approach is presented in section IV. The proposed method is carried out on IEEE 30-bus radial distribution test system, and the results are presented and discussed in detail in section V. The concluding remarks are drawn in Section VI.

II. VEHICLE-TO-GRID

Plug-in Hybrid Electric Vehicles (PHEVs) are hybrid electric vehicles that can draw and store energy from an electric grid to supply propulsive energy for the vehicle energy consumption. This simple functional change enables a PHEV to displace energy from petroleum with multi-source electric energy [17]. This has important and generally beneficial influence on petroleum consumption, pollution, as well as on the performance and makeup of the electric grid. Because of these characteristics and their near-term availability, PHEVs are seen as one of the most promising means to enhance the sustainability of the energy sectors [18].

A widespread adoption of electric vehicles will need to be taken into account in all activities within power systems. However, some activities will more likely be subject to more severe modifications, in technical as well as in operational terms, than others. This can easily be understood since the vehicles will be connected to lower network levels and hence entities active on these levels will be affected more [19]. Among which UC problem is one of activities that is considerably influenced by the PHEVs.

There are several constraints that should be considered in electric vehicles modelling.

- *State of charge*

This constraint express that each vehicle should have a desired departure state of charge level.

- *Number of discharging vehicles constraint*

All the vehicles cannot be discharged at the same time because of power transfer, current limit. For reliable operation and control of GV, only a limited number of vehicles are assumed to be able to discharge at a time.

$$N_{GV}(t) < N_{GV}^{\max}(t) \tag{1}$$

- *Efficiency*

Charging and inverter efficiencies should be considered.

III. IMPERIALIST COMPETITIVE ALGORITHM

Evolutionary optimization methods, inspired by natural processes, have shown good performance in solving complex optimization problems. All of these methods are similar in on aspect that the move from one solution to another is done using rules based upon human reasoning, so the called intelligent. Heuristic algorithms may search for a solution only inside a subspace of the total search region. They are not limited by the search space characteristics like existence of derivative of the objective function and continuity.

Several heuristic methods can be addressed such as: particle swarm optimization, simulated annealing, Tabu search and genetic algorithms; each one with some advantages and disadvantages in different areas of the problems. These algorithms are generally inspired by modeling the natural processes and other aspects of species evolution, especially human evolution. But Imperialist Competitive Algorithm has been conceptualized from socio-political evolution of human as a source of inspiration for developing a strong optimization strategy. ICA is a relatively new evolutionary optimization algorithm.

Imperialism is the policy of extending the control of an imperialist beyond its boundaries. It may try to dominate other countries by direct rule or via controlling of markets for goods. ICA is a novel global search heuristic that uses imperialistic competition process as a source of inspiration [15].

This algorithm starts with an initial population (a number of randomly produced solutions). Each solution in the population is called country. Considering the value of objective function as the measure, some of the best countries in the population selected to be the imperialists and the rest form the colonies of these imperialists. In this algorithm the more powerful imperialist, have more colonies. As the competition starts, imperialists try to achieve more colonies and the colonies start to move toward their imperialists. So during the competition the powerful imperialists will be improved and the weak ones will be collapsed. At the end of algorithm just one imperialist will remain. In this stage the position of imperialist and its colonies will be the same. The algorithm steps are summarized as follows.

1. *Generating Initial Empires*: The goal of optimization is to find an optimal solution in terms of the variables of the problem. An array of optimization variable values is called "country". The cost of a country is found by evaluating the objective function for this country. To start the optimization algorithm we generate the initial

population of size $N_{country}$. The N_{imp} of the most powerful countries are selected to form the empires. Other countries will be the colonies each of which belongs to an empire.
2. *Moving the Colonies of an Empire toward the Imperialist*: Imperialist countries start to improve their colonies. This has been modeled by moving all the colonies in this empire toward the imperialist. It means that a new country will be generated based on the position of each country in the empire and the distance of this country and imperialist.
3. *Finding the Total Power of an Empire*: The total power of an empire is mostly affected by the power of its imperialist. However, the power of its colonies of an empire has an effect, on the total power of empire. The mean value of the cost function of other countries in the empire will be added to the value of objective function for the imperialistic with a small coefficient to form the power of each empire.
4. *Imperialistic Competition*: each empire tries to take the control and ownership of colonies of other empires. This competition brings about a decrease in the power of weaker empires and an increase in the power of more powerful ones slowly. The competition is modeled by choosing a number of weakest colonies of the weakest empires and allow for the empires to compete for acquiring the chosen colonies.
5. After a number of iterations only the most powerful empire will remain and all the countries will be controlled by this imperialist which is the optimum solution of the problem.

