Optimal Siting and Sizing of Hybrid Energy Systems (PV-WT-CHP) and Electric Vehicle Charging Stations Simultaneously based on Game Theory Approach

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Abstract:

This paper proposes a methodology for practical siting and sizing of Hybrid energy systems (HESs) consist of: wind turbine (WT), photovoltaic (PV) and combined heat and power (CHP) units. In this method, the interaction of Plug-in Electric Vehicles (PIEVs) in the electric distribution system is considered. Electric Vehicle are seen to have some negative impacts on electric distribution system performance, such as increasing power losses, voltage variations and even customer energy prices. An important issue is that high penetration of electric vehicle (EVs) brings heavy electricity demand to the power grid. One effective way to alleviate the impact is to integrate local power generation such as Hybrid Energy Systems (HESs) into charging infrastructure. In this paper at the first stage, candidate buses for installation of Hybrid Energy Systems (PV-WT-CHP) and EV charging station. Then, the heat selling possibility of the buses is determined through the Bus Heating Factor (BHF) using a fuzzy method. Utilizing this factor and the electrical power to heat ratio of the units, the HESs placement proposal is suggested at the second stage. Moreover, the financial benefit of investors obtained from heat selling of the CHP units (in Hybrid Energy System) is determined through an economic analysis (EA) at this stage. Studying the interaction between EVs and HESs in the distribution system and the frequency regulation process of candidate buses at the third stage, the financial benefit of the distribution company obtained from loss reduction and the voltage profile improvement is evaluated through a technical analysis (TA). Finally considering the distribution company and investors as players, the best location and capacity of HESs 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 in the city of Hamadan.

Keywords: Hybrid (PV-WT-CHP) Energy Systems (HESs), allocation, electric vehicle charging station, Nodal pricing method, Bus heating factor, Game theory.

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1. Introduction

With the increasing demand for electrical energy and considerable electrical energy efficiency of distributed generation (DG), these units are more likely to be utilized in the distribution systems near consumption.

The privatization of the power industry, environmental issues together with the advancement of new technologies concerning DG is the most driving factors for the development of these power generation technologies.

One of the key points that should be considered when determining the location and size of distributed generations for supplying electrical energy of consumers especially the sensitive ones, is the defense factor.

A study following the September 11 attacks suggests that a distribution system which has more reliant on DG for heat and electricity supply may be five times less sensitive to systematic attacks than a centralized power system in which electrical energy is mainly supplied from centralized generations i.e. large-scale power plants [1].The North American blackout event of 2003 induced rigorous reviews on possible solutions to minimize the risk of such disruption in the future, lead to consideration of DG and especially CHP, to reduce the vulnerability of threatening terrorist attack in the power systems [2-4].

The use of DG in the distribution system has proved to be beneficial, considering technical and economic issues [5-6].

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 [7,8], which can by achieved using intelligent search methods such as genetic algorithm (GA), particle swarm optimization (PSO) and TABU search (TS) [9,10].

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 [11, 12].

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 [13, 14].

The Improvement obtained from these technical indicators is more considerable by nodal pricing methods that consider the electrical energy prices of buses to which CHP is connected. In other words, the CHP installation can be more effective at the nodal pricing of buses [15]. 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 that 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 [16] using non-cooperative GT and Nash-Stackelberg equilibrium, a new method to determinate the power market is presented. Lance B. Cunningham [17] 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 [17] 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 [18] 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 [19-21]. 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 [22, 23]. 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 [24-26]. 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 [27-29].

In this paper a new method has been developed for hybrid energy systems (HESs) consist of: wind turbine (WT), photovoltaic (PV) and combined heat and power (CHP), placement in the distribution system using game theory. Previous approaches only evaluated from distribution company or investor point of view, but in this paper financial benefit of the Distribution Company and investor are evaluated together through a game theory approach.

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 Hybrid Energy Systems (PV-WT-CHP) and EV charging station by introducing a fuzzy function. The second stage examines the heat selling capability of the buses based on a bus heating factor, and with considering the heat capacity and electrical energy to heat ratio of HESs consist of CHP market, it allocates several CHPs to candidate buses based on an economic analysis. Investigating the interaction between PIEVs and HESs in the distribution system and the frequency regulation process of candidate buses at the third stage, the financial benefit of the distribution company due to loss reduction and the voltage profile improvement is evaluated through a technical analysis. Finally, considering the distribution company and investors as players, the best location and size of HESs 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 HESs and EV charging station will be achieved for installing in the distribution buses.

