Journal of Artificial Intelligence in Electrical Engineering, Vol. 12, No. 47 ,November 2023

Optimal Scheduling of a Micro-grid through Hybrid Method of Nash Equilibrium –Genetic Algorithm

AmirKhanjanzadeh[1],Mohammad Hossein Salmani Yengejeh[2](Corresponding Author),MehdiRajabzadeh[3], Amir Hashempour Mafi [4],NasserMoslehi Milani [5]
[1] Department of Electrical Engineering,Chalous Branch, Islamic Azad University, Chalous, Iran
[2]Department of Mathematics, Chalous Branch, Islamic Azad University, Chalous, Iran
[3]Department of Computer Engineering, Chalous Branch, Islamic Azad University, Chalous, Iran
[4]Department of Computer Archelogy, Chalous Branch, Islamic Azad University, Chalous, Iran
[5]Department of Physics, Ahar Branch, Islamic Azad University, Ahar, Iran
Email: amirkhanjazadeh@gmail.com[1], salmani@iauc.ac.ir[2], Rajabzadeh.ad@gmail.com[3,] hashempoormafi.amir@gmail.com[4]nmilani@gmail.com[5]

Receive Date: 14 Jan 2024 Accept Date:13 June 2024

Abstract

Increasing the use of fossil fuels and environmental concerns have led to the expansion of renewable resources and their replacement with conventional sources. In this paper, a robust algorithm for a micro-grid (MG) planning with the goal of maximizing profits is presented in day-ahead market. MG containing wind farms (WFs), photovoltaic (PV), fuel cell (FC), combined heat and power(CHP) units, tidal steam turbine (TST) and energy storage devices (ESDs). This algorithm is divided into two main parts:

1) *Optimal planning of each energy resource;*
2) *Using the Nash equilibrium –genetic algorithm (NE-GA) hybrid method to determine the optimal MG strategy.*

In energy resources optimal planning, using a stochastic formulation, the generation bids of each energy resource is determined in such a way that the profit of each one is maximized. Also, the constraints of renewable and load demands and selection the best method of demand response (DR) program are investigated.

Then the Nash equilibrium point is determined using the primary population produced in the previous step using the NE-GA hybrid method to determine the optimal MG strategy. Thus, using the ability of the genetic algorithm method, the Nash equilibrium point of the generation units is obtained at an acceptable time, and This means that none of the units are willing to change their strategy and that the optimal strategy is extracted. Comparison of results with previous studies shows that the expected profit in the proposed method is more than other method.

Keywords: micro-grid, Nash-Genetic hybrid method, wind farm, photovoltaic, combined heat and power, expected profit.

1. Introduction

Due to the fact that many Distribution Energy Resources, when used alone, do not have the capacity, flexibility and capability of controlling enough to carry out system management and market-oriented activities, these can be solved by forming a MG by a group of energy resources and removable loads [1-3]. In [1], Binary backtracking search algorithm optimization algorithm minimizes some objectives such as: the power generation cost, power losses, delivers reliable. In [2], fuzzy optimization is proposed to model the uncertainty in renewable energy resources. Wind power generation and market price uncertainties is modeled by using confidence bounds and scenarios, respectively in [3]. VPPs can participate in the wholesale market and collaborate on managing the transmission system. In this situation, distributed energy sources can take over the responsibility of delivering the system's protection services and play the role of centralized production [4-8]. In [8], the energy management system is considered as the heart of the virtual power plant, and the power distribution is aimed at minimizing the cost of generating electricity and final cost, reducing greenhouse gases; And to prevent loss of power generated by renewable sources, and to balance the electrical power flow, the water purifier and controllable loads have been used. In [9-11], the power plant and flexible loads have been integrated into the day-ahead electricity market in the form of a virtual power plant, and the mathematical model of these resources has been given. Flexible loads cover the uncertainty of wind power that its objective function is to maximize profits from market participation. In [12] explores the virtual power plant (VPP) management modes in providing different ancillary services such as loss reduction, voltage and frequency control, and power quality improvement. Also, load uncertainty and output power of renewable resources are considered, and wind output power and consumption forecasting error are modeled with Gaussian and normal function respectively, and the VPP is planning its distributed generation resources using the priority list. In [13], the VPP is regarded as a new solution for the management of distributed generations in the decentralized power system. It sends the quantity and price to the dispatch control center, where it predicts the load and cost of energy in each node connected to the power plant. In [14], the VPP operator will decide on the distribution of units per hour based on variable costs and repair and maintenance costs to provide electrical and thermal energy at a minimum cost. The VPP in this reference has the ability to generate heat and electricity, and its main goal is to minimize customers' electricity costs by considering network constraints. It also can exchange the electrical power with the main grid in instance price. In [15], the exploitation of the VPP is aimed at maximizing the revenue generated by the sale of power to final consumers. The reference [16] uses an optimization algorithm to reduce network congestion and imbalance between load and generation. In this algorithm, a large number of loads are combined with direct control in a MG and the load shedding is optimized over a certain control time interval. In the reference [17], the MG include a wind, solar, and gas power plant, and the plant will close profit-sharing contracts by closing bilateral contracts, and the issue is solved with integer linear planning. In reference [18], a VPP with a proposed strategy in the energy and reserve day-ahead markets has taken part that has been solved objective function consist of load and supply equilibrium constraints, distribution network security constraints and dispersed resource constraints. In reference [19], weekly scheduling includes a MG consisting of alternative renewable resources, a storage system, and a traditional power plant. The optimal distribution problem is formulated as a linear complex integer linear planning model, which maximizes the weekly earnings of a VPP with respect to long-term bilateral contracts and technical constraints. The uncertainty of wind power and solar power generation has been solved by using a pump-storage unit for flexible operation as well as having a conventional power plant as a backup production. In reference [20], the MG exchanges electricity in both day-ahead and balance markets and seeks to maximize expected profits. Uncertain parameters, including the output power of distributed generation and market price have been modeled through scenario based on Historical data. In reference [21], a probabilistic price based unit comment method has been used to model uncertainties in market prices and generation resource to propose a VPP in the day-ahead electricity market. In reference [22], a method is proposed to solve the problems of integration of large-scale distributed generation resources based on optimal power control algorithms. In [23], determining the pricing strategy of a VPP is proposed for participation in energy and reserve markets. In the reference [24] a new method for evaluating reliability has been developed and a VPP has been introduced to model MGs with renewable resources, and the reliability of the power plant has been investigated. Then, the Monte Carlo method is used to evaluate the reliability of active distribution systems by considering different operating modes under one or more incidents. The results show that using this model, a cost reduction of 50% is achieved. In the reference [25] modeling and testing of a VPP in the power system is performed. The purpose of this study is to plan the achievement of maximum revenue in the market. In [26], using a two-stage simulation, a complex of resources consist of CHP is scheduled in the day-ahead and real-time electricity market. In this system, real-time decision making power and heat is made and the goal is to achieve maximum power. In Ref. [27], using the game theory method, a method for dividing profits in VPPs including demand response loads has been performed in day-ahead and balance market. In this model, the uncertainty of market prices, renewable generations, consumption, and losses are considered. Reference [28] is a method for determining the optimal offer of a VPP consisting of a CHP and renewable energy sources and demand response loads. In this regard, three strategies have been investigated and the results show that the real-time pricing method is flexible and has a good performance. In [29], a method for planning a VPP unit, including renewable resources and loads with non-elastic characteristics in the electricity market is presented. The results of this study show that, by combining flexible resources with loads and renewable resources, system performance improves and the mathematical expected cost decreases. In [30], operational models of a set of VPPs are presented. In this model, the integrated multi-VPP management that is interrelated is examined; and income distribution between units is evaluated using game theory. In [31], the use of industrial flexible load and its planning in the power system has been investigated and various methods of this planning have been reviewed. In [32], the CHP planning and renewable resources in a distribution system has been investigated. In this regard, the planning problem has become a multi-objective planning problem and the objectives of the planning are to minimize costs and pollution. In [33], using a two-stage planning method, an optimal out-of-risk offer model for a VPP in the energy and spinning services market is presented, so that a risk value is considered for controlling the desired profit and the uncertainty of the renewable resources is taken into account, as well as the uncertainty caused by the load demands and reserves, is considered in the uncertainties of the day-ahead, reserve and balance market price. The goal of the VPPs plan is to maximize the profit in different markets. In [34], industrial VPP and its management have been studied, and it has been shown that profitability increases if a single management involves generators and loads in the form of a MG. Planning for this set is done in the short-term electricity market.

