Optimal Performance of Micro-Grids Networks with Uncertainty using Game Theory Coalition Formulation Strategy

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ABSTRACT:
The demand for energy is constantly increasing, which is pushing the limitations of the current grid, increasing reliance on fossil fuels, and increasing CO2 emissions. These concerns have renewed interest in discovering ways to reduce power demand on the grid through renewable energy. However, the distribution characteristics of renewable energy make it difficult to integrate effectively into the traditional power grid. As power networks increase in scale, the drawbacks of the conventional grid, such as high cost and difficult operation, will become more apparent, and it will no longer meet increasing safety, reliability, and diversity. Therefore, applying efficient methods for improving the performance of micro-grids is necessary. In this paper, the application of CRPSO algorithm based on the game theoretic formulation strategy for reducing the exchange of power between the macro station and micro-grids is proposed. The objective function of optimization involves minimizing the cost of power, loss, communication and load shedding. The advantages have caused the load of the micro-grids to be implemented as much as possible through the exchanges between the micro-grids and the cost of utilization and power supply of the loads to be minimized. Uncertainties in wind speed and solar radiation flux are also considered for the purpose of applying the random property of the distributed generation resources. The simulation results on the 33rd IEEE standard system in different scenarios indicate the desired performance of the proposed method.

KEYWORDS: Game Theoretic Coalition Formulation Strategy, Optimal Allocation of Dispersed Generation Resources, Uncertainty, CRPSO Algorithm, Micro Grid.

1. INTRODUCTION

Renewable energy applications will be a feasible solution for energy scarcity and environmental problems as a result of the rapid advancement of global economic growth. However, the distribution characteristics of renewable energy make it difficult to integrate effectively into the traditional power grid. As power networks increase in scale, the drawbacks of the conventional grid, such as high cost and difficult operation, will become more apparent, and it will no longer meet increasing safety, reliability, and diversity needs. However, in most cases, to increase the reliability of the micro grid, a power link between the micro grids and the macro station is constructed to exchange the power with the macro station when needed. At peak times or due to events in the micro grid, part of the power generation may be lost, and therefore the power supply of the micro grid requires the exchange of power with the macro station. In this case, due to the far distance between the macro station and the micro grids, and due to factors, such as energy transmission cost, loss cost, communication cost, etc., the final cost of the purchased power for the micro grids is very expensive. One of the available solutions for reducing such problems is exchanging the power of each micro grid with its adjacent micro grids which are the closest to them. This reduces the costs of power transmission, loss and communication, and the cost of power purchased in this way is much less than the cost of power purchased from the macro station.

In order to improve the above-mentioned methodology, the allocation DG units has been proposed to form coalitions with more diverse choices. Therefore, in the final method of this paper, the adjacent micro-grids-form coalitions has been performed by using an algorithm. These coalitions are improved or modified through optimizing the allocation of DG units, including their type, size, and location to reduce the total cost of the optimal utilization of micro-grids, including the costs of purchase, transmission, loss, and communication. The allocation of the DG units must be in such a way that, taking into account their costs, the total cost of micro-grid utilization in a given time period is reduced, or the technical parameters are improved to justify the allocation of the DG units.

Due to the fact that the micro-grid power is often produced by fluctuating DG units, it is tried when supplying the power in the micro-grid-power management to have a support from the power plant or the main electricity network. For this purpose, the power plant is constructed at an optimal distance between the micro-grids. Due to the far distance between the power plants and some micro-grids, power exchange with the power plant often leads to a lot of losses. In reference [1], to reduce the exchange of power between the micro-grids and the power plants, Game Theoretic Coalition Formulation Strategy (GT-CFS) has been used, according to which, the dimensions of the coalitions between the micro-grids are controlled by the main power supply connected to the power plant. Moreover, in the above-mentioned paper, decisions are made for the micro-grids based on the network conditions, whether to remain in the same coalition or separate from it. In each coalition, the profit is shared with the micro-grids. In [2], the game theoretic coalition formulation strategy is presented using an innovative integration method including a request for power transmission and integration to find the best collaborative structure. In [3], the long-term power exchanges have been conducted between several countries to supply their power and maximize their social welfare.

One way to improve the economic status of micro-grid utilization is to use energy storage resources that are used at peak times to compensate for the shortage of load and reduce the power exchange with the macro station. In [4], Energy Storage Systems (ESS) are used in the micro-grids by applying a Distributed Model Predictive Control (DMPC) algorithm in grid networks. The cost function in the above-mentioned article includes maximizing the economic profits of the micro-grids, reducing the power storage resources and meeting all the constraints of the system. The proposed algorithm in this paper is solved using Mixed Integer Linear Programming (MILP). In [5], the utilization of the distribution network was carried out using the concept of multi-micro-grid with the aim of minimizing the cost of power exchange between the micro-grids. Based on the results of this study, the mean, standard deviation and probability density function of each generated power with a Small-Scale Energy Resource (SSERs) are determined by considering the optimization constraints. In reference [6], the game theoretic coalition formulation strategy has been presented based on the Shapley Value-Based Payment Calculation, so that all micro-grids benefit from coalition profits. Allocating the DG units has always been used as one of the solutions to improve the operation of the micro-grids. In [7-9], the allocation of DG units has been done with the aim of improving the technical and economic parameters as well as reducing the costs of micro-grid utilization.

Planning for micro-grid utilization has always been accompanied with uncertainties, considering which leads to plan a more accurate and realistic program. Uncertainty involves taking into account all the parameters that may change due to changes in the environmental and economic conditions, as well as human factors, etc. In [10], a general classification is proposed for the application of uncertainty in power systems, including probability method, possibility method and hybrid method. In this paper, the DG units of wind and photovoltaic turbines have been selected due to their technical and economic advantages for allocation of the micro-grids. The renewable energy resources of wind and sun radiation flux are fluctuating due to the changing atmospheric conditions along a day. Hence, in order to account for these changes, uncertainties in wind speed and radiation flux have been considered to bring the results closer to real situations. The results of simulations in different scenarios, which include non-coalition exchanges, coalition exchanges, and coalition exchanges with DG placement, illustrate the positive effects of the proposed method properly. The structure of the tested system consists of a number of Micro-Grids (MG) and Macro Stations (MS) connected to the main power grid and is shown in Fig. 1. In this figure, all MGs and MSs are connected to each other and form a radial distribution grid. Moreover, typically, the coalition of the adjacent micro-grids, which are directly exchanging the power, as well as the communication lines between the micro-grids and the macro station are shown respectively with continuous lines and dotted lines. In this figure, an agent is allocated to each micro-grid which analyzes and exchanges the information with the other micro-grids and the macro station through a computer system and a communication line. The agents are responsible for purchasing and selling energy at each micro-grid and the exchange of information to form a coalition between the micro-grids. In [11-15], the optimal performance of the micro grids is done by applying the uncertainty.

2. PLANNING FOR OPTIMAL PERFORMANCE OF MICRO-GRID NETWORKS

The main purpose of Optimal planning in micro-grid networks is to supply the load energy to the micro-grids in a 24-hour time period. Planning for optimal utilization of the micro-grids is carried out, with the purpose of forming micro-grid coalitions using the game theoretic coalition formulation strategy. In this planning, main cost of supplying the micro-grid power such as the cost of purchase, loss, communication, and load shedding have been reduced.