This paper is arranged as follows. The fuzzy bus heating factor for economic analysis and the nodal pricing method for technical analysis are defined in sections 2 and 3, respectively. The GT algorithm for proposed method is described in section 4, and finally the case study results for the sample feeder in the city of Hamadan are provided in section 5.

2. Economic analysis using the bus heating factor

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

$$P_{T_i} = P_{e_i} + P_{h_i} \tag{1}$$

$$P_{h_i} = \sum_{j=1}^{n} P_{h_{ij}} \tag{2}$$

Where:

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

P_{h_i} : The electrical equivalent of heat selling possibility at bus *i*.

P_{T_i} : Total power.

In the above equations, P_{h_i} is supplied by HESs 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 Phi the sale of heat (equivalent to electric power) for each bus of network that is supplied by generator at the same bus only.

2.1. Bus Heating Factor (BHF)

Indicates the possibility of selling steam and warm water to Defense Sensitive buses, and with regard to the consumers around the bus is calculated as follows:

$$BHF_i = \frac{P_{h_i}}{1MW}, BHF_i \geq 0.1 \tag{3}$$

Where:

P_{h_i} : The possibility of heat selling (equivalent to electric power) to the consumer "j" at bus "I".
BHF_i : bus heating factor of bus *i*.

The thermal coefficient of buses can be achieved by normalizing the possibility of heat selling at 1MW capacity. Finally, the buses with higher amount of *BTC* are considered as eligible for HESs installation, in which the objective functions of the optimization problem are evaluated.

P_{h_i} is the function of effective coefficients phase sharing (minimum) of heat selling and will be expressed by equation (4):

$$P_{h_i} = \sum_{j=1}^{N} P_{h_{ij}} = \sum Q_{h_{ij}} \times f_{ij}\,(\beta \cap d \cap x \cap \Psi) \qquad (4)$$

Here:

Qh$_{ij}$: The heat consumption (equivalent to electric power) of consumer "j" at bus "i".
β : Type of consumer.
d: The distance between the heat consumer and power plant.
x: Coefficient of CHP from HESs technology that depends on the conditions that heat be generated by CHP.
ψ : Fuel delivery coefficient.
N: Total number of consumers around each bus.

Calculation of β : According to the National Building Regulations in Iran [30], there are four groups of building types, A to D. This grouping is based on the following three factors:

- Usage continuity of building during the day and the year.
- The temperature difference between the interior and exterior environment of the building.
- The significance of stabilization of temperature of indoor spaces.

β is determined based on the user type in Table 1. A higher value for β indicates more possibility of heat selling to the consumer.

Table. 1. Buildings classification according to the National Building Regulations

User type	β	sample
A	**1**	Hospitals, hotels(4 and 5stars), industries with the heating consumption for the generation process (cement, steel, meltedmetals, sugar, food, greenhouse Town)
B	**0.75**	Integrated academic and large schools (with dormitory),skyscrapers, large residential complexes (with central heating systems).
C	**0.5**	Stores, factories (heating and sanitary use only), international airport
D	**0.25**	Places of business (shopping centers), offices
All cases	**0**	spread consumers that can not using of central heating systems

2.2 Amount of Heat Consumption (Equivalent to electrical Power) Q$_{hij}$

The calculation of the energy needed for different loads (various applications) according to references [31,32], has been done for 1000 m^{2}infrastructure, and this point is considered that, Hamadan city 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 use 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.

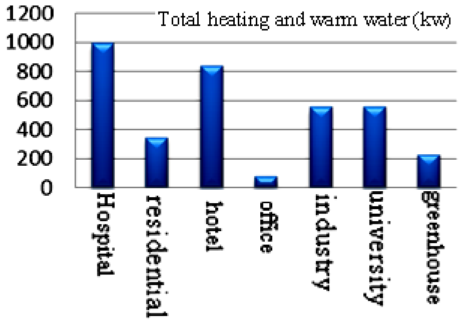

Fig. 1. Qh$_{ij}$ for different consumers, with infrastructure of 1000m^2

(4)

2.3. Distance between Heating Consumer and Power Plant (d)

The other issue that should be considered in heating distribution is the distance between heating consumer and power plant, so that by increasing the distance, heat selling possibility will be reduced while the transport cost will be increased. In other words, the bus heating factor (fitness) is proportional to the inverse distance:

$$f(d) \approx \frac{k}{d} \qquad (5)$$

That is, *d* is the difference between heating consumer and power plant and *k* is a coefficient that depends on the heat transfer capability of the system that is calculated based on the practical results. The possibility of heat and warm water transferring to different locations is expressed by following fuzzy membership function.