In this paper, the presented issue can be shortly explained as follows:

1. Prediction of uncertainties via hybrid method (HM) of WT-ANN-ICA.
2. Generating the scenarios of WS, tidal steam speed (TSS), PVPG, market price, electrical load demand and decreasing the scenarios with the scenario-reduction backward method, and modeling them through the tree scenario method.
3. Using the Nash equilibrium –genetic algorithm (NE-GA) hybrid method to determine the optimal MG strategy.
4. Studying the expected profit of energy resources with and without DR program.

2. The Proposed Method

An algorithm is proposed for programming generation and unit commitment of an MG including three WFs, one PV, one TST, one FC, two CHP units and ESDs considering NE-GA, Fig. (1). This flowchart has 6 steps including data receiving; uncertainties prediction; scenario generation and reduction process for stochastic parameters; extraction of energy resources profit; finding Nash equilibrium point using hybrid method of NE-GA; and the output results.

2.1. Uncertainties Prediction and Senario Generation

Load demands, wind speed, TSS, PVPG, and market price are considered to be stochastic in the modeling presented. To model such behaviors, Weibull and Normal probability distribution functions utilizing wavelet transform-artificial neural network-imperialist competitive algorithm [35] have been used to prediction and generate a number of scenarios for wind speed and other uncertainties (Load demands, TSS, PVPG, and market price), respectively. In this paper, this model is assumed to generate 100 scenarios for each parameter. To minimize the computation cost of the proposed scheduling procedure, k-means classification method [13] is used to reduce the number of applied scenarios to 10. The explanation of scenario generation and reduction processes is beyond the scope of this paper. As it can be seen in Fig. 2(a)–(e), different generated scenarios for the load demands, wind speed, TSS, PVPG, and market price e are illustrated, respectively.

2.2. Objective function of WFs, PV, TST, FC, CHP units and ESDs

In this study, the optimal scheduling of MG including WFs, PV, TST, FC, CHP units and ESDs is examined with the 24– hour time horizon as well as considering uncertainties and DR programs in order to maximize the expected profit. The multi-stage stochastic programing is applied to deal with uncertainties. Since the power generation of units should be determined before applying stochastic processes, they constitute the first or here-and-now decisions stages and do not depend on the scenarios. Other variables like buy or sell power from and to the market and charge or discharge of storage devices are at the second or wait-and-see decisions stage. This mixed integer nonlinear optimization problem is solved through MATLAB software.