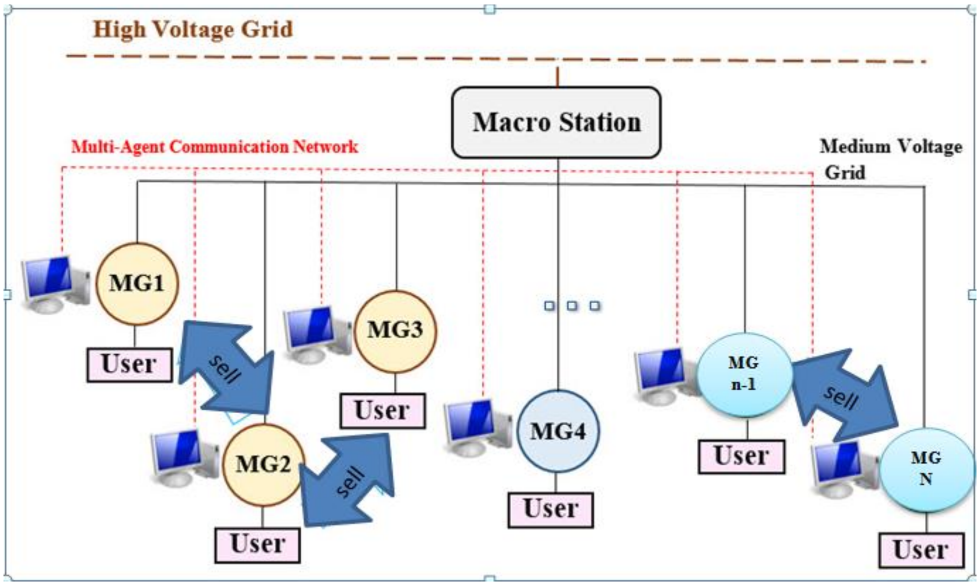

Fig. 1. The system structure including micro-grids and macro station.

2.1. Problem Statement

In this article, every day is considered as 24 one-hour period. The total number of micro-grids is assumed to be N, and the amount of power generated by MG_i in each period is assumed to be G_i with the load of Di. It should be noted that both G_i and Di are active powers because it is assumed that the amount of load reactive power is generated over each period of time. Considering the above-mentioned quantities, the amount of load demand for each micro-grid in each period is specified as follows. $R_{eqi} > 0$ indicates the sufficiency of the micro-grid power to provide its loads and the existence of surplus generation. This excess power can be transmitted to the other micro-grids or the macro station. $Req_i < 0$ indicates the insufficiency of the micro-grid power to provide its loads and the generation of overload. This excess load should be transmitted to the other micro-grids or the macro station. Furthermore, $Req_i = 0$ indicates the sufficiency of the micro-grid power to provide its loads and the absence of surplus generation or overload.

$$\mathrm{Re}q_i = G_i - D_i \tag{1}$$

Moreover, θ_{max} is the maximum load percentage that can be shed at each period. Therefore, the exact form of the above function can be rewritten with regard to the load shedding as follows:

$$\mathrm{Re}q_i = G_i - (1-\theta_{\max})D_i \tag{2}$$

By specifying the demand for each micro-grid, the micro-grids with surplus generations are included in the S_s category and the micro-grids with overloads are included in the S_b category. It should be noted that the micro-grids with zero power demands are included in none of these categories because there is no need to purchase or sell energy.

In utilizing the micro-grids, there are a few cost and price parameters that are explained in the following. Cg is the cost of generating electrical energy that depends on the type of renewable or non-renewable energy, but is usually considered equal for all micro-grids for the purpose of simplification. C_b is the retail price of the electrical energy purchased from the macro station by the micro-grids; this price varies in different periods, and is usually the highest at the peak load times. C_l is the cost of electrical energy transmitted per unit of length. Thus, this cost depends on the distance between the energy buyer and the seller. C_1^{com} is the cost of communication per unit of length which is also related to the distance between the energy buyer and seller similar to the transmission cost. C_{shed} is the cost of compensating for the load shedding of customers whose load has been shed during the load shedding process. In fact, this cost is determined by the importance of the load shed.

In this paper, each-micro-grid plays the role of an actor looking for other micro-grids to form a coalition to save their own costs and the total cost of power supply to the loads through exchanging power directly with them. Each coalition is divided into two categories of buyers and sellers. In each coalition, first, the power between the buyer (S_b) and sellers (S_s) is exchanged locally; then, if there is a demand for power, the power exchange is done between the micro-grid and the macro station. The order of joining the coalitions in this study is so that the costs of utilizing all the modes of joining the micro-grids to the coalition are examined and the least costly one is selected.

The purpose of this part of the paper is to reduce the cost of energy supply in each coalition. The cost of each coalition at the period includes the following four costs: Costs of electrical power purchase for each micro-grid purchasing from the other micro-grids or the macro station;

Costs spent on power losses; Communication costs related to the exchange of information between the micro-grids;

Costs of compensating for load shedding of the customers whose load has been shed when needed.

In the proposed method, each seller micro-grid sells the electrical energy to the other micro-grids at production price, but it should be noted that the seller micro-grids benefit from the reduction of the total cost. However, in this section, the profits gained by the energy sellers are not calculated. For each coalition S, the total costs are calculated in accordance with reference [16] through the following equation:

$$\mu(\mathrm{S},\Omega)=\begin{pmatrix}\sum_{i\in S_b} Cost_i^{pur}+\sum_{i\in S} Cost_i^{loss}\\ +\sum_{i\in S} Cost_i^{com}+\sum_{i\in S} Cost_i^{shed}\end{pmatrix} \quad (3)$$

Where, Ω is the order of joining the buyers in the coalition S. In this equation, the goal is to minimize the cost of the micro-grids. The cost of purchasing energy MGi from MG_j is shown with C_{ij} comprised of the cost of energy generation and the cost of energy transmission. It is given in the following equation [16].

$$C_{ij}=C_g+l_{ij}C_l \quad (4)$$

Where, l_{ij} is the distance between MGi and MG_j. Moreover, the cost of energy purchase from the macro station is shown with C_b which is calculated in the following equation [16].

$$Cost_i^{pur}=\sum_{j\in S_s} C_{ij}f_{ij}+C_b f_{i0} \quad (5)$$

Where, f_{ij} is the power exchanged between the two micro-grids MGi and MG_j and f_{i0}, is the power exchanged between MGi and the macro station. The losses due to the power exchange between the two micro-grids are calculated through the following equation [16].

$$P_{ij}^{loss}=\frac{R_{ij}f_{ij}^2}{U_0^2} \quad (6)$$

If there is still power (surplus generation or overload) after the exchange of power between the micro-grids, the losses associated with the power exchange of the micro-grid MGi with the micro-grid MG_j and the macro station are calculated through the following equation [16].

$$P_{i0}^{loss}=\frac{R_{i0}f_{i0}^2}{U_0^2}+\alpha f_{i0} \quad (7)$$

Where, R_{ij} and U0 represent the resistance and voltage of the line between MGi and MG_j, respectively. Both R_{ij} and Ri0 are proportional to the distance. Moreover, α is the percentage of power loss associated with the transformer in MS. By calculating these two losses, the total loss cost of MGi is calculated using the following equation [16].

$$Cost_i^{loss}=C_b P_{i0}^{loss}+\sum_{j\in S} C_{ij}P_{ij}^{loss} \quad (8)$$

$Cost_i^{com}$ is the communication cost of the micro-grid MGi for exchanging information with the other micro-grids in the coalition, which is given through the following equation, here C_1^{com} is the cost of communication of information per unit length [16].

$$Cost_i^{com}=\sum_{j\in S-\{i\}} l_{ij}C_1^{com} \quad (9)$$

$Cost_i^{shed}$ is the cost of compensating for the load shedding of the MG_i customers whose loads have been shed. It is calculated through the following equation [16].

$$Cost_i^{shed}=C_{shed}\theta_{\max}D_i \quad (10)$$

Given the following equation, the value of the function for each coalition $S\subseteq N$ of coalition game micro-grids is defined through the following equation [16].

$$v(S)=\min_{\Omega\in\Omega_S}\mu(\mathrm{S},\Omega) \quad (11)$$

Where Ω_S is the total of all buyers who have joined the coalition S. Minimizing Equation (11) actually reduces the costs of coalition utilization. It should be noted that in all calculations of energy costs, Real-Time Price System (RTP) has been used. In this system, the actual price of energy, which is settled in the electricity market is applied and trades are done with it. The problem of the game theoretic coalition formulation strategy can be divided into three sub-categories based on reference [16].