IV. PROPOSED METHOD

This section explains the proposed method for DER placement in the presence of electric vehicles. First problem formulation and objective function are presented and then the description of the proposed method is provided.

A. Problem Formulation and Objective Function

The benefits and costs of DERs application is presented in the following. Investment Cost, Operation Costs as well as Maintenance Costs are the cost associated with DER implementation. On the contrary, DER benefits include: Power Purchase Reduction (*PPR*) from the electricity market and Loss Reduction (*LR*).

PPR is the benefit achieved because of decrease in the amount of electric power purchased from electricity market due to DER power generation [20].

$$PPR = \sum_{k=1}^{N_{DER}} P_k^{DER} \times EP \qquad (2)$$

where, P_k^{DER} is the output power of the *k*th DER unit and EP is the price of energy.

Reducing the efficiency of transmitting energy to customers significantly, losses in distribution systems draw considerable attention [1]. The total decrease in the losses of a distribution system can be calculated as follows:

$$LR = (P_{Loss} - P_{Loss}^{DER}) \times EP \qquad (3)$$

where, P_{Loss} is the power loss before employment of DER units and P_{Loss}^{DER} is the total loss of the distribution network after employment of DER units in the network.

On the other hand, costs associated with employment of DER units is composed of three components including capital cost of DER units; operating cost of the DER units; and the maintenance cost. Capital cost includes the costs associated with procurement, installation and costs of required equipments for the connection of DER to the distribution network. Operating costs include the fuel cost in case the DER unit is not renewable and maintenance cost consists of maintenance and repair costs [20].

B. Proposed Method Description

Figure 1 depicts the proposed optimization procedure of this study to include the effect of EV on planning of DER units. Initially the system data and load data at different buses are fed into the optimization algorithm. Afterwards, the optimization problem and the algorithm parameters are initialized. Then, the power consumed and delivered by the EVs to the distribution network is determined. After that, a Power Flow (PF) for base case (normal condition without DERs and with EVs) is performed and using the results obtained by this PF, loss of the base case of the distribution network is determined. In this study, all of the buses except the reference bus are considered as a candidate location for DER installation.

In the next step, Empires are initialized. In this study, each solution is a matrix that has the size of $1\times(N_B - 1)$ in which N_B is the number of buses of the distribution system under study representing the number of buses of the system except the reference bus. The value of each array in each soultion indicates the size of DER unit at that bus; the size of zero represents that DER unit should not be installed at that bus.

In the next step, a PF is performed taking into account EVs for each solution created by the ICA; in this PF based on the solution, DER units are considered to be located in their loaction. Employing the PF results the costs and benefits of each solution is calculated and overally the fitness of each solution of ICA is determined.

After that, the optimiztion procedure goes on by moving the colonies of an empire toward the imperialist. Imperialists tend to improve their colonies by moving all the colonies within their territory toward themselves. Consequently, a new country will be created using the position of each country in the empire and its distance with the imperialist.

If there is a colony in an empire which render better solution than the imperialist, it will replace the imperialist. Total power of each empire composed of the power of the imperialist and its colonies is calculated affterward.

