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Optimal power generation planning in the micro-grid with the aim of reducing power and pollution costs and considering uncertainty using genetic algorithm

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Abstract

A micro-grid usually consists of a set of distributed generation resources, a power storage system and loads that can be exploited in both grid-connected and island operations, The use of micro-grid can have many benefits for consumers and for power generator companies, from point of view of consumers micro-grid has the capability to simultaneously provide electricity and heat, increase reliability, reduce greenhouse gas emissions, and improve the quality of electricity and from point of view of companies The use of micro-grid will reduce the facility for the development of transmission lines and, in addition, will eliminate peak consumption points, which will also result in network losses reduction. Micro-grids can be a good solution for energy generation, considering the environmental and economic issues. In this paper, determining the economic power dispatch of a grid-connected micro-grid system by Stochastic programming is examined. The hybrid system studied consists of wind turbines, solar arrays, hydrogen fuel cells, combined heat and power storage units, the purpose is to minimize the cost of generating power and reduce the cost of environmental pollution using the genetic algorithm in the study period.

Keywords: Distributed generation resources, Economic power dispatch, Stochastic programming, Hybrid system, Genetic algorithm.

1. INTRODUCTION

The rise of environmental protection and the depletion of fossil energy sources have motivated to integrate the renewable energy sources into existing power system. This integration not only minimizes emissions (NOx, CO2, SO2, small quantities of toxic metals, etc.) but also decreases total operating cost. Selecting the generating unit states to be ON and OFF during any interval of the day is known as a unit commitment (UC) problem, which is a complex non-linear mixed integer programming problem. It becomes more challenging in the presence of renewable energy sources and environmental constraints. Power generating units using fossil fuel emit harmful pollutants (CO2, SOx, NOx) into the atmosphere, which not only affects humans but entire living beings. Moreover, these pollutants may cause acid rain that is responsible for damaging forest and vegetation's as well as causing global warming [18].

The present electric power utilities are supported by renewable generations (RGs) to cater local load as well as to export power to the utility. Modular, environment-friendly, economic electricity, and rural electrification are certain advantages of renewable energy sources (RESs). The use of RG with the power system not only helps in minimizing peak loads, but also in reducing the emission of greenhouse gases. With RG, the passive distribution network becomes active and the conventional protection system becomes no more effective which is designed for passive system. Islanding of distributed generation (DG) is one of the most important protection issues over the last decade [8].

A Micro grid system is particularly a portion of the power distribution system that formed by integrating loads, distributed generators (DGs) and energy storage system (ESS). Recently there has been a general upsurge of interest in the concept of using micro-grids (MGs) and thus, they are being described as flexible and intelligent network or even active power network with a great potential to promote and to increase the renewable energy resources integration. At the same time, they are able to improve overall system reliability, efficiency and security [19]. MGs can operate in parallel with the main utility grid, as an autonomous power island (off grid mode) or in transition between main grid-connected mode and island operating mode (on/off grid mode) [11], [20], [16], [9].

Micro-grid energy management system (MGEMS) can coordinate the operation of MG in grid-connected mode or in islanded mode. In grid-connected mode, the micro-grid either draws or supplies power from or to the main grid, depending on the generation and load with suitable market policies. Also, it can separate itself from the main grid whenever a power quality event in the main grid occurs. Moreover; MGEMS can regulate power flow for each source depend on the outputs commands from the optimization program. The MGEMS requires an accurate economic model to identify the operating cost and emission functions taking into account the consumer power demand for each DG unit. In addition, an accurate algorithm to optimize the use of individual DGs by reducing the operating costs and emission factor to a minimum level within the constraints of the system. These constraints are considered like power balance for supplying the electrical loads, fuel costs and equipment performance specifications, limitations due to safety, fuel supply limitation and restrictions on noise or pollutant emissions [12], [14].

In mathematics, optimization algorithm is the discipline concerned with finding inputs of a function that minimize or maximize its value that may be subjected to constraints. The optimization algorithm does not necessarily mean finding the optimum solution to a problem only, but also this solution must be feasible to the characteristics of the problem [1]-[4], [6].

Authors in [15], presents a new model for optimum operation of a micro grid, consisting dispatchable supplier (micro turbine), non-dispatchable supplier (wind turbine), energy storage system, and loads. It has the capability of energy exchanging with upstream distribution network and contains both controllable and uncontrollable loads.

For the controllable loads by presenting a new controlling algorithms, the consumption of these loads is changed or postponed to another time, with regard to the uncertainties of wind generation and the energy price of upstream distribution network, and of course by considering the welfare level of consumer. In recent years, all researchers in the field of optimization of MGs are interested to present modern, fast and efficient algorithms. The objective of these algorithms allow autonomous or grid connected decision making to determine the hourly optimal dispatch of each DG unit.

In this paper, a micro grid energy management system or MGEMS based on genetic algorithm (GA) is presented for MG in grid connected mode (on grid mode) considering winter and summer load profile as a two cases study.