2.1.1. Minimizing costs of coalition utilization

The purpose of the implementation of coalition strategy among the micro-grids at this stage is minimizing the objective function through Equation (11), which minimizes the payment of each coalition. The total payment of each coalition depends on the amount of transaction between the micro-grid and the MS, since the power exchanged between a pair of seller and buyer micro-grids does not affect the total payment. The method of implementing this method is as follows:

A. In this method, the power buyer micro-grids are ranked based on the order of membership (older membership) and the power seller micro-grids are ranked based on the distance (less distance).
B. In the first coalition, the first buyer micro-grid purchases energy from the first seller micro-grid.
C. If the power of the power seller micro-grids is depleted, the power is purchased from the MS.
D. If the power demanded by the buyer micro-grid is not supplied, the buyer purchases from the next seller micro-grids until its power is completed.
E. Otherwise, if the buyer's power demand is not supplied, the next buyer would supply it.
F. Resuming from step 4 to the completion of the load of all micro-grids.
G. If after supplying the power of all buyer micro-grids, the power seller micro-grids can still be available for sale, they will exchange their power with the MS.

2.1.2. The optimal coalition structure

Once the load of all micro-grids is supplied, and the power exchange between the micro-grids and the MS is completed to maximize coalition payments, the profits should be distributed fairly among the coalitions. One of the methods used in this regard is the "Shapley Value" method [17]. In the coalition (N, υ, φ), the Shapley Value for each MGi is calculated through the following equation [16].

$$\phi_i(v) = \sum_{S \subseteq N-i} \frac{|S|!\left(|N|-|S|-1\right)!}{|N|!}\left(v\left(SU\{i\}\right)-v(S)\right) \qquad (12)$$

Where, each subcategory of the coalition S is considered to be without i member and the profit associated with it $v\left(SU\{i\}\right)-v(S)$ which has been earned by the actor I with different rankings in the coalition is added to it. Afterwards, the average profit from the different conditions is calculated and determined as the profit of the MGi micro-grid in the coalition.

Considering the power purchase and loss costs, the micro-grids' cost of purchasing energy from each other may be more than their purchase from the MS. Thus, considering a general coalition including all the micro-grids is not reasonable. Rather, the micro-grids must be grouped into different coalitions in such a way to achieve the desired goals. In this section, the dominance relationship has been used which has created the concept of the Pareto order. Considering the coalition K including the members of {K_1, K_2, ..., K_k} and the coalition L including the members of {L_1, L_2, ..., L_k}, and their profit margin as φ_j (K) and φ_j (K) according to Equation (12), the K-series dominates over the L-series by the Pareto order if and only if Equation (13) is met [16].

$$\begin{aligned} &K \triangleright L \Leftrightarrow \phi_j(K) \ge \phi_j(L), \quad \forall\, j \in K, L \\ &\text{and } \phi_k(K) > \phi_k(L), \quad \exists k \in K, L \end{aligned} \qquad (13)$$

Based on the comparison of the individual relations of the micro-grids, a three-step algorithm has been used to determine the structure of the coalitions. This algorithm is based on the two laws of merging and splitting as listed below.

A. merging coalitions

Merging rule: Merging each set of coalitions (S_1, S_2... S_k) $U_{j=1}^{k} S_j$ occurs if the following condition is met [16].

$$\{S_1, S_2, \ldots, S_k\} \triangleright U_{j=1}^{k} S_j$$

This rule explicitly states that if the cost of all the micro-grids in the coalition after merging is smaller than or equal to the state before merging, and if at least for one micro-grid, this condition is met, the merging occurs.

B. Splitting coalition

Splitting rule: Splitting each set of coalitions (S_1, S_2... S_k) $U_{j=1}^{k} S_j$ occurs if the following condition is met [16].

$$U_{j=1}^{k} S_j \triangleright \{S_1, S_2, \ldots, S_k\}$$

This rule explicitly states that if the cost of all the micro-grids in the coalition after splitting is smaller than or equal to the state before splitting, and if at least for one micro-grid, this condition is met, the splitting occurs.

According to the two rules above, the optimal micro-grid structure is determined in the following three steps:

Sending the information required from the MGs to MS.

Determining the structure of the coalitions by using the rules of micro-grids merging and splitting.

Efficient power exchanges so that the power is exchanged between the micro-grids first, and if there is still a shortage of power or excess power, the power exchange can be done between the micro-grids and the MS.

2.2. Coalition Game Theory Formulation for the Optimal Utilization of the Micro-grids

Considering N micro-grids, the game theoretic coalition formulation strategy for the optimal utilization of the micro-grids can be written as an aggregate algorithm through the following steps.

Step 1: Considering a set N of micro-grids, each of which has the load Di and the generation Gi, and a set S = {S1, S2... SN}, that at first, each coalition Si only contains MG_i.

Step 2: For each MG_i, Req_i is calculated using Di and G_i and then the information is sent to the MS using communication lines.

Step 3: The act of merging to and splitting from the coalition is performed as follows:

The coalition Si merges with the coalition Sj if

$$S_i \, U \, S_j \triangleright \{S_i, S_j\}$$

For the coalition Si with the members $\{S_p, S_q\}$, S_q (or S_p) splits from the S_i if $\{S_p, S_q\} \triangleright S_i$.

Step 3 continues until it converges to a final coalition S_{final}.

Step 4: Coalition exchanges occur including the following sub-steps:

Each MG agent receives the form of coalition from the MS.

In each coalition S_i, with S_{final}, MGs purchase their demands according to their rank of merging to the coalition.

If after the end of the exchanges within the coalitions, there is still a potential for exchange (overload or surplus generation), it will be exchanged with the MS.

Step 5: After the exchanges have been finished, the amount of cost and profit is calculated, and these results are presented with the structure of the coalitions as the output of the algorithm.

2.3. Optimal Allocation of DG Units

In this paper, the optimal allocation of DG units has been carried out based on the game theoretic coalition formulation strategy to improve the results of coalition exchanges among the micro-grids and reduce the cost of micro-grid utilization while increasing the profits.

2.3.1. DG Units Model

In this section, a model is presented for the components of dispersed generation resources, including wind turbines and photo voltaic, which have been selected for optimal allocation in this study [18].

2.3.2. Photo Voltaic (PV)

The output power of a cell from the PV is determined through Equation (14).

$$P_s = \begin{cases} P_{s-rated} \dfrac{s}{s_r} & s \le s \le s_r \\ P_{s-rated} & s_r \le s \end{cases} \quad (14)$$

In the equation above, P_s indicates the output power of the PV in W, $P_{s\text{-rated}}$ indicates the nominal power of PV in W, S indicates the sun radiation flux in kW / m^2, S_r indicates the nominal sun radiation flux for PVs in kW / m^2.

2.3.3. Wind Turbine (WT)

The cost of generating wind units is very low and usually ignored. The total power generated by the wind units depends on the wind speed and is calculated through the following equation:

$$P_{W(t)} = \begin{cases} 0 & V_{ws}(t) < V_{cutin}, V_{ws}(t) > V_{cutout} \\ P_{WG\max} \times \left(\dfrac{V_{ws}(t) - V_{cutin}}{V_{rated} - V_{cutin}} \right) & V_{cutin} \le V_{ws}(t) \le V_{rated} \\ P_{WG\max} & V_{rated} \le V_{ws}(t) \le V_{cutout} \end{cases} \quad (15)$$

Where, P_{Wgmax} is the nominal power of WT in W, V_{ws} (t) is the predicted wind speed in m / s, V_{cutin} is the minimum wind speed for the operation of WT in m / s, V_{cutout} is the maximum wind speed for the operation of WT in m / s, and V_{rated} is the nominal wind speed for the operation of WT in m / s.