$$\overline{f(d)} = \begin{cases} 1 & d < 333 \\ \dfrac{1050-d}{717} & 333 \le d \le 1050 \\ 0 & d \ge 1050 \end{cases} \qquad (6)$$

2.4. Fuzzy Membership Function

Fuzzy digit $f(d)$ in parametric mode is the regular pair of $(\overline{f(d)}, \underline{f(d)})$ which must satisfy the following requirements:

1. $\underline{f}(d)$ Continuous boundary function from left.
2. $\overline{f}(d)$ Continuous boundary function from right.
3. $\underline{f}(d) \le \overline{f}(d), 0 \le f(d) \le 1$

2.5. Determination of Technology Coefficient (x)

This ratio expresses which technology is used to generate electricity and heat in the CHP (Table 2). Coefficients x_1 to x_5 can be determined according to the CHP thermal output. For example, for gas turbine technology, which provides heat, warm water, LP and HP steam, coefficient x has its highest value. In some CHP units, a variety of absorption chillers [33], adsorption chillers [34], and desiccant dehumidifier systems in humid areas [35] can be integrated into CHP units. In these systems the technology coefficient will be raised.

Table. 2. Various CHP technologies in Hybrid Energy System

Fuel cell	**Micro turbines**	**Gas turbine**	**Reciprocating engine**	**Steam turbine**	**Technology**
1-2	0.4-0.7	0.5-2	0.5-1	0.1-0.3	**Typical power to heat ratio**
30-63%	18-27%	22-36%	22-40%	15-38%	**The Power electrical efficiency(HHV)**
55-80%	65-75%	70-75%	70-80%	80%	**Total efficiency(HHV)**
Warm water , LP-HP steam	Heating, warm water, LP steam	Warm water, LP steam	LP- HP steam	LP- HP steam	**Using of output heat**
0.70	**0.35**	**0.9**	**0.45**	**0.20**	**X_{CHP}**

2.6. Fuel Delivery Coefficient (ψ)

Since the natural gas is used as the main source of fuel by these power plants and gas lines have three operating pressures including 1000 PSI for gas transmission, 250 PSI and 60 PSI for gas distribution in the cities; therefore, with considering the consumers distance around each bus from the transmission and distribution gas lines (*d*), and the experimental results obtained from the gas company, the corresponding fuzzy digits ($\psi(d)$) with different gas pressures are shown in Fig.2.

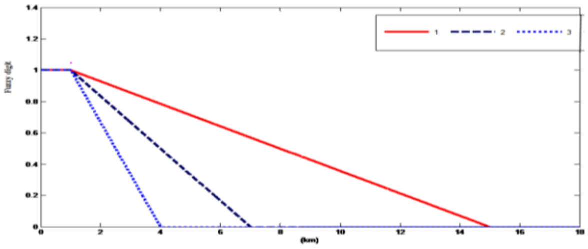

Fig. 2. Fuzzy digit corresponding to $\psi(d)$ for the pressure of (1)1000PSI, (2) 250PSI and (3) 60PSI

Finally, by determining the bus heating factor, the amount of saving achieved from the thermal cost at each bus (with regard to government support in this area [36]) can be obtained after CHP installation as follows:

$$C_{H_i} = BTC_i \times \Delta t_i \times \lambda_H \tag{7}$$

Where:

C_{H_i} : saving the thermal cost after CHP installation, $\frac{\$}{year}$

λ_H : The cost of per "MWh" heating, is equal to7.2 $, since the project of “targeted subsidies" is executed.

Δt_i : 8760 hour in a year.

3. Technical Analysis Using Nodal Pricing Method Considering Plug-in Electric Vehicles

To analyze the power system frequency response of the test distribution network, a step increase in the active power of a system load is simulated here. When the demand increases, the system frequency will reduce. The extra demand has to be met by the generators and the EVs participating in the frequency regulation process to normalize the system frequency. The frequency response of the distribution network with and without V2G regulation is given in Fig 3. The rate of change of frequency (ROCOF) and the minimum frequency drop (frequency nadir) in the network with the support of V2G regulation is less when compared to the case without EVs participating in power balancing. The V2G regulation provides a more stable, better damped and fast recovery of the system frequency. The EVs battery storage units have only very small delays when compared to the dynamics of the conventional generation unit which gives the former a more active role in the frequency control.