2. The Structure of the Micro-grid

Micro grid is an electrical power supply system in some areas centering on a decentralized power supply independent from the existing wide area power supply system, and it is critical to secure its security because it is a core domain of Smart grid 2.0 as well as a closely related part with general customers [17]. The micro-grid is a complete system, which is connected to the grid through the Point of Common Coupling (PCC). It contains various forms of power generation, such as renewable energy generation (wind power generation, solar photovoltaic power generation, etc.) and non-renewable energy generation (micro gas turbines, fuel cells, etc.). The energy storage system is a necessary part that can improve the stability of the micro-grid. Energy storage applications deliver short-term power to improve quality, voltage support and frequency support for renewable generation smoothing and end user energy management [10].

Authors in [7], have demonstrated how the storage devices can supplement energy generation to consumption to achieve a balance between energy demand and supply within the micro grid. Necessity of optimal control of the power storage devices of the micro grid was also indicated. The micro-grid system can also provide cooling and heat supply to load users through the form of Combined Heat and Power (CHP), which improves the multi-level utilization efficiency of energy. Figure 1 is a schematic of the under study microgrid. The above schematic diagram shows the structure of the microgrid system. PV refers to the photovoltaic power generation system; Wind Turbine refers to wind turbine system; Fuel Cell refers to Fuel cell power generation system; CHP refers to Combined Heat and Power generation unit; and storage refers to the energy storage system.

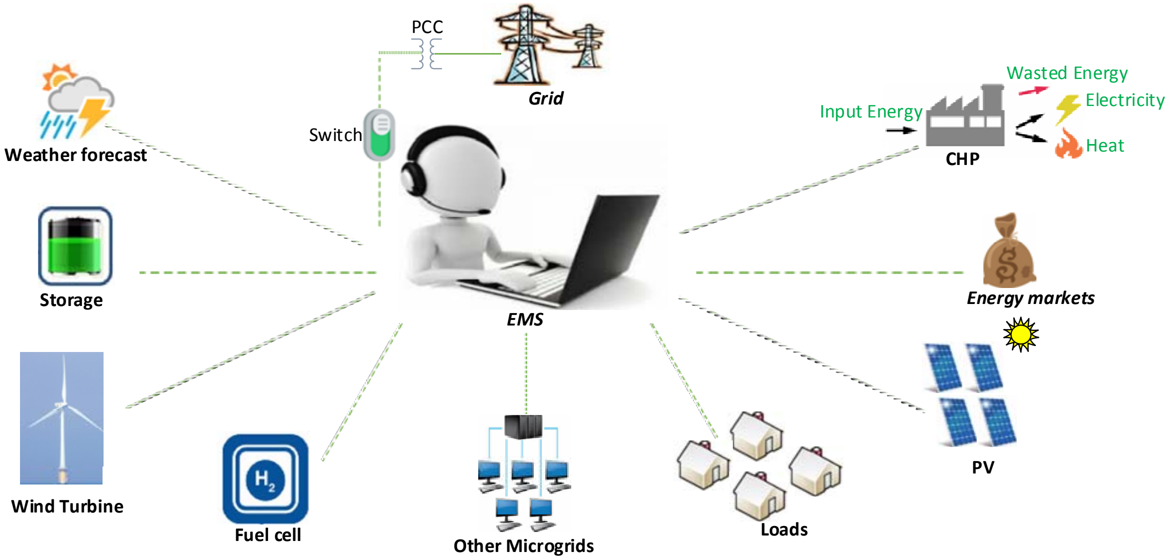

Fig.1 Under studied micro-grid includes resources like wind, PV, FC and CHP

The framework of a stochastic hybrid system (SHS) can be used to establish a stochastic model for a microgrid The SHS model can capture the interaction between probabilistic events (such as a failure of a device) and discrete / continuous mode dynamics in a microgrid. The discrete modes can be used to describe the operation status of devices, such as CHP plant (on/off/shutdown), wind turbine (connected/ disconnected), energy storage (supply/store/load) and electrical loads (connected/disconnected), as well as the status of the connection between the main grid and microgrid (connected/disconnected). Further, each discrete mode is associated with specific continuous dynamics. For instance, a wind turbine in a connected mode provides a certain amount of electric power to the microgrid based on its physical configuration and wind speed. On the other hand, no electric power is provided by a wind turbine in a disconnected mode. Based on the SHS model, the trajectory of state evolution in microgrid operation (e.g., the amount of power generated by each generator over time) can be obtained. Such a model can be potentially applied for generation scheduling and demand response in microgrids by leveraging stochastic control. Economic dispatch in electric power system refers to the short-term discernment of the optimal generation output of various electric utilities, to meet the system load demand, at the minimum possible cost, subject to various system and operating constraints viz. operational and transmission constraints. The economic load dispatch problem (ELDP) means that the electric utilities (i.e. generator's) real and reactive power are allowed to vary within certain limits so as to meet a particular load demand within lowest fuel cost. The ultimate aim of the ELD problem is to minimize

the operation cost of the power generation system, while supplying the required power demanded. In addition to this, the various operational constraints of the system should also be satisfied [5].

