Optimum Cost-performance Evaluation of Hybrid Energy Systems in presence of Plug-in Electric Vehicles

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Abstract: This paper proposes a methodology for practical techno-economic evaluation of Distributed Generation (DGs) for electric vehicle charging station in smart grid. In this method, the interaction of Electric Vehicles (EVs) in smart grid is considered. An important issue is that high penetration of electric vehicle (EVs) brings heavy electricity demand to the power grid. One effective way is to integrate distributed generation (DGs) into charging infrastructure. In this paper at the first stage, candidate buses for installation of DGs and EV charging station. Then the financial benefit of investors obtained from heat selling of the CHP units (in DGs) is determined through an economic analysis at this stage. Studying the interaction between EVs and DGs in the distribution system, the financial benefit of the distribution company obtained from loss reduction is evaluated through a techno analysis. Finally considering the distribution company and investors as players, the best location and capacity of DGs and EV charging station will be achieved for installing in the distribution buses using a Nash equilibrium point in game theory (GT) approach. The applicability of the proposed method is examined on a sample distribution feeder.

Keywords: Techno-Economic evaluation, DG, electric vehicle charging station, smart grid.

1. Introduction

The use of DG in the distribution system has proved to be beneficial, considering technical and economic issues [1-3].

Among the different types of DG technologies, CHP is capable of generating heat and electricity simultaneously through a combined cycle of co-generation scheme. It supplies the heating or cooling systems of consumers through recycling its waste heat, making it a lucrative option to increase efficiency by 75% and even more. Since the natural gas is abundant in Iran, these power plants are considered as beneficial substitutes for the generating electricity and heat separately. However, improper placement of distributed generation resources may diversely affect the performance of the power system. Accordingly, determining the location, number and size of DG units, for installation on the distribution system, known as the DG placement problem, is crucial to optimally operate the system. Reduction of losses, improvement of the voltage profile together with voltage regulation are considered as some significant indicators to optimize the location and capacity of these generators [4,5], which can by achieved using intelligent search methods such as genetic algorithm (GA), particle swarm optimization (PSO) and tabu search (TS) [6].

When it comes to CHP placement, in addition to the above technical analysis, the economic analysis is usually considered. In this analysis, the investment criterion is considered to optimize the heat and power output of CHP units, simultaneously [7].

With the installation of CHP at the distribution network, the distribution network changes from a passive network into an active one that may result in improving the network performance in terms of energy loss and power quality [8].

The Improvement obtained from these technical indicators is more considerable by nodal pricing methods that considers the electrical energy prices of b uses to which CHP is connected. In other words, the CHP installation can be more effective at the nodal pricing of buses [9]. In addition to improving the technical indicators that are desirable for distribution companies, CHP installation will create the opportunity to benefit from supplying heating and warm water for consumers around the bus, which is favorable to CHP investors.

Thus, considering technical and financial aspects in CHP placement, which highly depends on the strategy and policy of players in this activity, is a challenging issue for both the distribution companies and the investors.

In recent years, Game Theory (GT) has become just popular to solve such types of problems. Generally, where a group of individuals or firms competes with each other or they cooperate in a team, GT can be used to model competition between them. Song Yiqun [10] using non-cooperative GT and Nash-Stackelberg equilibrium, a new method to determinate the power market is presented. Lance B.cunningham [11] also using Game Theory and Corn out equilibrium, a way to model the transmission line congestion in the electricity market, is presented. Lance B.cunningham [11] cooperative Game Theory has been used, and the consumers of heat and power are considered as members of the coalition to achieve higher profits by reducing investment and increasing the efficiency of co-generating electricity and heating (CHP). Samaie and Moradi [12] present a hybrid and practical method for allocation of combined cooling, heating and power (CCHP) generator at the bus. They obtain the suitable location of CCHP based on Game Theory and considering the Distribution Company and investors as players.