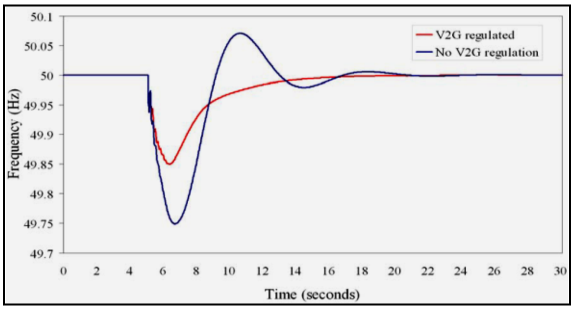

Fig. 3.Frequency profile for a step increase of load

Fig4. Shows that the deviations are largely reduced considering V2G, except for few periods, where the deviations in the form of sharp peaks are caused by the hourly scheduled power changes.

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 CHP [37]. 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 [15], in this paper the characteristics of formulas are defined as follows:

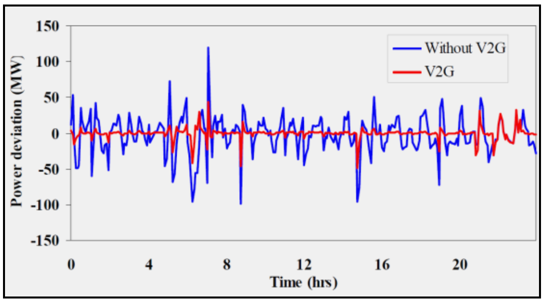

Fig. 4. Power exchange deviations without V2G and with V2G

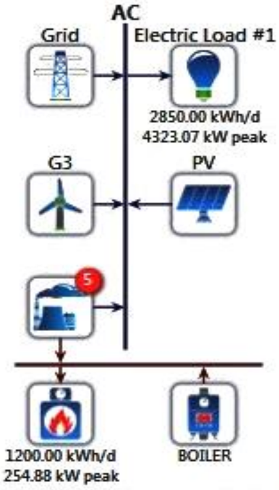

Fig. 5. Hybrid energy systems consist of photovoltaic (PV), wind turbine (WT), combined heat and power (CHP) units. (Using HOMER Software)

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 [38]:

$$\rho_{Pe_i} = \frac{\partial P_L}{\partial P_{e_i}} \tag{8}$$

$$\rho_{Qe_i} = \frac{\partial P_L}{\partial Q_{e_i}} \tag{9}$$

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**:**

$$N_i^a = \lambda + \lambda . \rho_{P_{e_i}} = \lambda(1+\rho_{P_{e_i}}) \tag{10}$$

$$N_i^r = \lambda . \rho_{Q_{e_i}} \tag{11}$$

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

$$\begin{aligned} C_i^{no-HES}(P_{e_i}, Q_{e_i}) &= (N_i^a(P_{e_i}, Q_{e_i}) \times P_{e_i} \\ &+ N_i^r(P_{e_i}, Q_{e_i}) \times Q_{e_i}).\Delta t \end{aligned} \tag{12}$$

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

$$C_{total}^{no-HES} = \sum_{i=1}^{N} C_i^{no-HES}(P_{e_i}, Q_{e_i}) + (\lambda \times P_L).\Delta t \tag{13}$$

HES installation decreases the distribution losses, and so the nodal pricing will be reduced [39]. The price of electrical bill with HES installation on the period Δt at bus *i* will be obtained as follows:

$$C_i^{HES}(P_{e_i},Q_{e_i})=\{(N_{i,HES}^a(P_{e_i},Q_{e_i}) \\ \times(P_{e_i}-P_{HES_i})+N_{i,HES}^r(P_{e_i},Q_{e_i}) \\ \times(Q_{e_i}-Q_{HES_i})\}.\Delta t+\{C_{(HES)}\times P_{HES_i}\}.\Delta t \tag{14}$$

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

$$C_{total}^{HES}=\sum_{i=1}^{N}C_i^{HES}(P_{e_i},Q_{e_i})+(\lambda\times P_{L,(HES)}).\Delta t \tag{15}$$

Where:

N_i^a : Nodal pricing of active power without HESs

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

N_i^r : Nodal pricing of reactive power without HESs

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

Q_{e_i} : Reactive power consumption at bus i

P_{HES_i} : Active power supplied by the HESs at bus i

Q_{HES_i} : Reactive power supplied by the HESs at bus i

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

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

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

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

P_L : Active power losses without HESs.