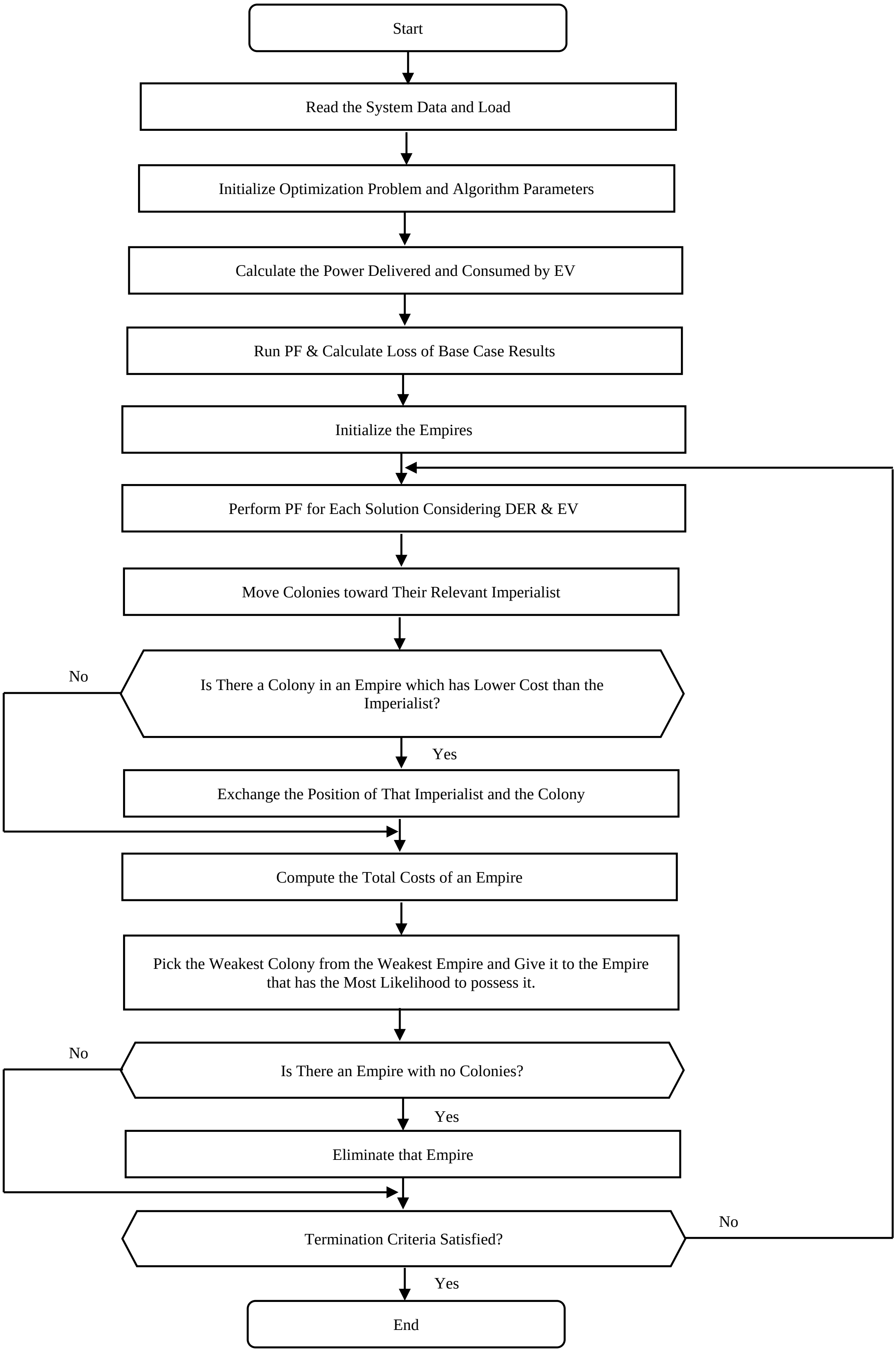

Figure 1. Flowchart of the proposed procedure to consider EV effect on DER placement

Imperialistic competition is performed in the next step, in which each empire tries to take control and ownership of colonies of other empires imperoving the power of more powerful ones and worsening the power of weaker empires, slowly. Then of there is an emptire without colonies, that empire will be removed. Finally, the termination criteria are checked to determine whether they are satisfied or not. In this study, the termination criterion is specified to be a pre-specified number of iterations.

V. CASE STUDIES

The proposed method for investigating the impact of EV on DER locating and sizing is carried out on the IEEE 30-bus distribution test system [21] which is consisted of one main feeder, 6 auxiliary substations, and 22 load buses. Table 1 provides the active (KW) and reactive (KVAR) loads for each bus, resistance and inductance of each feeder. The total load of this test system is 15*MW* while the base voltage is considered to be 23*KV*. Figure 2 depicts the schematic of the IEEE 30-bus test system.