Some of the previous studies on electric vehicle integration have focused on the availability of generating capacity to accommodate additional demands of electric vehicles, based on the assumptions that the charging of vehicles is limited to the off-peak hours [13-15]. However, such system level analysis may not address the coincident peaks of electric vehicle charging as well as conventional loads in the distribution system levels. The uncertainty that may result from the electric vehicle driving patterns, penetration levels and charging of electric vehicles in the electric distribution systems could result in new system peaks and negative distribution system impacts. However, the coordination of smart charging (controlled charging) of the electric vehicles through two-way communication systems can facilitate most of the battery charging during off-peak hours [16,17]. During the last two decades, some research has been conducted investigating the impacts of market integration of electric vehicles into the utility distribution load profile [18-20]. Other recent investigations have also examined the network limitations of large numbers of electric vehicles on the distribution system operation in terms of overloading, power quality and loss of life of components [21].

In this paper, a new method has been developed for DGs allocation. Using cooperative game theory, investors and distribution companies have been modeled as the coalition members in the proposed method to achieve higher profits and improved technical indicators of network. The proposed new method has three stages as follows: At the first stage, candidate buses for installation of DGs and EV charging station by introducing a fuzzy function. Investigating the interaction between EVs and DGs in the smart grid the financial benefit of the distribution company due to loss reduction is evaluated through a technical analysis. Finally, considering the distribution company and investors as players, the best location and size of DGs consist of CHP units is finally determined using a game theory (GT) approach, in which the distribution company and investors are modeled as players. By obtaining the Nash equilibrium point in game theory method, the suitable location and capacity of the DGs and EV charging station will be achieved for installing in the distribution buses. Finally, the case study results for the sample feeder are provided.

2. Techno-Economic Evaluation

In this section techno-economic evaluation of DGs for electric vehicle, charging station in smart grid is presented.

2.1. Economic Evaluation

The power at bus i can be represented by (1):

$$P_{Ti} = P_{ei} + Q_{hi} \tag{1}$$

$$Q_{hi} = \sum_{j=1}^{n} Q_{hij} \tag{2}$$

where:

P_{e_i} : Active power consumption at bus *i*.

Q_{hi} : The electrical equivalent of heat selling possibility at bus *i*.

P_{T_i} : Total power.

In the above equations, Q_{hi} is supplied by DGs sources that only connected to bus "i", and if it will be supplied by other busses, heat and cooling loss, eliminate this possibility while P_{e_i} can be supplied by other buses of the network. The optimization problem can be divided into two parts:

- Optimization with regard to consumption of P_{e_i} for each bus of the network that can be also supplied by generators at other buses.
- Optimization with regard to Q_{hi} the sale of heat (equivalent to electric power) for each bus of network that is supplied by generator at the same bus only.

***Amount* of heat consumption (equivalent to electrical power) Q_{hij}**

The calculation of the energy needed for different loads (various applications) according to references [21], has done for 1000 m^2 infrastructure, and this point is considered that, Iranian power plant uses natural gas with special heating value of 9434 Kcal/m^3 or 1060 Btu / ft^3. For example, in multi-unit residential building that uses the central heating systems (for 1000 m^2 infrastructure).

A) The warm water consumption: 231.84 (kw)

B) The heat consumption for heating: 117.16 (kw)

Total heating and warm water consumption of different buildings is shown in Fig.1.

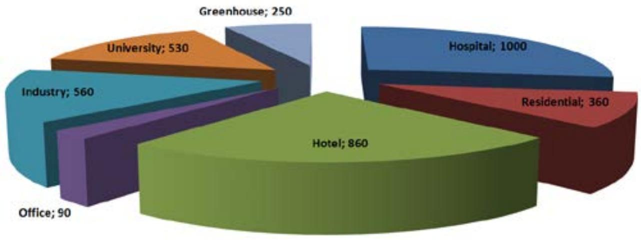

Fig. 1. Qh_{ij} for different consumers, with infrastructure of 1000m^2

2.2. Technical Evaluation

The distributed generation resources in the network will change the power flow and losses on two-level of transmission and distribution networks. Many tariffs structures at the distribution level, use the equal share of the losses cost for consumers, which discourages the consumers to install DG [22]. For solving this problem, "Nodal Pricing Method" is utilized. The price of electricity in the nods indicates the marginal price of electricity in the network busses [12], in this paper the characteristics of formulas are defined as follows:

Marginal loss coefficient (MLC) is the active power losses network change (P_L) due to changes in production or consumption of the active power (P_{C_i}), and the reactive power (Q_{C_i}) at bus "*i*" that defined as follows:

$$\rho_{Pe_i} = \frac{\partial P_L}{\partial P_{e_i}} \tag{3}$$

$$\rho_{Qe_i} = \frac{\partial P_L}{\partial Q_{e_i}} \tag{4}$$

where:

ρ_{Pe_i} : Marginal loss coefficient of active power at the bus *i*.

ρ_{Qe_i} : Marginal loss coefficient of reactive power at the bus *i*.

The medium point between generation and transmission levels is called "power supply point" (PSP). If "λ" is the price of active power in PSP in $\frac{\$}{MWh}$, and if the active and reactive power consumption at bus *I* change as P_i and Q_i respectively and no congestion exists in the distribution network, then we can calculate the nodal pricing for active and reactive power as follows:

$$N_i^a = \lambda + \lambda . \rho_{P_{e_i}} = \lambda(1 + \rho_{P_{e_i}}) \tag{5}$$

$$N_i^r = \lambda . \rho_{Q_{e_i}} \tag{6}$$

The price of electrical bill without CHP installation on the period Δt will be obtained as follows:

$$C_i^{no-DG}(P_{e_i},Q_{e_i}) = (N_i^a(P_{e_i},Q_{e_i})\times P_{e_i} + N_i^r(P_{e_i},Q_{e_i})\times Q_{e_i}).\Delta t \qquad (7)$$

and the total of it for each feeder is equal to:

$$C_{total}^{no-DG} = \sum_{i=1}^{N} C_i^{no-DG}(P_{e_i},Q_{e_i}) + (\lambda \times P_L).\Delta t \qquad (8)$$

DG installation decreases the distribution losses, and so the nodal pricing will be reduced [25]. The price of electrical bill with DG installation on the period Δt at bus i will be obtained as follows:

$$C_i^{DG}(P_{e_i},Q_{e_i}) = \{(N_{i,DG}^a(P_{e_i},Q_{e_i}) \times (P_{e_i}-P_{DG_i}) + N_{i,DG}^r(P_{e_i},Q_{e_i}) \times (Q_{e_i}-Q_{DG_i})\}.\Delta t + \{C_{(DG)} \times P_{DG_i}\}.\Delta t \qquad (9)$$

and the total of it for each feeder is equal to:

$$C_{total}^{DG} = \sum_{i=1}^{N} C_i^{DG}(P_{e_i},Q_{e_i}) + (\lambda \times P_{L,(DG)}).\Delta t \qquad (10)$$

where:

N_i^a : Nodal pricing of active power without DGSs

$N_{i,DGs}^a$: Nodal pricing of active power with DGs

N_i^r : Nodal pricing of reactive power without DGs

$N_{i,DGs}^r$: Nodal pricing of reactive power with DGs

Q_{e_i} : Reactive power consumption at bus i

P_{DG_i} : Active power supplied by the DGs at bus i

Q_{DG_i} : Reactive power supplied by the DGs at bus i

C_{total}^{no-DGs} : Price of electricity supplied by the network without DGs

C_{total}^{DGs} : Price of electricity supplied by the network with DGs

$C_{(DGs)}$: Price of electricity supplied by DGs.

$P_{L,(DGs)}$: Active power losses by considering DGs.

P_L : Active power losses without DGs.