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

$$Q_{HESsi}=\begin{cases}0, i\neq i_{best}\\ Q_{HESsi}, i=i_{best}\end{cases} \tag{16}$$

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

$$T=C_{total}^{no-HESs\ (a)}-(C_{total}^{HESs\ (b)}+C_{total}^{HESs\ (c)}) \tag{17}$$

Where:

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

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

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

$C_{total}^{HES(c)}$: Price of HESs electricity.

(13)

While the power injection of one or multiple CHPs or the power consumption of customers' changes, the voltage in some buses may exit the permissible range [43]. The voltage rise at the HESs connection point and its impact on the voltage profile needs to be considered [40]. In addition, the voltage of each bus should be limited within the minimum and maximum defined permissible range in the distribution network; therefore, HESs should be installed considering the voltage limit condition in (18).

$$V_i^{min}\leq V_i\leq V_i^{max}\ ,\ i=1,2,\ldots,N_n \tag{18}$$

Where:

V_i : Voltage magnitude at bus *i*

$V_i^{\min}$: The minimum permitted voltage at bus *i*

$V_i^{\max}$: The maximum permitted voltage at bus *i*

N_n : Number of network buses.

Hybrid energy system in this paper consist of photovoltaic (4.5 KW), wind turbine (3 KW), and combined heat and power (CHP) units (5*200 KW), is given in Fig 5. By increasing the penetration of the renewable energies, it is more essential to considering different uncertainties in a smart grid [44]. When Renewable energy resources are used to supply the local loads individually, many problems are created such as high investment costs and low security of supply because of uncertain nature of them. To solve these problems, Hybrid Renewable Energy Systems (HRESs) has emerged [40]. HRES is a combination of renewable and traditional energy resources to meet the load in both grid connected and standalone modes. HRESs are used in grid connected mode in some places such as universities, hospitals, factories, electric vehicle charging stations and town. In the Hybrid Renewable Energy Systems (HRES), when the grid electricity prices are low, the HRES meets the load from the grid and charges the energy storages with renewable resources. Then, during the periods in which the grid electricity prices are high, the HRES meets the load with its resources and sells the extra energy to the grid. The HRES provides some advantages, e.g., increasing penetration of renewable energy resources, decreasing Cost of Energy (CoE), reduction of greenhouse gas emission, and providing access to electricity for people in remote areas [41].

In evaluate of optimal sizing of HRES's, uncertain parameters may differ with notice to the location and type of the components.

Wind speed, solar radiation, component cost, and primary load are the most uncertain parameters. As illustrated in Table3, there are three uncertain parameters with different values. These values considered in case study.

Table. 3. Uncertain parameters in case study

Uncertain parameters	Values
Wind speed (m/s)	5.4 – 6.7
Solar radiation (kWh/m^2/day)	4.5 – 5.2
price of electricity (US $ / MWh)	50

Wind speed (m/s) at renewable penetration (%) is shown in Fig 6.

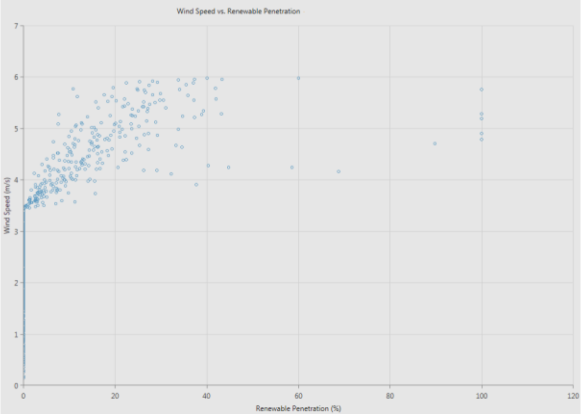

Fig. 6. Wind speed vs. renewable penetration

Solar radiation (kW/m^2) at renewable penetration (%) is shown in Fig 7.