3. The Problem Formulation

3.1. Objective Functions

In the cost objective function of this project, electricity purchase (or sales) tariffs from the network are considered. In addition, the cost function also includes the cost of setting up of each unit. The main purpose of the cost function is to meet the required grid load with the lowest operating cost. This objective function is expressed as follows.

$$F_1 = \sum_{t=1}^{T} \{ \sum_{i=1}^{ug} (Di(t) \times P_{DGi}(t) \times C_{DGi}\ ) +$$

$$(Di(t) \times SUC_{DGi}) +$$

$$\sum_{j=1}^{us} (Dj(t) \times P_{ESSj}(t) \times C_{ESSj}(t)) +$$

$$(Pgr(t) \times Cgr(t)) - \ (Pgs(t) \times Cs(t)\} \quad (1)$$

Ug and Us are the numbers of distributed generation units and storage devices respectively. And T is the number of hours studied. And D is the binary variable (zero or one). Simulation for each specific hour and Ns scenario is considered. C is the sales tariff in each unit of generation. The start-up cost of units is SUC_{DGi}, which is defined as:

$$SUC_{DGi}\left(t\right) = \beta i \times \left(1 - e^{-\frac{t_{off}}{\tau}}\right) \qquad (2)$$

Where βi is the cost of cooling start-up, τ is the constant of cooling time of the unit and toff Specifies the time that unit is off.

The next objective function of the project is contamination objective function. Total contamination generated in 24 hours is modeled as follows:

$$F_2 = \sum_{t=1}^{T} \{\sum_{i=1}^{ug} (Di(t) \times P_{DGi}(t) \times E_{DGi}(t)) + \sum_{j=1}^{us} (Dj(t) \times P_{ESSj}(t) \times E_{ESSj}(t)) + (Pg(t) \times Eg(t))\} \qquad (3)$$

In which P_{DGi} (t), P_{ESSj} (t) and P_g (t) are the inputs of the objective function, representing the generation power of the units, the storage system, and the received power from the main grid respectively Parameter E also shows the amount of pollution generated in a kilowatt of generated power.

3.2. Constraints

At any time, t and scenario s, the balance of power between generators and the loads and the grid must be maintained as:

$$\sum_{l=1}^{ul} P_l\left(t\right) - \sum_{i=1}^{ug} P_{DGi}\left(t\right) - \sum_{j=1}^{us} P_{ESSj}(t) - Pgr\left(t\right) + Pgs\left(t\right) = 0 \qquad (4)$$

Contamination factors include atmospheric pollutants including sulfur dioxide (SO2), carbon dioxide (CO2), nitrogen oxide (NOx) generated by thermal fossil fuel units. In this article, it is intended that each unit cannot exceed from the permissible contamination level:

$$\sum_{i=1}^{ug} E_{DGi}\left(t\right) \times P_{DGi}(t) \le E_{Max.Dg} \qquad (5)$$

$$\sum_{i=1}^{us} E_{ESSj}\left(t\right) \times P_{ESSj}(t) \le E_{Max.ESS} \qquad (6)$$

$$Eg(t) \times Pg(t) \le E_{Maxgrid} \qquad (7)$$

In which $E_{DGi(t)}$, $E_{ESSj(t)}$, $E_g(t)$ are pollution limit in Kg / Kwh for distributed generations, the storage system and the main grid respectively. Each distributed generation unit or the storage system has a maximum and a minimum value of generation, according to which it generates. These limits are modeled as follows:

$$P_{DGimin} \le P_{DGi}(t) \le P_{DGiMax} \quad i = 1, 2, \ldots, ug \quad (8)$$

$$P_{ESSjmin} \le P_{ESSj}(t) \le P_{ESSjMax} \quad j = 1, 2, \ldots, us \quad (9)$$

If it is not possible to charge and discharge the battery simultaneously, the results of the simulation have problem and are not technically significant. Therefore, in order to solve this problem, we add the constraints as coupling constraints to the problem to eliminate possibility of charge and discharge of the battery simultaneously, and to define the energy stored in the battery as a time-dependent parameter. Under these conditions, the output response for the storage system at any time will depend on the price conditions available for the generating equipment in the micro-grid and the main grid, as well as the amount of available energy stored in the storage system during the preceding hours. To this end, we add the following constraint to the optimization problem:

$$E_t = E_{(t-1)} + \left(P_{ch} \times \eta_{ch} \times \Delta t\right) - \left(P_{disch} \times \eta_{disch} \times \Delta t\right) \quad (10)$$

Where $P_{charging}$ and $P_{discharging}$ show the amount of charge and discharge power in the battery during a period of time. And η_{ch} and η_{disch} are the charge and discharge efficiency of the battery respectively. E (t) is the amount of energy stored in the reservoir at time t.