The DGs is intended as a negative load at its bus and to simplify the calculations assume that Q_{DGsi} and P_{DGsi} are zero at all buses except that DG is installed.

$$Q_{DGsi} = \begin{cases} 0, i \neq i_{best} \\ Q_{DGsi}, i = i_{best} \end{cases} \qquad (11)$$

and The larger difference "$C_{total}^{no-DGs} - C_{total}^{DGs}$" leads to the distribution company profit increases by DG installation, and its formulation will be as follows:

$$T = C_{total}^{no-DGs\,(a)} - (C_{total}^{DGs\,(b)} + C_{total}^{DGs\,(c)}) \qquad (12)$$

Where:

T : Benefits of technical indexes improvement (for the distribution company)

$C_{total}^{no-DG(a)}$: Price of electricity supplied by the network without DGs

$C_{total}^{DG(b)}$: Price of electricity supplied by the network with DGs

$C_{total}^{DG(C)}$: Price of DGs electricity.

Hybrid Renewable Energy Systems (HRES)

Lund [26] in the simulation model, uses an HRES that includes PV, wind, diesel generator, micro turbine and storage backup. This model includes heat production from solar thermal, industrial CHP, heat pumps, heat storage and boilers.

The performance of several designs of hybrid systems composed of solar thermal collectors, photovoltaic panels and micro-CHP systems presented in [27]. Trinkl [28] in a system dynamic model uses HRES and a micro turbine. The system modelled a heating system supported by solar energy along with heat pump.

However, the hybrid renewable energy system in this article (fig 2) consist of photovoltaic (4.5 KW), wind turbine (2×10 KW), diesel generator units (5×200 KW), and 5 battery storage.

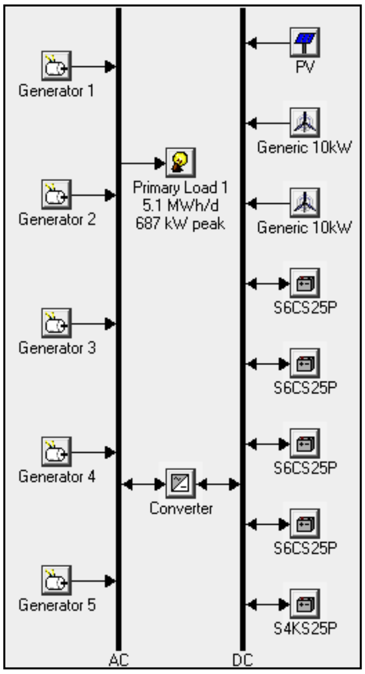

Fig. 2. DG system consist of photovoltaic (PV), wind turbine (WT), combined heat and power (CHP) units, battery storage. (Using HOMMER Software)

3. Game theory approach

In the game theory, a game is a set of rules known to all players that will determine any of their choices and the consequences of every choice. The normal form of the game represents the number of players, set strategies, and the payoff functions of each player. Assuming there are *n* players, a set of players is:

$$N=\{1,2,\cdots,n\} \tag{13}$$

The decisions set that player *i* can get it is named "strategy space of player *i*and is shown as follows:

$$S_i=\{s_{i1},s_{i2},\cdots,s_{im}\} \tag{14}$$

Since there are **n** players, the strategies of all players are:

$$S=\{S_1,S_2,\cdots,S_n\} \tag{15}$$

where:

s_i: The jth strategy of player *i*.

m : The total number of strategies.

s_{ij} : The jth strategy of player *I* in the strategy set S.

On the other hand, payoff function for the player *i* shows the outcome or result (including profit, utility, etc.) that player *I* will achieve at the end of the game. This payoff will depend on the chosen strategies by all players, and is shown as follows:

$$u_i=u_i(s_{i1},s_{i2},\cdots,s_{nj}) \tag{16}$$

That $s_{ij}\in S_i$, shows jth strategy of player *i* in the strategy set (Si). Also the combination of all players strategy is called a strategy profile, and is shown as follows:

$$s_j=(s_{1j},s_{2j},\cdots,s_{nj}) \tag{17}$$

Thus the normal form of an n-persons game, represents the player's strategy space ($S_1,\ldots,S_n$) and their payoff function ($u_1,\ldots,u_n$), is shown as follows [30] :