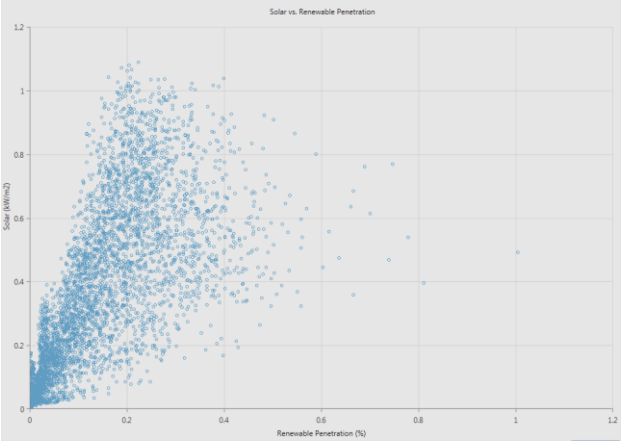

Fig. 7. Solar radiation vs. renewable penetration

The average amount of output electrical energy in photovoltaic (PV) and wind turbine (WT) is shown in Fig 8.

The uncertainty of wind speed and solar radiation has effect on simulation. These parameters are fed into HOMER software and best plan obtained, that shown in Fig 8.

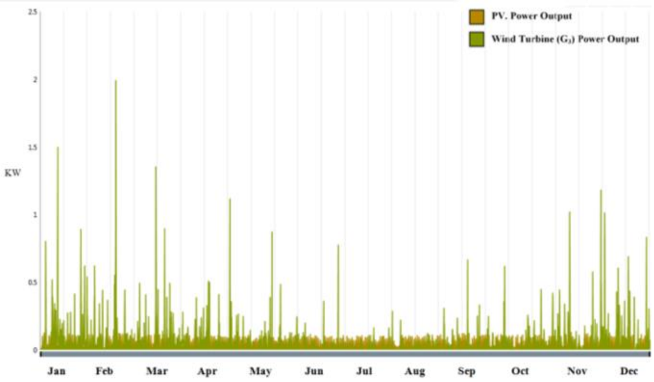

Fig. 8. The average amount of output electrical energy in photovoltaic (PV) and wind turbine (WT)

4. 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:

$$N = \{1, 2, \cdots, n\} \qquad (19)$$

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

$$S_i = \{s_{i1}, s_{i2}, \cdots, s_{im}\} \qquad (20)$$

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

$$S = \{S_1, S_2, \cdots, S_n\} \qquad (21)$$

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:

$$u_i = u_i(s_{i1}, s_{i2}, \cdots, s_{nj}) \qquad (22)$$

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:

$$s_j = (s_{1j}, s_{2j}, \cdots, s_{nj}) \qquad (23)$$

Thus the normal form of an n-persons game, represents the player's strategy space (S_1,...,S_n) and their payoff function (u_1,..., u_n), is shown as follows [41] :

$$G=\{S_{1j},\cdots,S_n;U_1,\cdots,U_n\} \tag{24}$$

Osborne, M.J. and Rubinstein [21] have shown that the solution of "Game" is a continuous selection of equilibrium strategies, the Nash equilibrium is used usually. In this equilibrium:

$$\forall i,\forall s_{-i}\in S_{-i}\quad U_i(s_i,s_{-i})\geq U_i(s_i',s_{-i}) \tag{25}$$

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 [42]:

$$\forall s_{-i}\in S_{-i}\quad U_i(s_i,s_{-i}')\geq U_i(s_i',s_{-i}') \tag{26}$$

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 [41] 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.

Game theory method is a powerful tool because it is able to manage competitors' decisions. So wherever there are different decision options and gains from different choices and there is possibility of collaboration or competition between players, it is possible to use the game theory to better understand and analysis of existing conditions. 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. The most form of DG is Combined Heat and Power (CHP) generation since it provides numerous advantages to both distribution company and electricity users [45].

In this paper, in order to allocate and determine the capacity of HESs "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 hybrid energy systems (HESs), the electrical power converted to heat ratio of different CHP technologies which are given in Table4 [35].
- Choose the capacity of CHPs that has been considered 0.5 and 1 MW in this paper.

Table. 4. Characteristics of CHP technologies (in HESs)

Fuel cell	Micro turbine	Gas turbine	Gas engine	Steam turbine	Technology
1-2	0.4 - 0.7	0.5 - 2	0.5 - 1	0.1 - 0.3	**Power to heat ratio**

By obtaining the Nash equilibrium point, the suitable location and capacity of the HESs generator will be achieved for installing in the bus network. The block diagram of the proposed algorithm for optimal allocation of HESs based on technical and economic analysis is shown in Fig.9.