2.4. Objective Function with Consideration of Uncertainty

In this paper, since the purpose of allocating the DG is to reduce the operation costs of the system including a number of micro-grids and MS, the objective function of optimization involves minimizing the total costs of the power supply, losses and communication. In order to equalize the objective function in this problem and the problem of the micro-grids coalition strategy, the cost of load shedding has also been added to it. The objective function at this stage is calculated through the following equation, which is a function of the location and capacity of the sources of dispersed generation:

$$\mu(\mathrm{S},\Omega,B,\mathrm{C}) = \left(\begin{array}{l} \sum_{i\in S_b} Cost_i^{pur} + \sum_{i\in S} Cost_i^{loss} + \sum_{i\in S} Cost_i^{com} \\ + \sum_{i\in S} Cost_i^{shed} + \left(\sum_{i\in N_{DG}} Cost_i^{invst} \right) \end{array} \right) \quad (16)$$

Where, B and C respectively indicate the location (grid) and the capacity of the DG Units. In the objective function above, since the location and capacity of the DG Units are specified, the cost of the power purchased from them, the cost of their power loss, and the cost of their communication with other micro-grid in the coalition are calculated as before, which also includes the cost of their repair and maintenance. Moreover, the cost of investing (installing) DG Units has been applied to this equation. After allocating the DG Units in the micro-grids, to increase the productivity of DG Units, coalition exchanges are again carried out with the following equation to reduce the cost of micro-grid utilization. In fact, Equation (16) is similar to Equation (11), with the only difference that DG Units are also allocated.

2.4.1. Application of Uncertainty

In this research, the DG units include wind turbine and photo voltaic accompanied with uncertainties in wind speed and sun radiation flux. In this study, in accordance with reference [19], the uncertainty has been applied in percentages of ± 20% to wind speed and solar radiation flux. Therefore, the objective function is changed so that its value is calculated for the uncertainties of +20 %, 0% and -20%, and finally, in order to consider the worst case, the largest (worst) function is used for each of these three modes as the value of the objective function. By doing so, the worst possible condition for the system is considered. Therefore, any situation that occurs in reality is not certainly worse but shows that the effect of the uncertainty in renewable energy resources on the generation capacity of the DG units is considered properly.

The objective function for the optimal allocation of the DG units in the game theoretic coalition formulation strategy among the micro-grids is given in the following equation by considering the uncertainty:

$$\begin{array}{l} f = \max \left\{ v(S)\big|^{uc=-20\%}, v(S)\big|^{uc=0\%}, v(S)\big|^{uc=+20\%} \right\} \\ v(S) = \min\limits_{\Omega\in\Omega_S} \mu(\mathrm{S},\Omega,B,\mathrm{C}) \end{array} \quad (17)$$

In the equation above, f is the symbol of the objective function, and uc is also the symbol of uncertainty in the parameters of wind speed and sun radiation flux. The rest of the parameters in the above-mentioned equation have been described in the previous sections.

2.5. Craziness-Based Particle Swarm Optimization (CRPSO) Algorithm

The following changes in the PSO Speed Update Equation increase the searching capacity for the overall optimal value, which creates the CRPSO algorithm. By adding craziness-based search, this algorithm helps to exit from the local optimal points and find the global optimal points. The changes applied to the CRPSO algorithm over the PSO are as follows:

a) Speed update equation: From reference [20], the speed update equation can be obtained as follows:

$$\begin{array}{l} v_i^{k+1} = r_2 \times v_i^k + (1-r_2)\times c_1 \times r_1 \times \left(P_{Best,I} - x_i^k\right) \\ + (1-r_2)\times c_2 \times (1-r_1)\times \left(g_{Bes} - x_i^k\right) \end{array} \quad (18)$$

Global and local searches are balanced by a random number r_2 stated in the previous reference. The direction change of the velocity can be modeled by the following equation:

$$\begin{array}{l} v_i^{k+1} = r_2 \times sign(r_3)\times v_i^k + (1-r_2)\times c_1 \times r_1 \times \left(P_{Best,I} - x_i^k\right) \\ + (1-r_2)\times c_2 \times (1-r_1)\times \left(g_{Bes} - x_i^k\right) \end{array} \quad (19)$$

In equation (20), sign (r3) can be defined as:

$$sign(r_3) = \begin{cases} -1 & r_3 \le 0.05 \\ 1 & r_3 > 0.05 \end{cases} \quad (20)$$

b) Entering craziness: The variation in the direction of the birds swarming or the fish moving can be controlled in a conventional PSO by a predefined craziness probability. The particles before the position update can be crazy under the following equation [21].

c)

$$v_i^{k+1} = v_i^{k+1} + Pr(r_4)\times sign(r_4)\times v_i^{craziness} \quad (21)$$

Where, P_r (r4) and sign (r_4) are defined as follows:

$$Pr(r_4) = \begin{cases} 1 & r_4 \le P_{craz} \\ 0 & r_4 > P_{craz} \end{cases} \quad (22)$$

$$sign(r_4) = \begin{cases} 1 & r_4 \le 0.5 \\ -1 & r_4 < P_{craz} \end{cases} \quad (23)$$

Equation of position update:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (24)$$

2.6. Optimal Allocation of DG Units Based on the Game Theoretic Coalition Formation Strategy

The optimal allocation of DG Units using the CRPSO algorithm based on the game theoretic coalition formulation strategy has the following steps:

Step 1: Initial valuing of the algorithm parameters (determining the size and location of DG Units)
Step 2: Initial valuing of the population
Step 3: Implementing the game theoretic coalition formulation strategy
Step 4: Determining the value of the fitness function (objective function according to Equation (16)
Step 5: Updating the particles' velocity
Step 6: Updating the particles' location
Step 7: Implementing the game theoretic coalition formulation strategy with the presence of DG Units on the passed population and calculating the objective function
Step 8: Choosing the best local and global responses
Step 9: Checking the stop conditions for the algorithm
Stop condition is not met: In this case, the algorithm process is resumed from step 5
Stop condition is met: The optimization process is finished and the algorithm process is resumed from step 10
Step 10: Selecting the optimal particle
Step 11: Presenting the output and optimizing the results

3. SIMULATION RESULTS

3.1. IEEE 33-Bus Test System Information

In this paper, the IEEE 33 buses system is modified such that each bus is considered to be a MG shown in Table 1, Fig. 2 and Fig. 3. The position, generation, and load of each MG are determined by Poisson distribution. The load range is selected between 1 MW and 3 MW, the location of all the micro-grids has been distributed in a square-shaped boundary with a length of 10 kilometers using the normal Gaussian distribution [16]. The position of MS is between the horizontal axis (x) and the high value of vertical axis (y). Other parameters of a system comprising positions (x, y), generation, load, and demand are given in Fig. 4 and Fig. 5. Therefore, the difference between the load generation and demand of each micro-grid can be in the range of -2 to 2 megawatts. It should be noted that the location, power and demand for the micro-grids are given in Table 1. The parameters for calculating the power exchange costs are given in Table 2. In this Table, the coefficients for calculating the power exchange costs are given in rows 1 through 6. The resistance equals to the length of the line unit, the maximum load shed, the distribution network voltage, and the maximum flow of the communication line between the micro-grids and the macro stations are given respectively in the following rows.

3.2. Cooperative Transaction for 1 Hour

The results for the studied period (1 hours) for without and with loss are shown in Fig. 4 and Fig. 5, and compared to similar results of non-coalition exchanges as bar graphs. The exchanges between the micro-grids were performed based on specific coalitions.