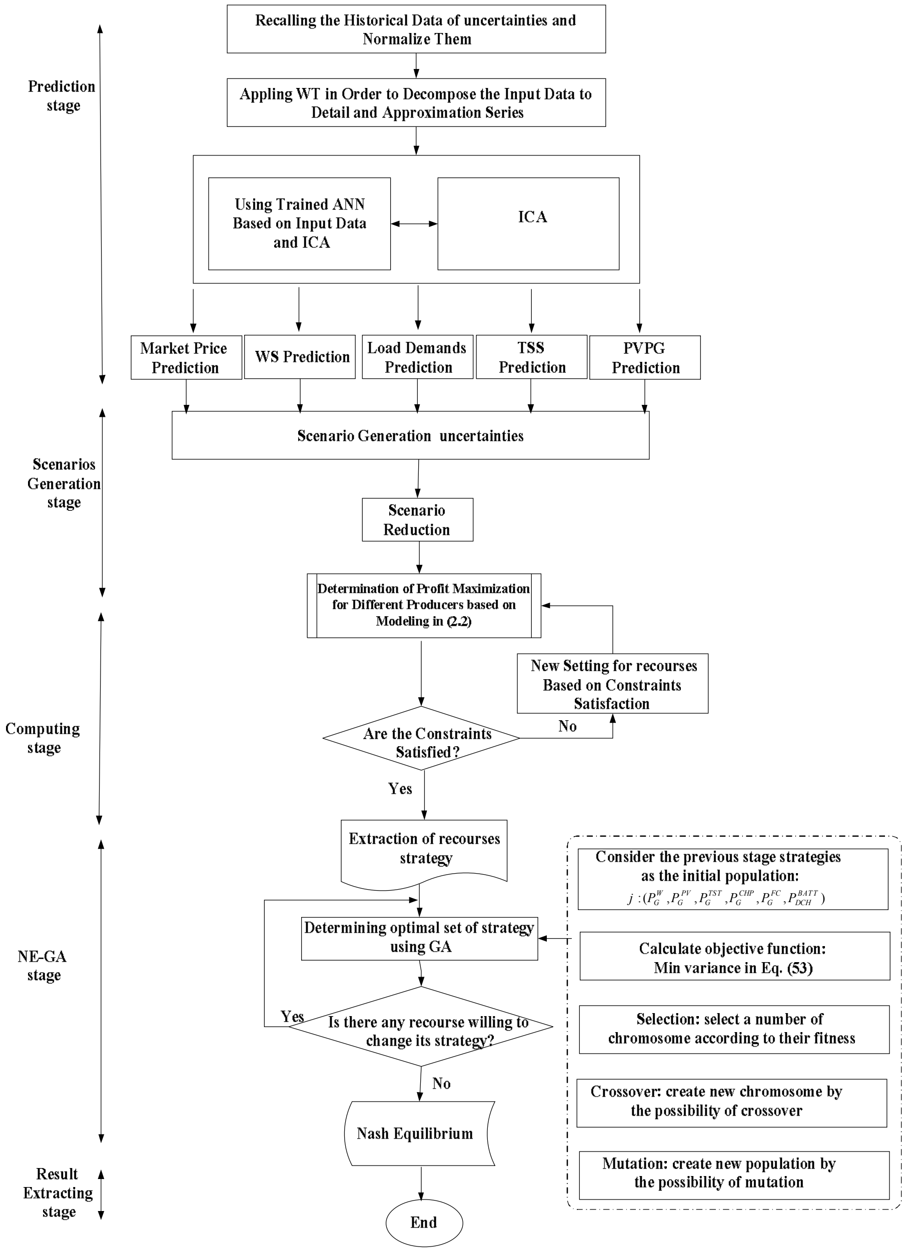


Fig. 1. The flowchart of the proposed method

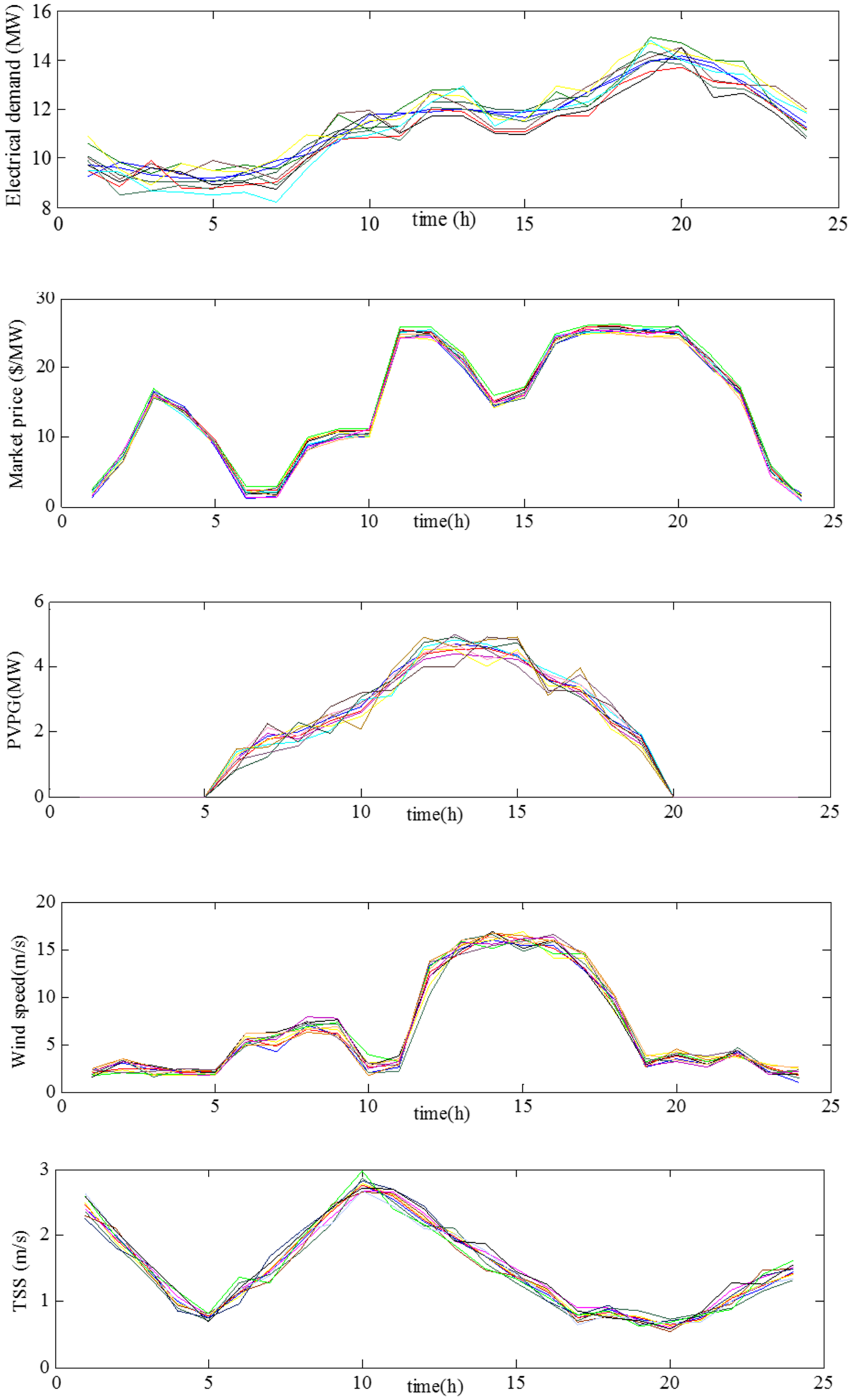


Fig. 2. The uncertainty scenario curves (a): Electrical demand, (b): Energy price, (c): PV power generation, (d): Wind speed, (e): Tidal steam speed.

$$MAX \qquad ER_T = \sum_{t=1}^{T} \rho_s [(P_G^i(s,t).E_P(s_p,t) - C_i(s,t)] \tag{1}$$

$$\rho_s = p_P \times \rho_W \times \rho_{TSS} \times \rho_{PV} \times \rho_{PL} \times \rho_{HL} \tag{2}$$

$$S = S_P, S_W, S_{PV}, S_{PL}, S_{HL}, S_{TSS} \tag{3}$$

$$C(W,t) = \sum_{W=1}^{W_N} A_W .M(W,t) \tag{4}$$

$$C(TST,t) = A_{TST} .M(TST,t) \tag{5}$$

$$\begin{aligned} C(s,CHP,t) = \sum_{CHP=1}^{CHP_N} [A_{CHP} + B_{CHP} .P_{G,CHP}(t) + C_{CHP} .P_{G,CHP}^2(t) + D_{CHP} .H_{G,CHP}^2(t) + E_{CHP} .H_{G,CHP}(t) \\ + F_{CHP} .H(t).P(t)].M(CHP,t) + U_{COST}(CHP,t).SU(CHP,t) + D_{COST}(CHP,t).SD(CHP,t) \end{aligned} \tag{6}$$

$$\begin{aligned} C(s_{PV},PV,t) = (A_{PV} . + [a^{CH}(PV) Z_{BATT}^{CH}(PV,t) + b^{CH}(PV) P_{BATT}^{CH}(s_{PV},PV,t)] + \\ [a^{DCH}(PV) Z_{BATT}^{DCH} + b^{DCH} P_{BATT}^{DCH}(s_{PV},PV,t)]).M(PV,t) \end{aligned} \tag{7}$$

$$\begin{aligned} C(s,K,t) = [[a^{CH}(K) Z_{BATT}^{CH}(K,t) + b^{CH}(K) P_{BATT}^{CH}(s,K,t)] + \\ [a^{DCH}(K) Z_{BATT}^{DCH} + b^{DCH} P_{BATT}^{DCH}(s,K,t)] + CC(K)].M(K,t) \end{aligned} \tag{8}$$

$$C(s,FC,t) = \left(A_{FC} + B_{FC} .P_G^{FC}(s,t)\right).M(FC,t) + U_{COST}(FC,t).SU(FC,t) + D_{COST}(FC,t).SD(FC,t) \tag{9}$$