Battery capacity at time t and scenario s is less than its maximum capacity:

$$P_{SB,S}(t) \le P_{SB\,Max} \qquad (11)$$

Battery discharge at time t and scenario s is less than the maximum battery discharge level. X (t) is a binary variable to indicate whether the battery can be discharged or not discharged, and P_{BSDC}, s is the discharge power at time t and scenario s.

$$P_{BSDC,S}(t) \le P_{BSDC\,Max} \times X(t) \qquad (12)$$

The battery charge at time t and scenario s is less than the maximum battery charge level. Y (t) is a binary variable to indicate whether the battery can be charged or not charged and P_{BSC} is the amount of power charged at time t and scenario s.

$$P_{BSC,S}(t) \le P_{BSC\,Max} \times Y(t) \qquad (13)$$

In order to eliminate the simultaneous charge and discharge of the battery and define the energy stored in the battery as a time-dependent parameter, Constraint (14) is expressed. In other words, at any time t and scenario s, the battery cannot be charged and discharged at the same time:

$$X_S(t) + Y_S(t) = 1 \quad X \text{،} Y \in \{0\text{،}1\} \qquad (14)$$

The amount of battery discharge at time t and the scenario s should be less than the battery storage at time t-1.

$$P_{BSDC,S}(t) - P_{SB,S}(t-1) \le 0 \qquad (15)$$

The total battery charge at the moment t and the scenario s with the battery storage at time t-1 should be less than the maximum battery capacity.

$$P_{BSC,S}(t) + P_{SB,S}(t-1) \le P_{SB\,Max} \qquad (16)$$

The amount of battery storage at the moment t and the scenario s is equivalent to battery storage at time t-1 and scenario s, plus battery charge at the current moment minus the battery discharge at the current moment, which is the same as the battery power balance.

$$P_{SB,S}(t) = P_{SB,S}(t-1) - P_{BSDC,S}(t) + P_{BSC,S}(t) \qquad (17)$$

Battery storage at time zero is equal to the initial battery power.

$$P_{SB}(t=0) = P_{initial} \qquad (18)$$

The uncertainties examined in this project are included uncertainty in load forecasting, wind power generation forecasting and photovoltaic generation forecasting. Uncertainty in load forecasting can be due to incomplete information and sometimes mistakes in load estimation. The more load information in the past years, the higher the degree of certainty (or in other words, the probability of a forecasted scenario). Uncertainty in the prediction of wind generation and photovoltaic generation can be due to the lack of consideration of effective parameters such as humidity and temperature in predicting wind speed and radiation levels in the region. By considering these parameters in the simulator of wind speed and solar radiation, such as neural networks, and increasing the amount of accurate information, the probability of the predicted scenario can be increased. Accordingly, in this project, five scenarios for each of the load parameters, wind speed and radiation amount are considered. Using the following equation, mathematical expectations of mentioned parameters can be calculated, then the parameters are entered into the optimization algorithm based on their probability of occurrence and the objective cost function and objective pollution function are minimized. The mathematical expectation function for stochastic variable x at time t and scenario s is defined as follows:

$$E(Xt) = \sum_{s=1}^{ns} Ps(Xt) \times Xt \quad s = 1,\dots,n \qquad (19)$$

Table 1 Load scenarios in winter and summer together with the probability of each scenario

Summer	***Scenario1***	***Scenario2***	***Scenario3***	***Scenario4***	***Scenario5***	***Winter***	***Scenario1***	***Scenario2***	***Scenario3***	***Scenario4***	***Scenario5***
***P/H*[1]**	0.02	0.03	0.9	0.03	0.02	***P/H*[1]**	0.02	0.03	0.9	0.03	0.02
1	71.31	71.84	66.89	64.75	65.01	***1***	66.49	72.66	68.48	69.27	71.02
2	68.03	67.08	62.18	67.46	63.53	***2***	73.29	66.85	65.87	67.23	71.51
3	61.63	58.21	62.44	65.76	63.88	***3***	65.07	66.95	68.43	66.09	63.88
4	62	61.57	60.46	64.81	65.89	***4***	68.41	68.93	61.28	61.23	67.35
5	58.71	64.1	57.46	56.16	65.28	***5***	60.04	67.45	67.81	64.92	67.24
6	62	64.58	62.45	62.27	66.56	***6***	70.75	63.36	70.3	61.43	61.17
7	70.43	67.7	69.83	63.21	70.61	***7***	70.89	74.49	70.69	75.55	76.39
8	70.92	75.51	69.11	75.57	76.48	***8***	88.38	84.62	89.88	94	92.24
9	77.91	74.94	81.5	80.98	82.27	***9***	91.36	88.39	95.83	93.15	87.73
10	78.29	82.57	85.56	85.51	87.5	***10***	94.86	87.49	93.59	92.15	95.36
11	85.1	88.35	83.07	85.32	82.93	***11***	85.35	87.46	83.1	91.9	83.17
12	88.09	95.99	87.94	89.91	94.41	***12***	88.5	90.52	83.38	90.43	82.69
13	94.43	97.11	95.54	92.07	99.38	***13***	90.74	88.57	89.25	86.87	88.15
14	95.76	97.07	96.6	94.05	96.3	***14***	86.82	86.9	86.37	84.17	82.18
15	95.69	88.59	91.47	90.38	90.07	***15***	83.48	88.79	84.33	87.42	88.45
16	92.24	84.8	84.93	84.37	88.74	***16***	83.57	88.51	86.44	87.34	86.78
17	83.1	82.26	88.25	91.36	90.86	***17***	85.75	90.74	82.08	88.78	85.03
18	91.67	85.33	90.51	90.81	90.81	***18***	94.95	93.57	93.19	90.22	85.27
19	90.94	83.17	88.2	88.2	83.41	***19***	102.31	97.24	100.01	93.47	97.62
20	87.84	94.46	94.27	86.49	88.11	***20***	101.96	100.2	101.89	96.7	100.65
21	90.65	96.53	90.57	90.4	91.51	***21***	94.4	97.41	93.12	99.78	94.93
22	96.95	91.39	91.44	91.36	96.97	***22***	91.51	88.72	95.76	93.13	88.82