In this study, two different cases are considered. The first one deals with the optimization problem of DER placement without EVs while the second one investigate the influence of EVs on DER Placement and sizing.

A. Case 1: DER Locating without EVs

In this case DER units are located and sized in the distribution test system without EVs. The benefits are loss reduction and power purchase reduction from the electricity network. Benefit Cost Ratio (*BCR*) is used as a benchmark to evaluate the solutions financially. Losses of the base case when there is no DER units and no EVs in the 30-bus distribution network is 1067.6943 KW/h in peak load.

Provided in Table 3, is the best solution obtained by the ICA for this case. The results obtained from other literature are also provided in this table. As the results demonstrate the proposed method is capable of finding the optimum solution which result in a better solution regarding other approaches. The best location for placement of a DER unit is bus 12 and the optimum size is about 250 KW. Moreover, the results obtained from the proposed method not only has improved the solution from financial perspective (higher *BCR*), but also further reduced the losses of the system. Employing the best solution the losses of the network will reduce about 9% in peak hours.

B. Case 2: DER Locating with EVs

In this case DER are located in the distribution network in the presence of EVs. EVs are considered to be located on bus 18 based on [22]. Based on this reference 20 EV each with the delivered power capacity of 2.5 KW are considered on bus 18.

Table 3 shows the optimum size and location of DER units in the presence of EVs. Bus 14 is the best locations for DER units' placement and the optimum size is about 138 KW. As it can be seen from this table and in comparison with the results of Table 2, the optimum solution is different. The loss reduction benefit has decreased in this case regarding case one, however since the size of DER unit has decreased the costs of DER placement has reduced and therefore the result will render a solution that has higher *BCR*.

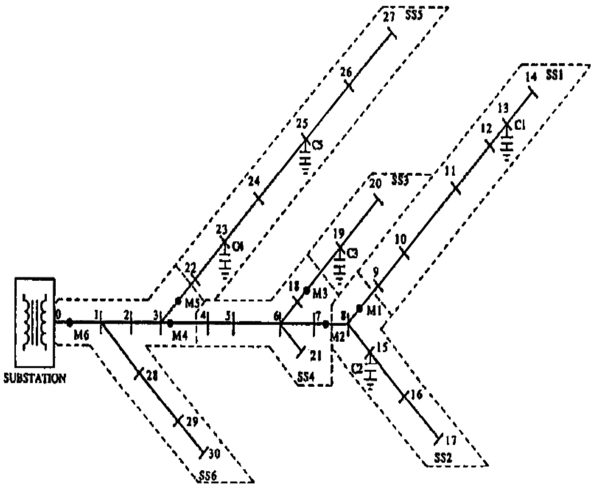

Figure 2. IEEE 30-bus distribution system [21]

Table 1. IEEE 30-bus distribution system data

From Bus *i*	To Bus *j*	r_{ij} (pu)	x_{ij} (pu)	Base active load at *j* (MW)	Base reactive load at *j* (MVAR)
Main Feeder	1	0.0963	0.3219	0	0
1	2	0.0414	0.0022	0.5220	0.1740
2	3	0.0659	0.0651	0	0
3	4	0.2221	0.1931	0.9360	0.3120
4	5	0.1045	0.0909	0	0
5	6	0.3143	0.1770	0	0
6	7	0.2553	0.1438	0	0
7	8	0.2553	0.1438	0	0
8	9	0.2506	0.1412	0.1890	0.0630
9	10	0.2506	0.1412	0	0
10	11	0.7506	0.4229	0.3360	0.1120
11	12	0.3506	0.1975	0.6570	0.2190
12	13	0.1429	0.0805	0.7830	0.2610
13	14	0.2909	0.1639	0.7290	0.2430
8	15	0.0898	0.0781	0.4770	0.1590
15	16	0.1377	0.0775	0.5490	0.1830
16	17	0.2467	0.1390	0.4770	0.1590
6	18	0.0915	0.0795	0.4320	0.1440
18	19	0.3005	0.2612	0.6720	0.2240
19	20	0.2909	0.1639	0.4950	0.1650
6	21	0.1143	0.0994	0.2070	0.0690
3	22	0.1066	0.1054	0.5220	0.1740
22	23	0.0649	0.0641	1.9170	0.0630
23	24	0.1083	0.0941	0	0
24	25	0.2760	0.2399	1.1160	0.3720
25	26	0.2009	0.1746	0.5490	0.1830
26	27	0.2857	0.1609	0.7920	0.2640
1	28	0.0881	0.0047	0.8820	0.2940
28	29	0.3091	0.1741	0.8820	0.2940
29	30	0.2106	0.1187	0.8820	0.2940