$$SU(i,t) = M(i,t) \times (1 - M(i,t-1)) \qquad i \in CHP, FC, B \tag{10}$$

$$SD(i,t) = (1 - M(i,t)) \times M(i,t-1) \qquad i \in CHP, FC, B \tag{11}$$

$$\begin{aligned} P_{buy}(s,t) + \sum_{CHP=1}^{CHP_N} P_{G,CHP}(t) + P_G^{FC}(t) + \sum_{W=1}^{W_N} P_G^W(s_W,W,t) + P_{BATT}^{DCH}(s_{PV},PV,t) + P_G^{TST}(s_{TSS},TST,t) + P_{BATT}^{DCH}(s,K,t) = \\ P_{sale}(s,t) + P_{BATT}^{CH}(s_{PV},PV,t) + P_{BATT}^{CH}(s,K,t) + \{(1 - DR(s,t).L_0(s,t) + L_{shift}(s,t)\} \end{aligned} \tag{12}$$

2.2.1 Problem modeling

An optimal bidding strategy is modeled and analyzed. The objective function of this optimization problem applied for the first time is expressed as Eq. (1),where, is the probability of scenario s. According to Eq. (2), the probability of s-th scenario is obtained by multiplying the probabilities of WS, TSS, PVPG, market price, electrical load demand in each other. The function Ci is the total operation cost of each of unit defined in Eqs. (4-9). The objective function is to maximize the expected profit of each unit considering constraints related to unit usages. The startup and shut down constraints of CHP, FC, and boiler defined in Eqs. (10,11). The power balancing constraint of MG is obtained through Eq. (12). The other constrains related to DR programs, WFs, PV, TST, FC, CHP units and ESDs are reported by [35].