$$G=\{S_{1j},\cdots,S_n;U_1,\cdots,U_n\} \tag{18}$$

Osborne, M.J. and Rubinstein [24] have shown that the solution of "Game" is a continuous selection of equilibrium strategies, the Nash equilibrium is used usually. In this equilibrium:

$$\forall i,\forall s_{-i}\in S_{-i}\quad U_i(s_i,s_{-i})\geq U_i(s_i',s_{-i}) \tag{19}$$

where**:**

s_i: Nash equilibrium strategy of player i

s_i' : None- Nash equilibrium strategy of player i

s_{-i} : Other players' strategy at the Nash equilibrium, That $s_i\in S_i$ is the Nash equilibrium strategy of player i and $s_i'\in S_i$ is None -Nash equilibrium strategy of player i.

The Nash equilibrium is a condition achieved by a set of strategies, and the players' decision to deviate from such state will reduce the profit. Search to find the equilibrium point includes the following steps:

Forming a set of possible strategies, except dominant strategies, (the s_i' strategy of player i, so that fulfills the following condition [23]:

$$\forall s_{-i}\in S_{-i}\quad U_i(s_i,s_{-i}')\geq U_i(s_i',s_{-i}') \tag{20}$$

1. Search to find the equilibrium point. The Nash equilibrium is determined with regard to the 1.

In terms of theory, there will be many equilibrium points, which in [23] some methods are presented for reducing the number of equilibrium points.
2. Considering of the rationality and the possibility of organized coalition for players.
3. Chosen methods to organize coalitions and the distribution of excess profits in the coalition participants.

If there is a possibility of a coalition among the players, the possible strategies of coalition may increase the dimensions of the problem significantly. Finally, the output of this method is semi-optimal path for all companies and their coalitions with regard to competitors' strategy. In this paper, in order to allocate and determine the capacity of DGs "The Static Game with complete information" is used.

In this method, players are:

- Electric Power Distribution Company State (player A)
- Investors (player B)

The possible strategies are:

- In DGs, the electrical power converted to heat ratio of different CHP technologies.
- Choose the capacity of CHPs that has been considered 0.5 and 1 MW in this paper.

By obtaining the Nash equilibrium point, the suitable location and capacity of the DGs generator will be achieved for installing in the bus network.

4. Case Study

In this part, a sample distribution feeder has been studied. With regard to the reciprocating engines CHP type (in DGs), and assuming 75% efficiency achieved through the placement method in this paper, the cost of electricity supplied by DGs is equal to 53 $ for a megawatt hour.

According to consumer information, the large thermal loads of feeder are installed on buses: 1, 5, 16 and 22.

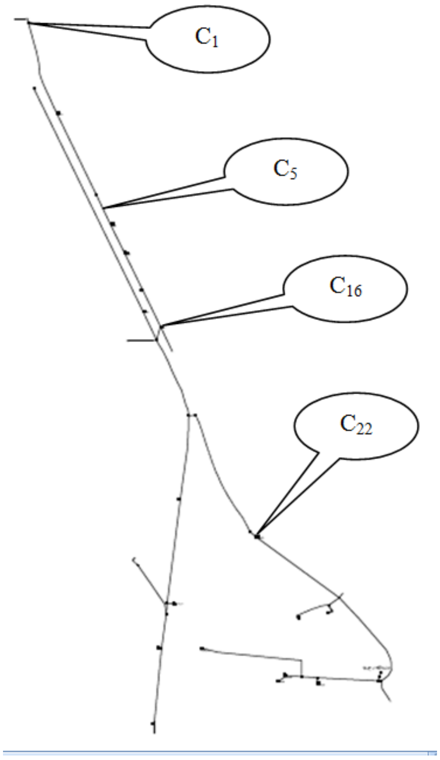

Fig. 3. The candidate buses for installation of DGs and Electric Vehicle Charging Stations

Thermal benefit calculation

At this stage we assume that DGs installed on the all proposed buses (1, 5, 16, 12) have 0.5 & 1 MW capacities and the electrical power to heat ratios is 0.7 and 1. Then for each case, the heating cost savings are calculated that is shown in Table 1.