3.3. Cooperative Transaction for 24 Hour

In this section, the game theoretic coalition formulation strategy is used to form a coalition and to carry out cooperative power exchanges between the micro-grids considering the losses for the studied period (24 hours), and then the results are compared with the exchanges without coalition between the micro-grids. The results for the studied period (1 hour) for without and with loss are shown in Fig. 6 and Fig. 7.

3.3.1. With Loss

In this section, micro-girds exchange power in 11 coalitions with the main post. Table 3 identifies the members in each coalition. In addition, in this table the buyers are arranged, accordingly, memberships are optimized. With careful consideration of these results, it can be found that the game theoretic coalition formulation strategy reduced all the system utilization costs but increased the power sellers' profit. It should be noted that the flow of the communication line between the micro-grids and the macro station did not exceed the permissible limit.

3.3.2. Without Loss

In this section, micro-girds exchange power in ٤ coalitions with the main post. Table 4 identifies the members in each coalition. In addition, in this table the order of buyers is optimally selected for the lowest cost, but the order of sellers is not important in this stage. However, when the transactions are done, the order of buyer is important; it depends on the distance for providing power of each buyer.

Table 1. Experimental System Information.

Number of micro-grid	Location- x (km)	Location- y (km)	Generation- G (MW)	Load- D (MW)	Request- R_{eq} (MW)
1	-3.5	-9.2	2.3894	1.7716	0.6178
2	-4.5	-7.8	1.0803	2.4536	-1.3733
3	1.7	7.7	2.4683	2.9345	-0.4662
4	8	0.7	2.6227	2.6405	-0.3178
5	5.1	-1.7	1.1296	2.2530	-1.1234
6	-9.5	-6	1.9732	2.7032	-0.7300
7	-5.5	1.2	2.9871	1.5776	1.4095
8	-8.5	-1.6	1.7794	1.7548	0.0246
9	1.6	6.8	2.4034	1.4607	0.9427
10	3.5	6.2	1.4296	2.9677	-1.5381
11	-8.5	1.4	1.9989	1.0146	0.9843
12	-7.9	3/4	1.1113	2.3896	-1.2756
13	-3.6	3.8	1.0710	1.7585	-0.6875
14	7.5	-9.9	1.9786	1.4278	-0.4492
15	-1.4	-3.2	1.5897	1.2554	0.3443
16	5.7	5.4	1.1296	1.1551	-0.0255
17	3.2	-2.2	2.4003	2.1364	0.2639
18	-5.2	-7.5	1.6312	2.7905	-1.1593
19	-5.8	2.4	2.5659	2.2219	0.3440
20	1.8	9.3	1.3615	2.6122	-1.2507
21	0.3	8.8	1.0487	1.0608	-0.0193
22	-5.4	1.2	2.5529	2.2371	0.3158
23	-8.3	6.5	1.8258	1.7228	0.1030
24	-6.5	1.3	1.9612	1.2809	0.6803
25	6.3	9	1.4936	1.2568	0.2368
26	3	-6	1.7456	1.0720	0.6736
27	-8.4	-2.7	2.6810	1.8037	0.8773
28	9.7	-4.4	2.7609	2.9464	-0.1855
29	-5.4	-7.3	1.4842	2.7802	-1.2960
30	8	-1.4	2.3936	2.1999	0.1937
31	1.2	-9.7	1.5369	1.7945	-0.2576
32	-0.5	6.7	1.8816	1.0375	0.8441
33	-8.8	-3.6	1.1925	2.5445	-1.3520

Table 2. Parameters for calculating the costs associated with micro-grids utilization [16].

Parameter	Value
C_g (cents/kW)	4
C_b (cents/kW)	10
C_l (cents/kW)	0.01
C_l^{com} $(cents/km)$	0.1
C_{shed} (cents/kW)	1
A	0.02
R (Ω/km)	0.2
$_{max}\theta$	10%
U_0 (kV)	50
I_{MS}^{max} (A)	100

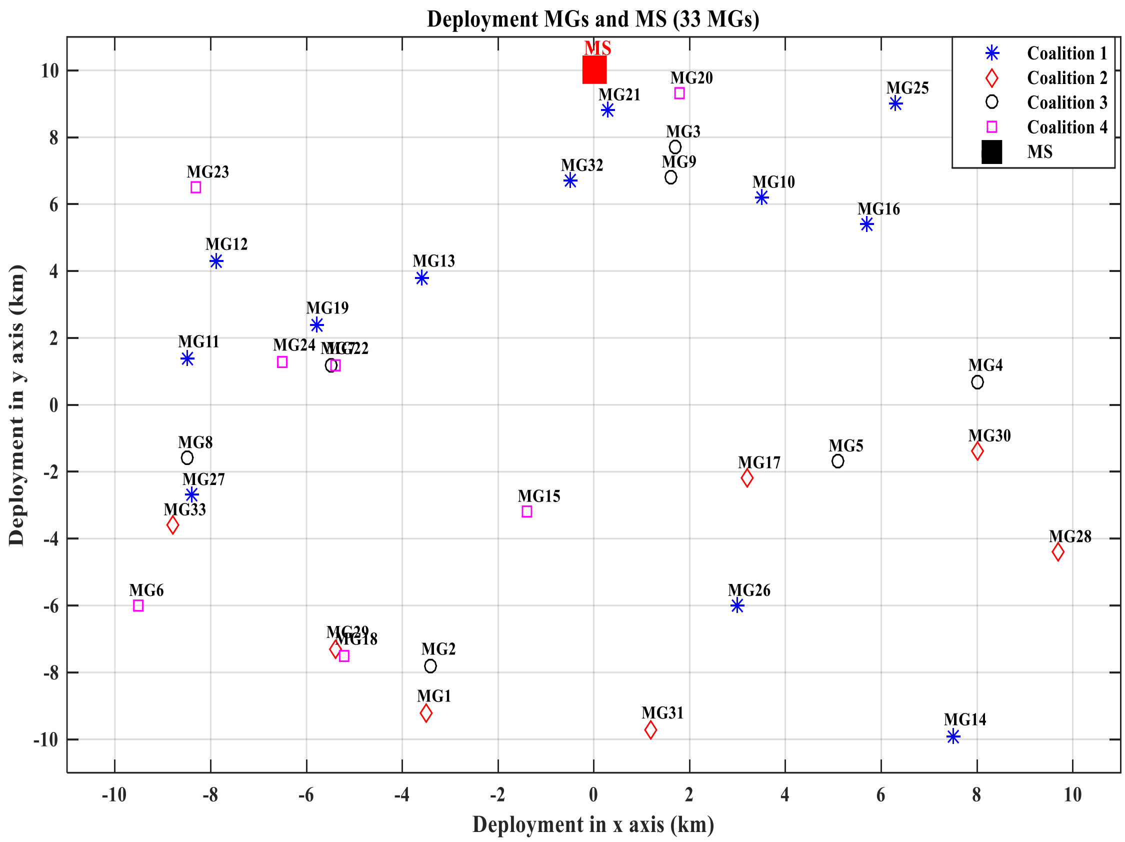

Fig. 2. Micro-grids deployment based on coalitional Game theory (without loss).