2.3 Nash equilibrium –genetic algorithm hybrid method

This paper presents a new method based on the combination of genetic algorithms to solve Nash problem and determine the optimum generation strategy of energy resources to maximize the profit. As mentioned, the energy resources intend to maximize their profit, so, there is no Agreement between the energy resources; and the game can be defined as a multi-player zero-sum one. Considering the relation between energy resources strategic, so, game theory is used for determining the optimum strategy and intelligent decisions.

2.3.1. Genetic Algorithm:

The genetic algorithm is an optimization method which uses Darwin's principle of natural selection for finding the optimum formula. In genetic algorithm, first, it is produced some answers for solving the problem recognized as the initial population, and each answer is recognized as a chromosome. Then, the appropriate number of chromosome pairs are selected according to their fitness rate to be used at the later steps. The chromosome, with higher fitness number, may be selected at the production steps several times, and then cross-over would be applied on the parents' chromosomes, and by composing them, it will be produced new chromosomes. Afterwards, the mutation would be applied on the chromosome resulted of cross-over, and will provide a new way for new information by changing the amount of chromosomes. Then fitness rate of new chromosomes are calculated in order to evaluate the children, and the new population is produced and evaluated. This process continues until the end condition of the algorithm to be provided.

2.3.2. Nash equilibrium

The concept of Nash equilibrium on which this paper is presented, is introduced for the games with two or more players, in which it is assumed that a player knows the strategies and pay-off of the other players, and he can obtain some pay-off just via his own choices and without directed imposition on the others'. John Nash tried to indicate that the result of relation between several players cannot be predicted, without considering them being together. There are many definitions for Nash equilibrium:

1)Nash equilibrium is a point in which none of the players cannot earn more profit by changing its own strategy when performance of the other players is fixed. In other words, xi is a Nash equilibrium point, if for each of the players we have:

$$\begin{aligned}&\forall i: u_i(x_1^*, x_2^*, \ldots, x_i^*, \ldots, x_n^*)\\&> u_i(x_1^*, x_2^*, \ldots, x_{i-1}^*, x_i, x_{i+1}^*, \ldots, x_n^*)\end{aligned} \tag{13}$$

Where xi means that the player xi is exited of the equilibrium point, and it will certainly lose.

2) Best response function of a player denotes the player best reaction (utility maximizing reaction) to any strategy profile chosen by other player. Player's best response function (correspondence) in a strategic game is the function that assigns to each a−i ∈ A−i the set:

$$BR(a_{-i}) = \{a_i \in A_i : u_i(a_i, a_{-i}) \geq u_i(a'_i, a_{-i}); \forall a'_i \in A_j\} \tag{14}$$

The action profile a∗ is a Nash equilibrium of a strategic game if and only if every player's action in this profile is the best response to the other player's actions (a∗−i):

$$ai^* \in BR(a-i^*) \qquad for \;\; i = 1,...,N \tag{15}$$

This function causes improving the time of calculation, especially, where the time is important. The presenting this paper is to obtain a strategy in which, if each of the players (energy resources) changed his strategy, he will lose; and this is precisely the concept of Nash point.

In this paper, to evaluate the performance of the proposed modeling, Evaluation Strategies (ES) such as profit maximization is considered as Eq. (16):

$$\left\{\begin{array}{l}
p_G^{W*} \in \underset{p_G^{W}}{\arg\max}\left[ES(P_G^{W}, P_G^{PV*}, P_G^{TST*}, P_G^{CHP*}, P_G^{FC*}, P_{DCH}^{BATT*}, t).profit^{W}(t)\right] \\
p_G^{PV*} \in \underset{p_G^{PV}}{\arg\max}\left[ES(P_G^{W*}, P_G^{PV}, P_G^{TST*}, P_G^{CHP*}, P_G^{FC*}, P_{DCH}^{BATT*}, t).profit^{PV}(t)\right] \\
p_G^{TST*} \in \underset{p_G^{TST}}{\arg\max}\left[ES(P_G^{W*}, P_G^{PV*}, P_G^{TST}, P_G^{CHP*}, P_G^{FC*}, P_{DCH}^{BATT*}, t).profit^{TST}(t)\right] \\
p_G^{CHP*} \in \underset{p_G^{CHP}}{\arg\max}\left[ES(P_G^{W*}, P_G^{PV*}, P_G^{TST*}, P_G^{CHP}, P_G^{FC*}, P_{DCH}^{BATT*}, t).profit^{CHP}(t)\right] \\
p_G^{FC*} \in \underset{p_G^{FC}}{\arg\max}\left[ES(P_G^{W*}, P_G^{PV*}, P_G^{TST*}, P_G^{CHP*}, P_G^{FC}, P_{DCH}^{BATT*}, t).profit^{FC}(t)\right] \\
p_{DCH}^{BATT*} \in \underset{p_{DCH}^{BATT}}{\arg\max}\left[ES(P_G^{W*}, P_G^{PV*}, P_G^{TST*}, P_G^{CHP*}, P_G^{FC*}, P_{DCH}^{BATT}, t).profit^{BATT}(t)\right]
\end{array}\right\} \tag{16}$$

where, argmax f (•) is a subset of the definitional domain, which maximizes the function f (•), refers to the optimal bidding strategy of energy resources i, refer to is the profit obtained from energy resources at time t, is the jth evaluation strategy at time t, is a set of bidding strategy of MG.