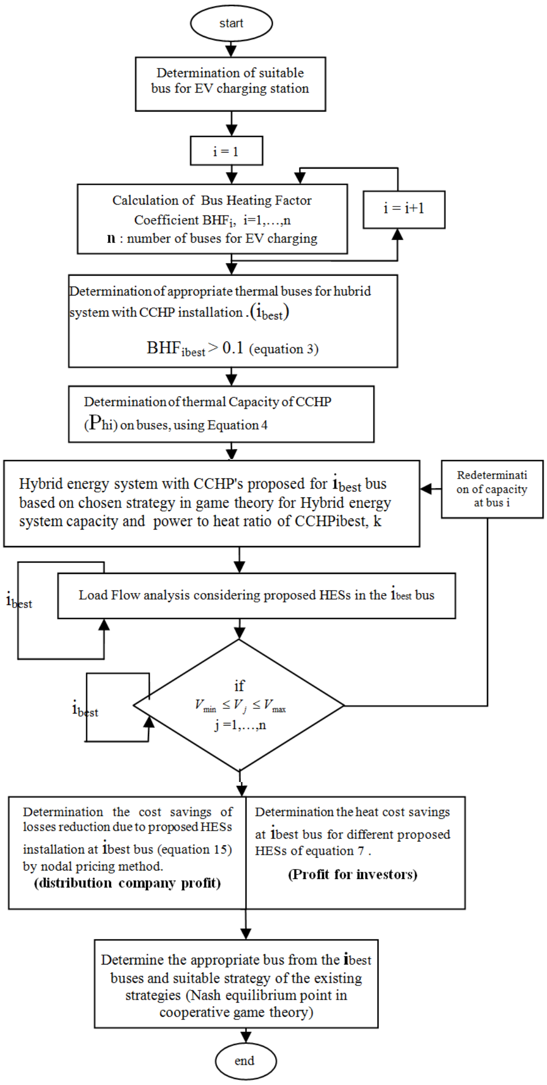

Fig. 9. Block diagram of HESs Placement algorithm

Where:
HESs $_{ibest,k}$: The HESs installed at bus i_{best} that follows the k strategy, (k : 1,..., k_{max}) .

5. Case Study

In this part, one of the 20 KV Hamadan distribution feeders has been studied (Einolghozat feeder). This feeder is fed by 63/20 KV station of Hamadan 2 (Fig.10). In this feeder, the length is 12 (Km), peak load of current is 80 (A), P_{max} is 2.3 (MW), this feeder have 63 buses, and the price of electricity supplied by the network (λ) is 50 US $ / MWh [42].

The system has been simulated for a fixed time in this paper. With regard to the reciprocating engines CHP type (in HESs), and assuming 75% efficiency achieved through the placement method in this paper, the cost of electricity supplied by HESs is equal to 53 $ for a megawatt hour.

Table. 5. Cost of used HESs

equipment life (year)	operation time $\frac{h}{year}$	maintenance and operation cost $\frac{US\$}{KWh}$	the investment of installation price $\frac{US\$}{KW}$
50	8760	0.5-2	900-1500

According to consumer information, the large thermal loads of feeder are installed on buses: 1, 5, 16 and 22 That their specifications are given in Table6.

Table. 6. Thermal specifications of major consumers buses

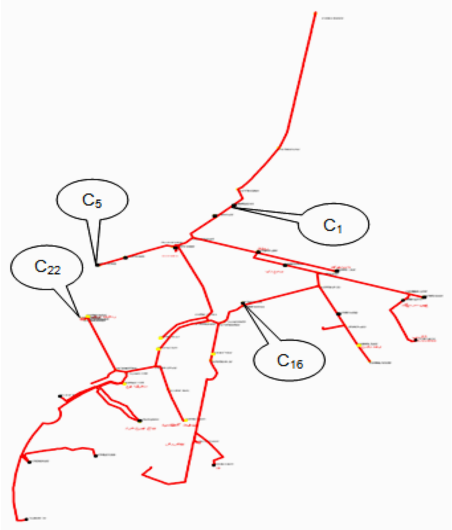

Fig. 10. Candidate buses for installation of Hybrid (PV-WT-CHP) Energy Systems and Plug-in Electric Vehicles

The buses in which heat selling possibility are available and $BTCi \geq 0.1$ are suitable for CHP installation (in HESs). In these buses the HESs capacities are calculated using fuzzy method (Table 7).