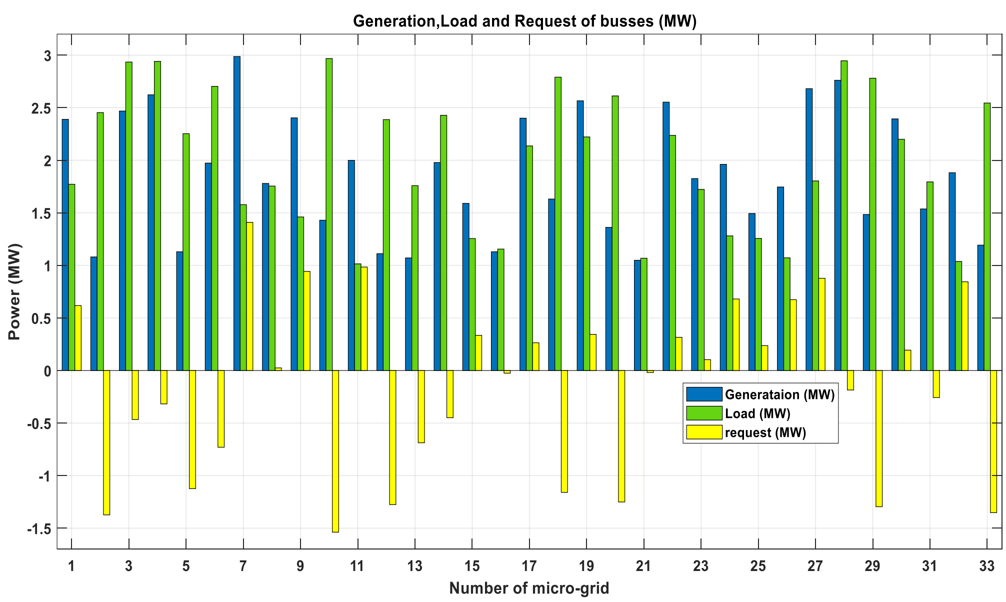

Fig. 3. Generation, Request and Load of busses (MW) in Modified IEEE 33 busses test system.

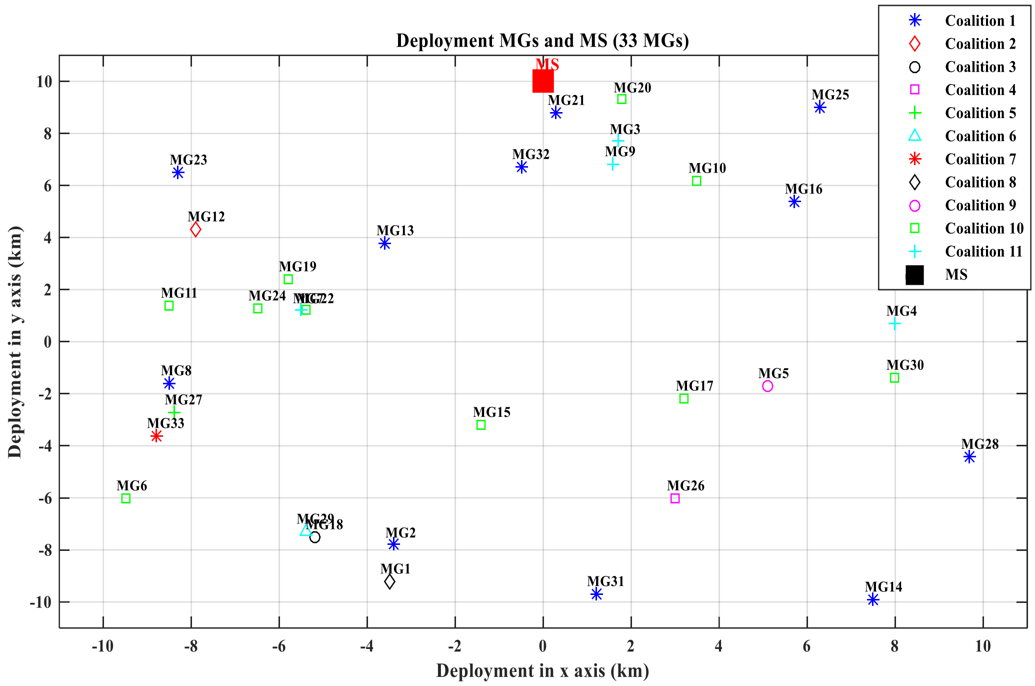

Fig. 4. Micro-grids deployment based on coalitional Game theory (with loss).

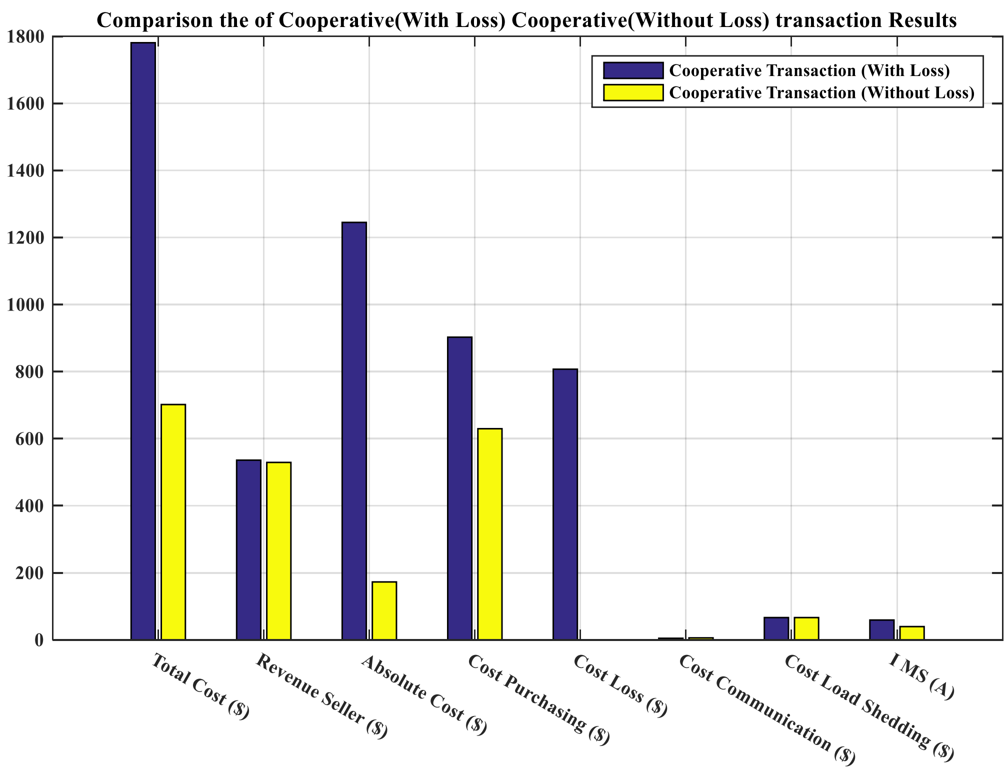

Fig. 5. Results of cooperative transaction without loss and with loss at the first hour.

Table 3. Result of formation coalition between micro-grids with loss.

Coalition	Micro-grids	
	Buyers	**Sellers**
S1	MG2 MG28 MG31 MG13 MG14 MG16 MG21	MG8 MG23 MG25 MG32
S2	MG12	---
S3	MG18	---
S4	---	MG26
S5	---	MG27
S6	G29	---
S7	G33	---
S8	---	MG1
S9	MG5	-
S10	MG20 MG30 MG6 G10	MG11 MG15 MG17 MG19 MG22 MG24
S11	MG3 MG4	MG7 MG9