To balance profit among energy resources and select the best bidding strategies, variance is presented as objective function [30]:

$$\mathrm{minV} = \sum_{j} (\overline{\mathrm{V}} - \mathrm{V_j}) \tag{17}$$

$$\overline{\mathrm{V}} = \frac{1}{i}(V_1 + V_2 + \cdots + V_i) \tag{18}$$

$$V_i = \frac{\sum_{t=1}^{24}\left[ES(j,t).profit^{i}(t)\right]}{24 \times \max\left\{ES(j,t).profit^{i}(t)\right\}} \tag{19}$$

3. Numerical Example

The structure of MG and numerical data concerned with energy resources are studied and then simulation results of optimal operation for the stochastic problem are analyzed.

Configuration of MG

In this article two case studies will be assessed:

1. Planning and determining the optimal strategy of MG energy resources connected to grid through NE-GA method,
2. Programming and determining the optimal strategy of MG connected to the grid and exploring the effect of DR problem on the profit of energy resources.

In cases 1 and 2, the MG is able to exchange energy through a grid based on electrical load demand and market price. Stochastic programming is applied on a typical MG, Fig. (3). The case studies are run on: three WFs, two CHP units, one TST, one PV, one low temperature fuel cell (PAFC), one electrical energy storage device together with the fixed and responsive electrical loads. The startup and shutdown costs of units are tabulated in Table 1. The heat buffer tank data and cost coefficients of CHP units are tabulated in Table 2. Both $DR_{\max}$ and $\varepsilon_{\max}$ are assumed 30%. The electrical-thermal characteristics of CHP units are displayed in Fig. (4). The parameters of WFs include: $WS_{co}(i) = 25^{m/s}$, $WS_{n}(i) = 11^{m/s}$, $WS_{ci}(i) = 2.5^{m/s}$ and the rated output power are equal to $P_{WN1} = 1.5^{MW}$, $P_{WN2,3} = 2.4^{MW}$. Historical data pertaining to the WS, electrical demand and market price, electrical energy storage devices data and photovoltaic power generation are proposed in [35]. The PV nominal power generation is $P_{\max}^{MW} = 4.68$, $P_{\min}^{MW} = 0$ and $\delta = 0.75$. Table (3) lists the parameters used for the tidal steam turbine [35].

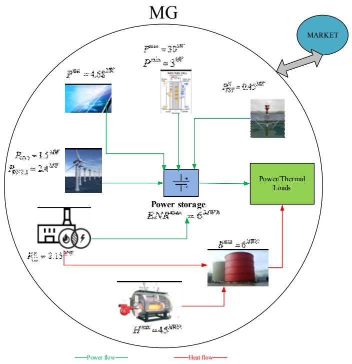


Fig. 3.Typical MG under study

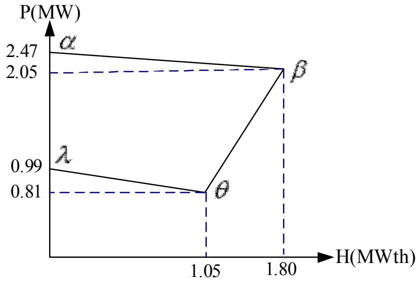


Fig.4. The electrical-thermal characteristic of CHP units

Table 1. The startup and shutdown cost of units

CHP units	A_{CHP}=0.0435	B_{CHP}=36	C_{CHP}=12.5	D_{CHP}=0.027	E_{CHP}=0.6	F_{CHP}=0.011
Heat Buffe Tank	$\eta_{loss} = 0.6$	$\eta_{gain} = 0.3$	σ=1%	$AH_{discharde}^{\max} =$ $AH_{ch\arg e}^{\max} = 2$	$AH_{\max} = 7$	$AH_{\min} = 0$

Table 2. The heat buffer tank data and cost coefficients of CHP units

Unit	UCOST	DCOST
CHP units	20	20
Fuel Cell	0.0207	0.0207
Boiler	9	9

Table 3. The tidal steam turbine data

Rated Speed	**2.4(m/s)**
Cut-in Speed	**0.7(m/s)**
Cut-out Speed	**4.2(m/s)**
Power Coefficient	**0.47**
Cross-sectional Area	**3.006(m^2)**

4. Simulation Results

Case Study 1: In the first case study, the effect of the proposed method on units planning and MG is studied by examining previous studies. Due to the fact that the MG is connected to grid, the MG management center in addition to providing its electrical and thermal load, has the ability to exchange electrical power with the main grid. So, although energy resources try to maximize their profits and determine the best strategy, the MG management center can also optimize its profit through power exchange. In Fig 5, the optimal generation bids of energy resources are shown using the proposed method for the WFs, TST, PV, FC, CHP, and the power exchanged between the MG and grid, respectively. These results are compared with the Ref. [35] (from the authors of this article). In the Ref. [35], there is no competition between resources in order to maximize its profit, and the objective of optimizing and determining the optimal strategy of the units is to maximize the profit of the MG. And this means that the owner of all production resources is MG, which is very difficult to realize this assumption. As shown in Fig 5-a, the WFs generation bids are shown in the 24-hour time horizons. Given the low cost of these units, the generation bids is at the maximum possible capacity based on wind speed. Similarly this trend for the TST unit is also in Fig 5-b. In the Fig 5-c, PV generation bids are shown. The energy storage devices of this unit have led to strategy changes relative to [35]. Which usually causes energy sales at hours with higher prices. In Fig 5-d, due to high generation costs in FC unit, usually power generation bids at the peak hours is higher in this unit, which simulation results also point to the same. In order to supply the MG heating load and the cost of generation of very high thermal power in the boiler, the generation of electric power in the CHP is dependent on the heating demand, so the generating bids of this unit is approximately the same as [35] that shown in Fig 5-e. The power of MG exchange with the grid using the proposed method in Fig 5-f will cause the power sales at peak hours and power purchases from the grid at low demand times and increase the profitability of the MG. In Table 4, the earned profit of units is compared using the proposed method and the Ref. [35]. Percentage of profit growth is related to the exchanged power between MG and grid, FC and PV unit with 9, 8 and 4.6 percent increase.