23	87.06	88.07	93.88	94.45	93.56	***23***	80.63	80.77	81.1	84	80.15
24	88.7	87.66	82.71	84.8	87.37	***24***	80.69	78.61	80.12	79.41	73.17

P/H[1]= Probability/Hour

4. Stochastic Scenarios in the Studied Microgrid

Changes in load are influenced by factors such as time per year, geographical location and climate change. Since there is uncertainty in the sun and wind and load, we use probabilistic scenarios to model wind and photovoltaic turbine power generations and load power. Five scenarios for wind turbine power generation and five scenarios for solar cells generation and five scenarios for load power in summer and winter are separately considered. The power consumption of load for different scenarios is in Table 1.

For example, at the first hour in the third scenario from winter, the probability of this scenario is 0.9, the power consumption of the load is 68.48 KW. Figure 2 shows the mathematical expectation of the load for winter and summer seasons.

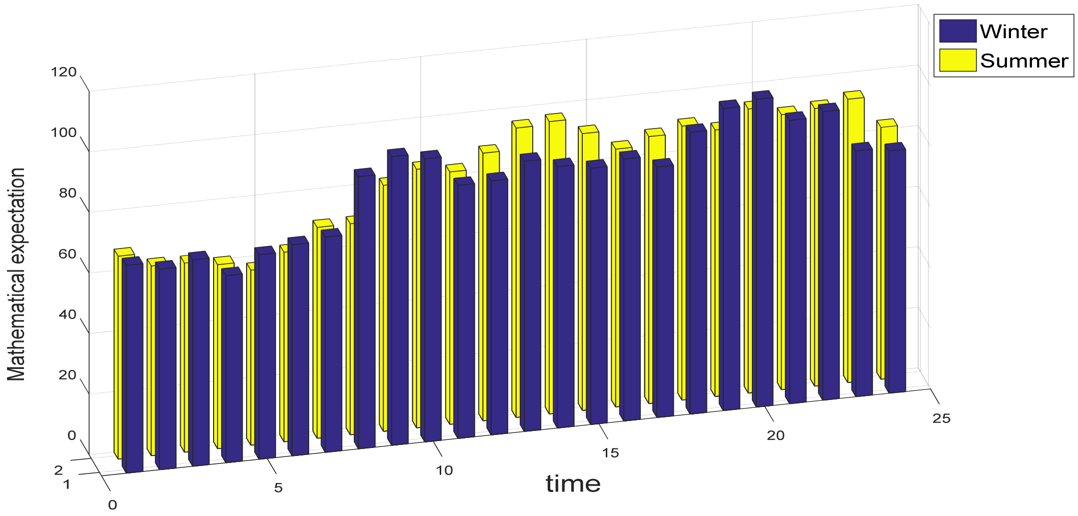

Fig.2 Mathematical expectation of the load for the winter and summer

Mathematical expectation of load at any particular time, and in each particular scenario, is obtained by multiplying the load power, which is random variable, in the probability of occurring load power (This is especially the case for other scenarios at that time) and answers are gathered together for all scenarios. This is done separately for each season, and Figure 2 is created. As it is shown, the value of mathematical expectation of load in peak hours is more in comparison to other hours of the day.

Changes in load affect the electricity market tariffs and supply contracts, increasing power generation is associated with increased power consumption. And reducing power generation by reducing power consumption. Figure 3 and figure 4 show the changes in the tariffs for the purchase and sale of electricity in different hours of winter and summer seasons respectively. This tariff is for general use at home. As shown in Figures 3 and 4, electricity tariffs are highest in the winter and summer at peak consumption hours. The availability to wind power generation and photovoltaic power generation depends on the amount of wind and radiation conditions. Given the uncertainty in predicting wind speed, scenarios for wind power are presented in Table 2.