Table. 7. Determination of CHP (in HESs) thermal capacity for candidate buses

Bus number	Thermal capacity of bus (kw) $P_{Sij} = Pis \times f(\beta, d, x, \Psi)$	BTC	HESs capacity based on buses thermal capacity (MW)
1	$3040 \times (0.25 \cap 1 \cap 0.75 \cap 1) = 760$	0.7	0.7
5	$5619 \times (0.75 \cap 1 \cap 0.5 \cap 0.25) = 1404$	1.4	1.4
16	$890 \times (0.25 \cap 1 \cap 0.75 \cap 1) = 220$	0.22	0.22
22	$1000 \times (0.75 \cap 1 \cap 0.75 \cap 0.25) = 250$	0.25	0.25

5.1. Thermal benefit calculation

At this stage we assume that HESs installed on the all proposed buses (1, 5, 16, 12) have 0.5 &1MW capacities and the electrical power to heat ratios is 0.7 and 1. Then for each case the heating cost savings are calculated using equation 7 that is shown in Table 8.

Table. 8. 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
	1	0.25	15768
22	0.5	0.25	15768

Bus Number	Type of Consumption located around each bus	Consumer infrastructure (m^2)	Heat and warm water consumption (KW) (Pis)
1	Load 1,(office) C_1	37840	3040
5	Load 2, (university)C_5	27825	5619
16	Load 16, (office) C_{16}	11110	890
22	Load 22,(Residential) C_{22}	13300	1000

Power / Heat Ratio = 0.7

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	0.7	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

5.2. Technical Indicators Benefit Calculation

HESs 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, as it is observed from Table 9, the active nodal price of each bus will be reduced dramatically with the installation of the HESs unit. The nodal prices for the HESs candidate buses before and after installation (for 0.5 MW and 1 MW) are presented in Table 9.It is assumed that HESs works in unit power factor, that is, it will produce the (real) active power only.

Table. 9. The Nodal Prices of active power obtained by fuzzy bus heating factor for fixed loads without and with HESs

Bus number	CHP (in HESs) capacity based on bus heating factor(MW)	Nodal pricing of active power at buses without CHP (in HESs) (US $ / MWh)	Nodal pricing of activepower at buses with CHP(in HESs) (US $ / MWh)
1	1	51.445	50.945
	0.5	51.475	51.175
5	1	51.015	50.965
	0.5	51.44	51.24
16	1	51.14	50.99
	0.5	51.41	51.31
22	1	51.485	51.035
	0.5	0.25	51.4

By HESs installation with the capacities mentioned, using (8) to (18) equations, and Table 10, the profits of losses reduction for the HESs buses candidates will be calculated.

By considering HESs installed at bus 1 and doing load flow analysis, the new calculated losses, the amount of electrical energy supplied by the HESs and the network will be determined and the cost of HESs and network electricity will be calculated (columns 5 and 6, Table 10). The HESs installation benefits are obtained from the equation {a-(b + c)} of column 7 in the Table 10. The column 7 indicates the benefits of HESs installation which is desirable for Distribution Company.

Table. 10. Distribution company profit produced by the HESs installed at each bus using the nodal pricing method

Bus number	Cost of network electricity without HESs[1] (a) $\frac{\$}{year}$	HESs capacity (MW)	losses (MW)	Cost of network electricity (b) $\frac{\$}{year}$	Cost of HESs 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 HESs installation.

5.3. 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 HESs. By installation of specified HESs at the candidate buses through the above strategies, the benefit of consumers and distribution companies (payoff (wining) for each player) is determined as shown in Tables 8 and 10. 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 (HESs installed capacity of 1MW 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.

6. Conclusion

This paper proposed a three-stage procedure for optimal HESs placement in the distribution system through a three-stage procedure in the presence of plug-in electric vehicles (PIEVs) in the electric distribution system. The procedure at its first stage, identified candidate busses for HESs placement. Then, the capability of selling heating energy is examined using a bus heating factor through a fuzzy system. 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 and the voltage profile improvement is evaluated, considering the interaction between PIEVs and HESs in the distribution system. Finally, a game theory approach is applied to find the optimal proposal for HESs placement.

In this method, the Distribution Company and investors are players A and B respectively. The scenarios that these two players can choose are the electrical power to heat ratio of CHP (0.7 or 1) and electrical capacity of HESs (0.5 MW or 1 MW). By installation of specified HESs at the candidate buses through the above scenarios, the benefit of consumers and distribution companies is determined. The Nash equilibrium point in a static game indicates that the benefits of both players are maximized.

The results achieved from implementing the approach on a sample distribution feeder in the city of Hamadan, showed the applicability of the proposed method for optimal HESs placement in the distribution system.

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