Table. 1. Benefit of the heating consumers in the different game strategies

Power / Heat Ratio = 1			
Bus number	**Electric capacity (MW)**	**Supplied Heating (MW)**	**Heat cost saving at each bus (investor profit)** $\frac{\$}{year}$
1	1	0.7	44150
	0.5	0.5	31536
5	1	1	63072
	0.5	0.5	31536
16	1	0.22	13875
	0.5	0.22	13875
22	1	0.25	15768
	0.5	0.25	15768
Power / Heat Ratio = 0.7			
1	1	0.7	44150
	0.5	0.7	44150
5	1	1.4	88300
	0.5	0.71	44781
16	1	0.22	13875
	0.5	0.22	13875
22	1	0.25	15768
	0.5	0.25	15768

A. *Technical indicators benefit calculation*

DGs installation will improve the network technical indicators, and this improvement is considered as beneficial for the electrical distribution company. Based on a load flow result and using the nodal pricing for candidate buses, the active nodal price of each bus will be reduced dramatically with the installation of the DGs unit. The nodal prices for the DGs candidate buses before and after installation (for 0.5 MW and 1 MW) are presented. It is assumed that DGs works in unit power factor, that is, it will produce the (real) active power only.

The DGs installation benefits are obtained from the equation {a-(b + c)} in the Table 2, that indicates the benefits of DGs installation which is desirable for Distribution Company.

Table. 2. Distribution company profit by DGs installed using the nodal pricing method

Bus number	**Cost of network electricity without DGs**[1] **(a)** $\frac{\$}{year}$	**DGs capacity (MW)**	**losses MW) (**	**Cost of network electricity (b)** $\frac{\$}{year}$	**Cost of DGs electricity (c)** $\frac{\$}{year}$	**Distribution company profit {a-(b+c)}** $\frac{\$}{year}$
1	1007400	1	0.189	341640	464280	201480
		0.5	0.235	754236	232140	21024
5		1	0.193	516840	464280	26280
		0.5	0.248	759930	232140	15330
16		1	0.198	519030	464280	24090
		0.5	0.262	766062	232140	9198
22		1	0.207	522972	464280	20148
		0.5	0.281	774384	232140	876

The total losses of the network will be 0.313 MW without DGs installation.

B. *Game theory for optimal selection*

In the proposed method, the distribution company and investors are players A and B respectively, the possible strategies that these two players can choose, are electrical power to heat ratio (0.7or 1) and electrical capacity (0.5 MW or 1 MW) of DGs. By installation of specified DGs at the candidate buses through the above strategies, the benefit of consumers and distribution companies (payoff (wining) for each player) is determined. We can specify the Nash equilibrium point in a static game with above complete information. This point chosen indicates that the benefits of both players are maximum and every player attempting to change these settings will lead to the detriment of other players and the whole set. It can be seen that the choice of strategy A_3 (DGs installed capacity of 1 MW and power to heat ratio of 0.7) at bus 5, the Nash equilibrium of this game indicates that at this point the player A and B are gain respectively 26,280 and 88,300 dollars per year.

5. Conclusion

This paper proposed a three-stage procedure for optimal DGs and EVs charging station placement in the distribution system. The procedure at its first stage, identified candidate busses for DGs placement. Then, the capability of selling heating energy is examined. Taking into account this factor and the electrical power to heat ratio of the units, an economic analysis is carried out at this stage to evaluate the financial benefit of the investors obtained from selling heat energy. Then, the financial benefit of the distribution company obtained from loss reduction is evaluated, considering the interaction between EVs and DGs in the distribution system. Finally, a game theory approach is applied to find the optimal proposal for DGs placement. The results achieved from implementing the approach on a s ample distribution feeder i, showed the applicability of the proposed method for optimal DGs placement in the distribution system.

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