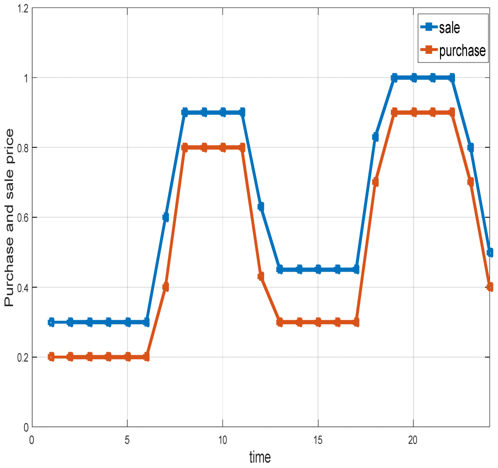

Fig.3 Electricity tariffs in the winter

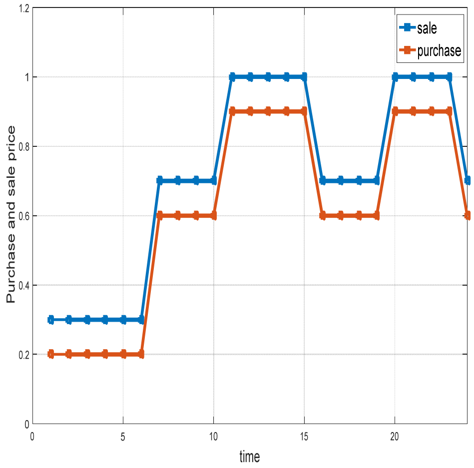

Fig.4 Electricity tariffs in the summer

Table 2 The scenarios of wind power generation in the winter and summer along with the probability of each scenario

Winter	*Scenario1*	*Scenario2*	*Scenario3*	*Scenario4*	*Scenario5*	*Summer*	*Scenario1*	*Scenario2*	*Scenario3*	*Scenario4*	*Scenario5*
P/H	0.05	0.1	0.7	0.1	0.05	***P/H***	0.05	0.1	0.7	0.1	0.05
1	3.83	7.08	3.27	3.03	3.01	***1***	15.9	14.17	14.4	12.75	16.11
2	7.17	7.17	5.13	5.34	5.4	***2***	11.93	12.82	12.37	14.95	14.78
3	6.43	7.2	3.48	5.5	4.09	***3***	13.62	9.52	13.06	10.15	10.18
4	4.18	5.42	7.04	7.97	4.46	***4***	7.47	8.2	10.08	7.9	11.09
5	8.09	6.28	7.19	7.34	8.16	***5***	10.68	8.66	9.21	10.14	6.76
6	6.95	9.24	5.6	8.27	6.67	***6***	7.87	9.46	9.26	6.34	7.15
7	6.9	7.72	6.5	6.87	8.05	***7***	8.18	8.2	5.5	5.23	6.99
8	7.05	8.74	9.54	10.23	9.94	***8***	5.75	5.72	6.41	6.33	6.86
9	9.9	9.15	7.07	8.17	8.6	***9***	6.65	3.99	7.63	4.56	6.52
10	5.81	6.65	8.58	6.36	6.48	***10***	6.23	7.69	4.7	6.34	5.48
11	8.24	7.6	4.21	6.2	8.3	***11***	4.16	7.98	5.15	7.38	4.9
12	4.16	5.4	4.77	4.7	7.31	***12***	8.63	7.35	4.81	7.53	5.95
13	6.17	5.38	4.3	5.9	7.55	***13***	5.13	6.35	7.22	4.68	5.26
14	4.7	5.31	8.44	4.68	6.24	***14***	9.06	5.45	5.41	6.26	6.64
15	8.49	4.56	8.81	4.95	4.09	***15***	6.75	7.73	6.98	5.06	5.47
16	8.19	5.38	6.46	7.6	4.8	***16***	7.18	9.09	6.14	8.74	8.13
17	5.16	7.13	8.42	7.46	7.86	***17***	11.19	10.21	10.76	8.63	11.87
18	6.88	6.3	7.35	4.47	8.34	***18***	8.86	7.88	8.59	10.78	12.76
19	7.72	9.4	7.44	5.85	7.53	***19***	11.03	12.52	13.71	12.02	13.05
20	10.68	9.23	11.29	6.72	8.66	***20***	14.56	12.02	13.87	13.64	14.43
21	2.01	2.41	2.97	4.64	3.99	***21***	12.36	15.06	12.81	14.48	16.23
22	6.52	2.51	5.74	4.05	2.68	***22***	16.74	14.19	16.24	17.35	16.9
23	4.13	3.15	3.81	6.31	4.07	***23***	19.75	19.8	18.73	18.12	19.81
24	5.29	4.19	2.81	6.67	5.21	***24***	19.71	18.85	17.17	17.81	18.49

For example, at the second hour in the third scenario in winter, with probability of 0.7, the output of the wind unit is 5.13 kilowatts .Figure 5 shows the mathematical expectation of the wind generation unit for winter and summer seasons. Mathematical expectation of wind generation at any particular time, and in each particular scenario, is obtained by multiplying the wind power, which is random variable, in the probability of occurring wind power.