Table 2. Optimum solution for Case 1 in comparison with other approaches

Approach	DER	Size (Kw)	*BCR*	Loss Cost
Proposed	12	249.1260	1.3866	142269.5793
ICA [1]	14	222.05119	1.2891	117889.2288
PSO [1]	11	223.3239	1.2369	372210.3527
	14	377.0356		
	18	130.2792		
HSA [1]	12	144.2115	1.2781	188197.1178
	14	213.3091		

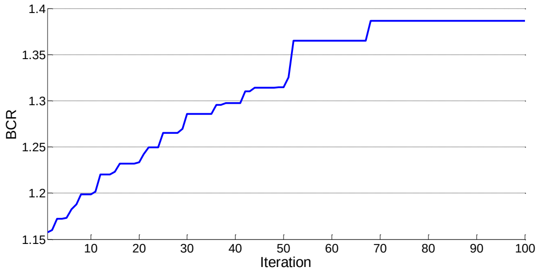

Figure 3. *BCR* improvement in ICA algorithm during iterations

Table 3. The optimum solution obtained by ICA for the Case 2

Approach	DER Location	Size (Kw)	*BCR*	Loss Cost Reduction ($)
Proposed Method	14	137.9092	1.3998	70509.6376

In order to further study the impact of EVs on DER placement the losses of the system in different cases are considered and provided in Table 4. As it can be seen the EVs themselves has reduced the losses of the system in peak load about 7 KW. Moreover, since the size of DER unit located in case 1 is higher than the second case therefore it has reduced the losses more than DER of case 2. However the decision factor in this study is *BCR* which case 2 shows better financial performance.

As the results show EVs can change the DER placement planning program, and it should be considered in this optimization problem considering the exploit of EVs in distribution network in the following years. As it was shown in the results of the case study, the presence of EVs and their integration into the distribution network can highly effect the DER planning. Therefore, it is necessary to consider the effect of EV integration in distribution system in operation and planning stages of distribution network, as they can considerably affect this studies. Depicted in Figure 3, is the convergence characteristic of the proposed algorithm. As can be seen in this figure, the proposed algorithm improve the *BCR* of the best solution as the number of iteration increases.

Table 4. Comparison of the results for different cases

Case	DER Location	*BCR*	Loss Before DER Locating at Peak Load (KWh)	Loss After DER Locating at Peak Load (KWh)
Case 1	12	1.3866	1067.6943	978.4699
Case 2	14	1.3998	1060.425	1009.2414

VI. CONCLUSIONS

In this paper, an effective approach for locating and sizing of DER units in the distribution system in the presence of EVs was proposed. The proposed algorithm based on ICA, decreases the power losses of the network while the obtained solution is financially justifiable. The obtained results demonstrate the capability of the proposed method in finding the proper location and size of DER units. Comparing the result of the proposed approach with those reported in the literature demonstrated the effectiveness of the proposed method. Moreover, comparing of the results from case 1 and case 2 showed the necessity of consideration of EVs in planning problem of DER placement as result might vary when EVs could provide electric power in parking lots.

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BIOGRAPHY

Reza Ghadiri Anari was born in Anar, Iran, on 19 July 1979. He received the B.Sc. degree in Electronics Engineering from Shahid Bahonar University, Kerman, Iran and the M.Sc. degree in Electrical Power Engineering from Shiraz University, Shiraz, Iran, in 2002 and 2005, respectively. He is currently working toward the Ph.D. degree in Department of Electrical Engineering, Science & Research Branch, Islamic Azad University, Tehran, Iran. His research interests include power systems, genetic algorithm and distribution systems.