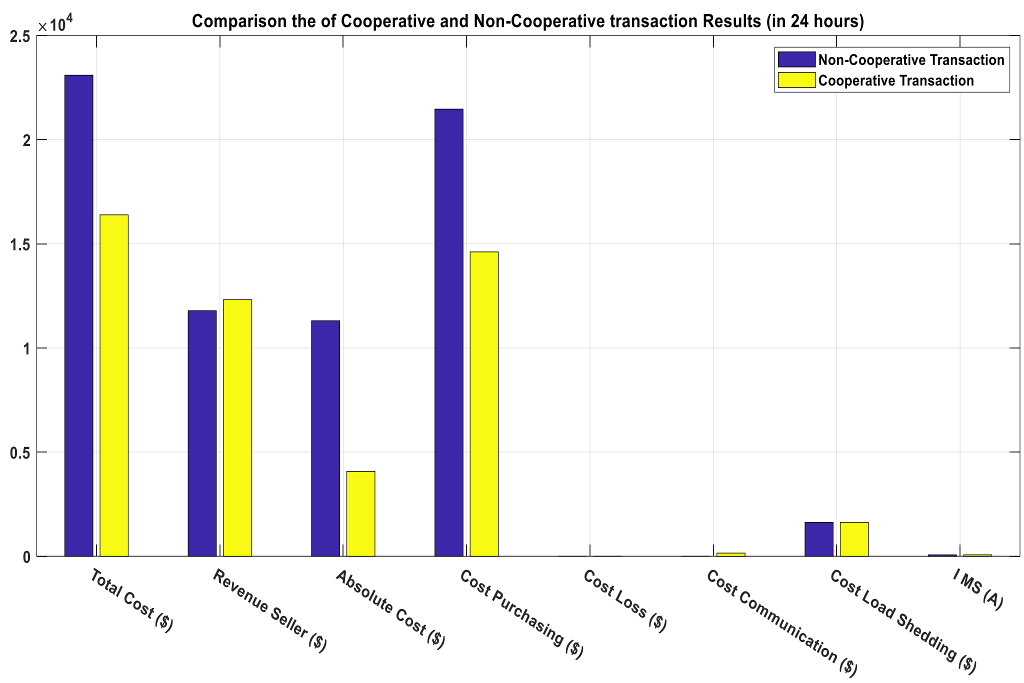

Fig. 6. Comparison of cooperative and Non-cooperative transaction without loss for 24 hours.

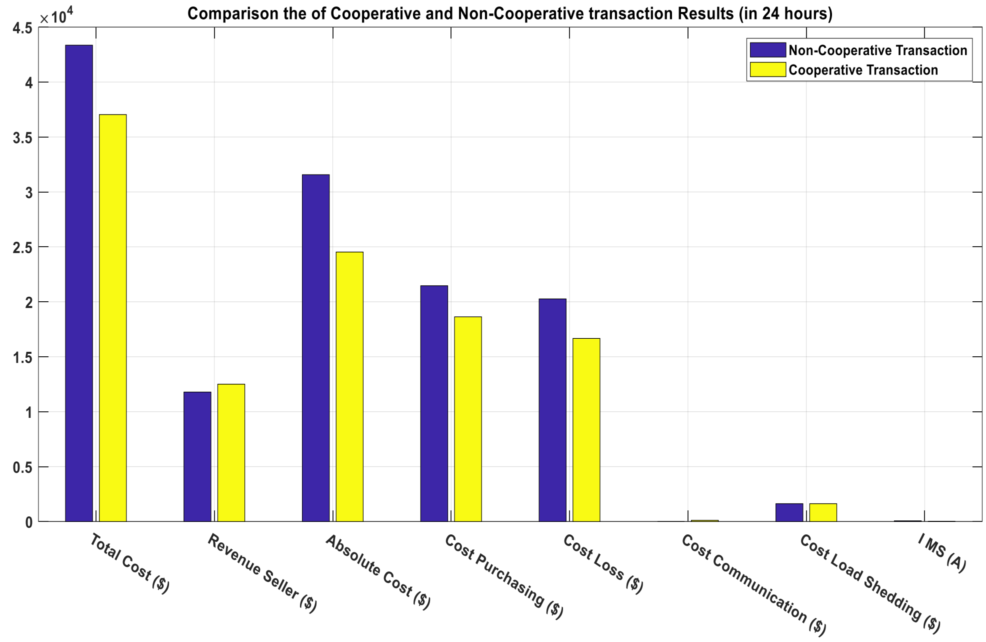

Fig. 7. Comparison of cooperative and Non-cooperative transaction with loss for 24 hours.

Table 4. Result of formation coalition between micro-grids without loss.

Coalition	**Micro-grids**	
	Buyers	**Sellers**
S1	MG12 MG13 MG14 MG11 MG16 MG21	MG10 MG19 MG25 MG26 MG27 MG32
S2	MG31 MG33 MG29 MG28	MG1 MG17 MG30
S3	MG2 MG3 MG5 MG4	MG7 MG8 MG9
S4	MG18 G20 MG6	MG15 MG22 MG23 MG24

3.4. Optimal Allocation of with the Uncertainty

In this section, to apply the random and variable properties of the renewable energy resources, such as wind energy and solar energy, uncertainty in wind speed and solar radiation flux has been considered. Uncertainty in these parameters has been considered in accordance with reference [19], with percentages of -20% and +20%. Given the number of variables and the complexity of the optimization equations, the number of replications and the number of particles has been considered to be 100. Other values of the parameters of the algorithm have been selected according to reference [21]. After doing 100 iteration at the first hour, the optimization process in this section is shown in Fig. 9. According to this figure, it can be seen that the convergence of the algorithm has reached the final response after almost 80 iteration. The results of the optimal allocation of the DG units in this section are given in Table 5, including the location and the generation capacity of each DG. Furthermore, in this table, the results of optimal allocation of DG are also displayed, without considering the uncertainty. Given the results of allocation in this section, it is observed that taking into account the uncertainty caused a smaller number of DG Units to be allocated in the micro-grids, compared to their allocation when not considering the uncertainty. This is because, despite the lack of uncertainty, the allocation of DG Units in some micro-grids is not economically profitable. In this scenario, it is clear that the uncertainty has had a greater impact on the generation capacity of the wind turbines, since no wind turbines have been allocated in this scenario, and only the photo voltaic has been allocated. Table 6 shows the results of the allocation of DG Units with -20% and +20% percentages of uncertainty and without uncertainty. The comparison of their total costs shows that the value related to the +20% uncertainty has the highest value, which has also been chosen as the objective function. Moreover, Table 6 shows the numerical results of the non-coalition exchanges, as well as the coalition exchanges before and after the allocation of DG with considering the uncertainty. By comparing these results, it is found that the results of the coalition exchanges are much better than the non-coalition ones, and the results of the coalition exchanges after the allocation of DG Units with considering the uncertainty is much better than before their allocation. Therefore, the positive impact of allocating DG Units with considering the uncertainty is also quite evident in this section.

Table 5. Results of optimal allocation of DG Units, including type and capacity and location.

Number of micro-grid	Wind turbine capacity (kW)		Photovoltaic capacity (kW)	
	With uncertainty	Without uncertainty	With uncertainty	Without uncertainty
1	0	220	0	0
2	0	30	0	0
3	0	0	0	0
4	0	0	0	70
5	0	60	0	0
6	0	500	0	0
7	0	320	0	50
8	0	0	0	0
9	0	0	0	0
10	0	70	0	180
11	0	20	0	0
12	0	380	0	80
13	0	220	0	120
14	0	100	0	0
15	0	0	0	340
16	0	100	0	400
17	0	270	0	180
18	0	0	0	0
19	0	380	0	0
20	0	200	0	0
21	0	70	0	0
22	0	0	0	0
23	0	170	310	0
24	0	230	0	0
25	0	110	0	0

26	0	0	0	0
27	0	0	0	0
28	0	0	0	160
29	0	0	360	460
30	0	110	410	320
31	0	0	0	0
32	0	140	0	0
33	0	320	380	100