Given the uncertainty in the solar radiation, the scenarios for PV power generation are presented in Table 3.

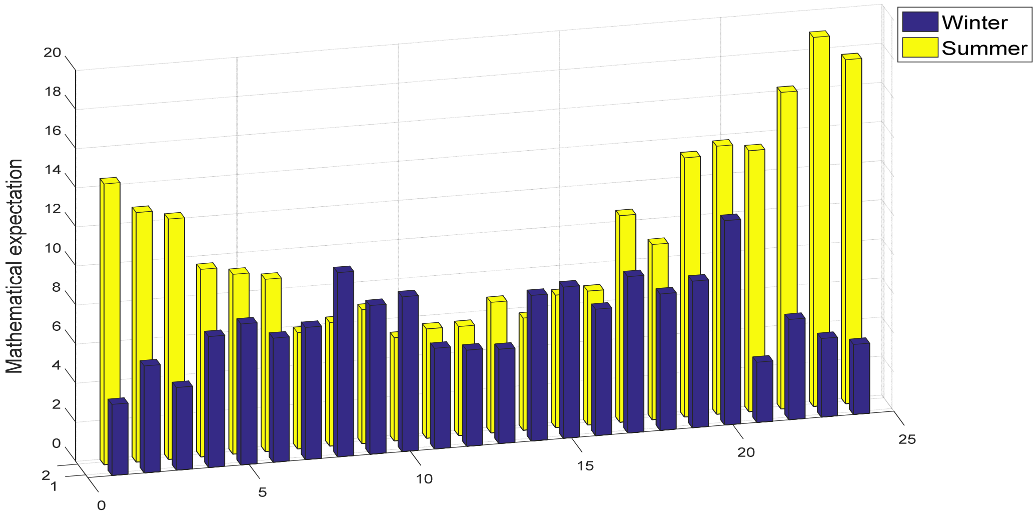

Fig.5 Mathematical expectation of the wind generation unit.

Table 3 The scenarios of photovoltaic power generation in winter and summer with the probability of each scenario

Winter	*Scenario1*	*Scenario2*	*Scenario3*	*Scenario4*	*Scenario5*	*Summer*	*Scenario1*	*Scenario2*	*Scenario3*	*Scenario4*	*Scenario5*
P/H	0.013	0.062	0.85	0.062	0.013	***P/H***	0.013	0.062	0.85	0.062	0.013
1	0	0	0	0	0	***1***	0	0	0	0	0
2	0	0	0	0	0	***2***	0	0	0	0	0
3	0	0	0	0	0	***3***	0	0	0	0	0
4	0	0	0	0	0	***4***	0	0	0	0	0
5	0	0	0	0	0	***5***	0	0	0	0	0
6	0	0	0	0	0	***6***	0	0	0	0	0
7	0	0	0	0	0	***7***	0.15	1	1.99	0.22	0.81
8	0	0	0	0	0	***8***	3.95	4.46	2.94	3.45	4.77
9	2.3	2.26	2.78	2.26	2.49	***9***	5.19	5.23	5.67	5.94	5.17
10	5.48	4.99	4.38	5.91	5.6	***10***	7.45	8.69	8.93	7.78	8.25
11	7.26	6.67	5.66	7.29	6.04	***11***	12.21	11.83	12.04	12.42	11.36
12	7.75	7.82	7.55	7.23	8.63	***12***	15.59	14.25	15.35	14.59	14.15
13	10.28	9.33	10.08	9.17	10.5	***13***	16.05	17.19	17.28	17.04	17.78
14	12.3	11.27	12.51	11.09	12.61	***14***	19.21	19.28	19.03	19.32	18.91
15	10.12	11.39	11.73	11.1	11.55	***15***	15.14	16.5	16.06	16.26	17
16	6.9	6.29	6.24	6.6	5.35	***16***	12.04	12.3	12.82	13.23	13.67
17	2.4	3.84	3.6	3.68	3.31	***17***	10.77	10.88	10.84	10.7	9.43
18	1.05	1.49	1.25	1.73	0.95	***18***	8.52	7.89	8.22	8.39	7.29
19	0	0	0	0	0	***19***	6.75	5.58	5.95	5.49	6.47
20	0	0	0	0	0	***20***	2.72	1.93	2.11	1.82	2.6
21	0	0	0	0	0	***21***	0	0	0	0	0
22	0	0	0	0	0	***22***	0	0	0	0	0
23	0	0	0	0	0	***23***	0	0	0	0	0
24	0	0	0	0	0	***24***	0	0	0	0	0

For example, the power generated by the photovoltaic unit at 10 o'clock in the first scenario in summer, with a probability of 0.013, is 7.45 kilowatt. Thus, for each scenario, there is an especial power generation, at every hour of the day, for wind or photovoltaic units, and there is an especial consumption power for load.