Table 4. Case study 1 results

	WFs	**TST**	**PV**	**FC**	**CHP units**	**Exchanged power**
Ref. [35]	1514.6	80.99	787.06	9.27	9155.2	647.12
NE-GA method	1537.1	81.72	823.48	10.01	9202.6	706.91

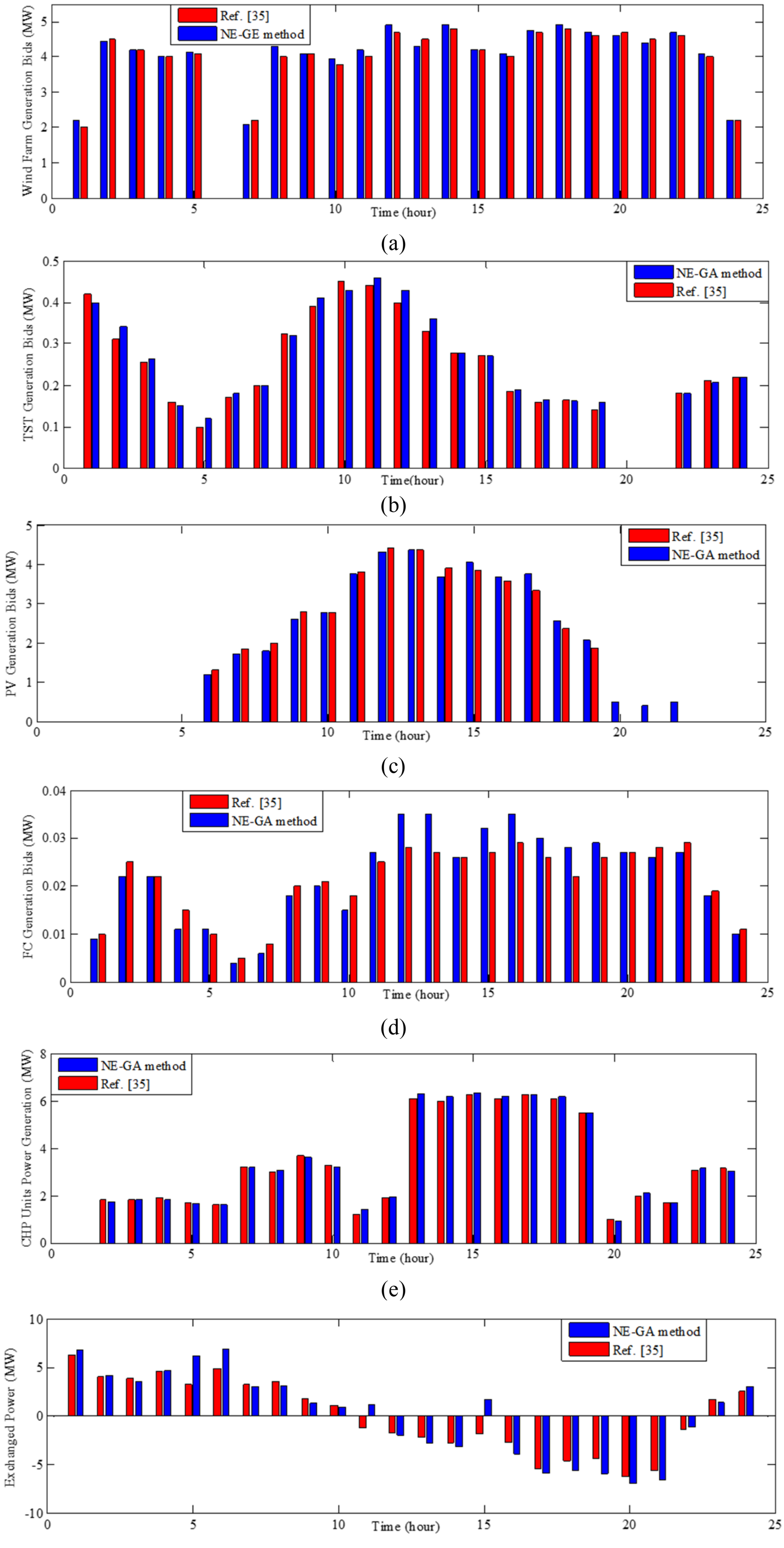


Fig. .5. The generated power of resources in the planning horizon

2. Case study 2: to explore the effect of DR program in determining of generation strategy of MG through NE-GA method. In this case, Critical Peak Pricing (CPP), Emergency Demand Response Program (EDRP) and CPP +EDRP methods are applied and energy resources can select the most appropriate method of DR program. In CPP method, the price of electricity varies according to the supply cost of electricity for different time periods; for example, a high price in a peak-load period; a medium price in an off-peak-load period; and a low-price in a low-load period. In EDRP programs, there are voluntary options and if customers do not interrupt their consumption, they are not penalized [34].

As it was mentioned before, there are different DR programs that can be used for the participation of interruptible loads in the scheduling problem. In this paper, 3 programs are used for this purpose. Based on this, 3 cases are considered to be examined in the proposed modeling. These are tabulated in Table 5.