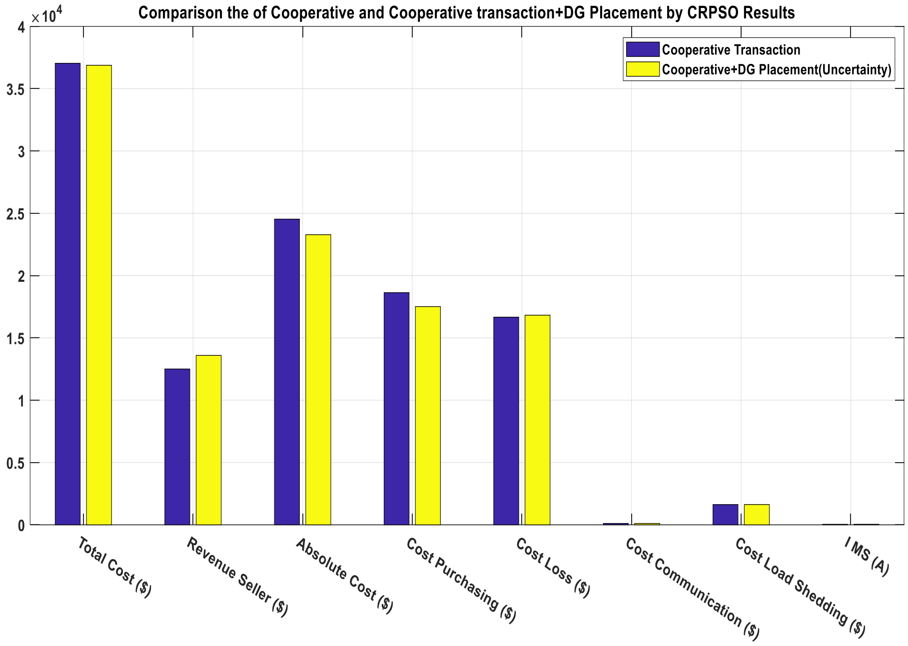

Fig. 8. Comparison of cooperative and non-cooperative transaction with uncertainty.

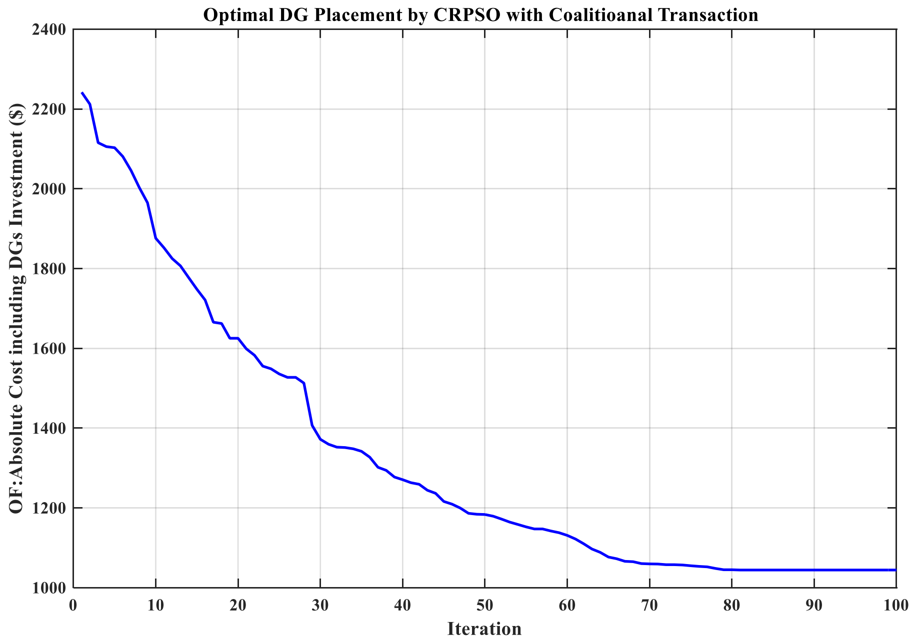

Fig. 9. CRPSO convergence for DG Units placement based on a coalitional Game theory with uncertainty (one hour).

Table 6. Coalition exchanges for micro-grids with the optimal allocation of DG units and uncertainty.

Parameter	Value by considering these states		
	-20% Uncertainty	Normal	+20% Uncertainty
Total costs ($)	36792	36814	36879
Sellers' profit ($)	13445	13522	13566
Net costs (Total costs-sellers' profit) ($)	23347	23292	23284
Power purchase costs ($)	17520	17515	17514
Loss costs ($)	16730	16758	16823
Communication costs ($)	112	112	112
Load shedding costs ($)	1627	1627	1627
Communication line to MS (A)	44	44.29	44.51
Investment for DG Units ($)	33	33	33

5. CONCLUSION

In this paper, the application of CRPSO algorithm based on the game theoretic formulation strategy was proposed to reduce the exchange of power between the macro station and micro-grids. First, the micro-grid utilization was done in a system consisting of 33 micro-grids independently without coalition, and then the coalitional Game theory was applied on MGs of the test system for a 24-hour period, and the coalitions were formed by merging and splitting the MGs. With careful consideration of these results, it can be found that the game theoretic coalition formulation strategy reduced all the system utilization costs but increased the power sellers' profit. It should be noted that the flow of the communication line between the micro-grids and the macro station did not exceed the permissible limit. Coalition formation also helps to reduce the power loss while transferring energy in a long distance. However, for the small number of micro-grids in the distribution system, the percentages of power loss reduction are not significant compared to the power loss reduction in the bigger distribution systems. Then, the optimal allocation of DG Units (wind turbine and photo voltaic) in the micro-grids was performed on the experimental system using the CRPSO algorithm for conditions with and without uncertainty in the parameters of wind speed and sun radiation flux. Reduction of the total cost of the micro-grids utilization was selected as the objective function using the micro-grids coalition strategy. This function included the cost of connecting (investing) DG Units as well. The results of the optimization process that included the type, capacity and location of the DG Units showed that despite the costs of investing DG Units, due to the beneficial and optimized contribution of DG Units to the micro-grids exchanges, the total costs and net costs of utilization reduced in both states of with and without considering the uncertainty, and the flow of communication lines has not exceeded the permissible range. Therefore, it seems that the proposed method is very effective in reducing the costs of utilization of the micro-grids.

Table 7. List of all the symbols.

N	Total number of micro-grids
G_i	Amount of power generated by MG_i in each period
D_i	Amount of load active power in each period
Req_i	Amount of load demand for each micro-grid in each period
θ_{max}	Maximum load percentage that can be shed at each period
S	The micro-grids with surplus generations
S_b	The micro-grids with overloads
C_g	Cost of generating electrical energy
C_b	Retail price of the electrical energy purchased from the macro station by the micro-grids
C_l	Cost of electrical energy transmitted per unit of length
C_1^{com}	Cost of communication per unit of length
C_{shed}	Cost of compensating for the load shedding of customers
Ω	Order of joining the buyers
C_{ij}	Cost of purchasing energy MG_i from MG_j
l_{ij}	Distance between MG_i and MG_j.

f_{ij}	Power exchanged between MG_i and MG_j
f_{i0}	Power exchanged between MG_i and the macro station
P_{ij}^{loss}	Loss power exchanged between MG_i and MG_j
P_{i0}^{loss}	Loss power exchanged between MG_i and the macro station
R_{ij}	Resistance of the line between MG_i and MG_j
U_0	Voltage of the line between MG_i and MG_j
$Cost_i^{com}$	Communication cost of the micro-grid MG_i for exchanging information with the other micro-grids
$Cost_i^{loss}$	Total loss cost of MG_i
$Cost_i^{shed}$	Cost of compensating for the load shedding of the MG_i customers
Ω_S	Set of sellers that joins coalition S in a specific order
φj (K)	Profit margin in coalition
P_s	Output power of the PV
$P_{s\text{-rated}}$	Nominal power of PV
P_{Wgmax}	Nominal power of wind turbine
$V_{ws}(t)$	Predicted wind speed
V_{cutin}	Minimum wind speed
V_{cutout}	Maximum wind speed
V_{rated}	Nominal wind speed
B	Location of the DG Units
C	Capacity of the DG Units
uc	uncertainty in the parameters of wind speed and sun radiation flux
v_i^k	Velocity parameter in PSO

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