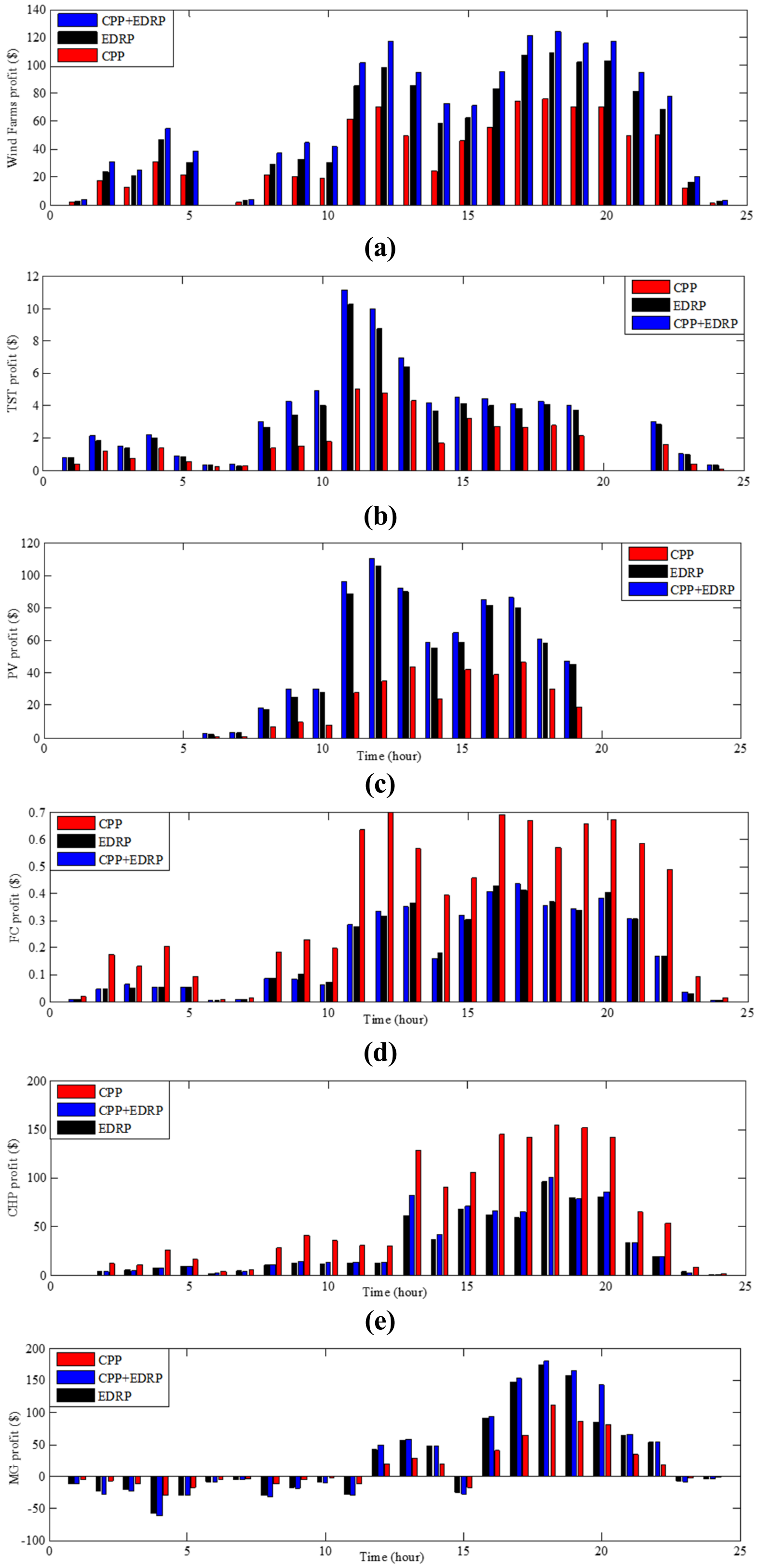
As it is shown in Fig. 6, the profit of different energy resources obtained in each DR program case is shown daily. This clarification concerns loads that have to select one DR program for their day-ahead scheduling and cannot choose another program based on the processes which are working in their properties. Thus, by using these figures, it can be found that the best DR program for achieving the maximum profit in a day can be obtained. Considering the energy resources profit in a day, it is obvious that CPP+EDRP and CPP are the most suitable programs for renewable and conventional units respectively. The value of DR participation in each energy resources is tabulated in Table 6. As it can be seen, units actively participate in DR strategies originated from scheduled and suitable shifting the load to achieve the most profit.

Table 5. Different DR programs

DR program type	Market price ($/MWh)	Incentive Value ($/MWh)
CPP	Scenario based on 20 $/MWh at 19 to 20	-
EDRP	Scenario based on 11 $/MWh at 10 to 16	16
CPP+EDRP	Scenario based on 20 $/MWh at 19 to 20 and 11 $/MWh at others	16

Table 6. Value of DR participation in each energy resources

Energy resources	Best DR program	Participation in market (MW)
WFs	CPP+EDRP	0.673
TST	CPP+EDRP	0.040
PV	CPP+EDRP	0.543
FC	CPP	0.0032
CHP	CPP	0.781
MG	CPP+EDRP	0.611



(a)

(b)

(c)

(d)

(e)

(f)

Fig .6. profit of different energy resources obtained in three DR program

4. Conclosions

In this paper, a new algorithm to manage energy resources of MG for scheduling issue has been considered. Firstly, the prediction and scenario generation of uncertainties are organized. Then, a new formulation to plan a day-ahead scheduling of MG is proposed. The model is presented as a stochastic mixed integer nonlinear programming optimization problem with regard to different generation, load, and system constraints. The objective of the problem is to maximize the profit of energy resources. This objective can be obtained Nash equilibrium point by the ability of the genetic algorithm.

Using proposed method, the profit growth related to the exchanged power between MG and grid, FC and PV unit with 9, 8 and 4.6 percent increased.

The obtained results show that the proposed modeling can be an appropriate way to have access to the maximum profit for energy resources with different DR programs. Considering results, it is obvious that CPP+EDRP and CPP are the most suitable DR programs for renewable and conventional units respectively.

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