Figure 6 shows the mathematical expectation of the photovoltaic generation unit for winter and summer seasons. Mathematical expectation of PV generation at any particular time, and in each particular scenario, is obtained by multiplying the PV power, which is random variable, in the probability of occurring PV power.

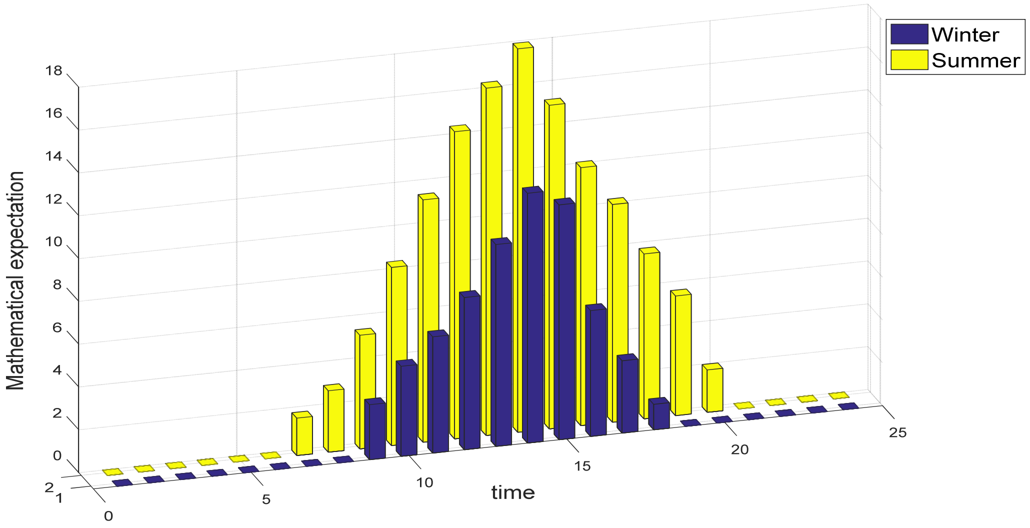

Fig.6. Mathematical expectation of the photovoltaic generation unit

Limit of unit's generation, generation costs and pollution factors of each unit are constraints that should be considered during operation. Each generator has the maximum generation capacity at the time of operation, as shown in Table 4. It is assumed that CHP and fuel cell generate power at all times between the maximum and minimum of their generation capacity to reduce the cost of start-up.

Table 4 generation limitation of distributed generation units and storage systems

Units	*Minimum power generation*	*Maximum power generation*
CHP	2	55
Fuel cell	1	40
Wind	0	20
PV	0	25
Storage	-20	20

For distributed generation units, the cost of generation per kWh is traditionally calculated by reducing the cost of investment and the costs of exploitation and repairs over the useful life of the unit and its division into total energy generation in one year. The first row in Table 5 describes the cost of generation of units as an average cost per useful life. In fact, the cost of generation in the early years is lower than the average cost, with increasing unit life, this cost will increase. The second row shows the CO2 which is generated by each unit, regardless of the amount of SO2 and NOx generated by same unit, due to their lower quantities

Table 5 Power generation tariffs and pollution factors

Parameters / Units	*CHP*	*Fuel cell*	*Wind turbine*	*PV*	*Storage*
Tariff (Euro/kwh)	0.46	0.31	0.8	0.7	0.35
CO2 (kg/kwh)	0.37	0.23	0	0	0

Wind power generation is heavily dependent on the weather Power generation can be well estimated for a 24-hour period. Wind energy will be dispatched due to its price during the period of optimization, photovoltaic generation can also be predicted according to patterns of previous days and conditions of the sun at different times. The fuel cell also has a limited output for a long period, but the total energy generated is determined by the amount of hydrogen's fuel. The discharge of the storage system depends on the maximum discharge capacity and the amount of stored energy available. The loads are predicted by considering several different aspects, although most of the loads can be controlled within the desired range which is known as Demand Side Management or DSM. Using genetic algorithms, we try to obtain optimal power generation in the micro-grid. The Genetic Algorithm is a broadly useful stochastic and parallel pursuit strategy in light of the mechanics of characteristic choice and normal hereditary qualities. It is an inquiry technique to have capability of getting close worldwide minima. Also, it has the ability to acquire the exact outcomes inside brief time and the limitations are incorporated effortlessly [13]. The proposed EMS based on GA is able to verify load demand during 24 hours' operation with the lowest electricity tariff by determining hourly optimal allocation for each DG unit in MG system. The MG in this paper is assumed to be interconnected to the main utility gird, and can purchase some power from utility grid at off-peak hours or when the production of the MG is insufficient to meet the load demand. On the other hand, there is a daily income to the MG when the generated power exceeds the load demand during on-peak hours depending on system constraints and market parameters. The optimization process of genetic algorithm for microgrid is shown in Fig.7.

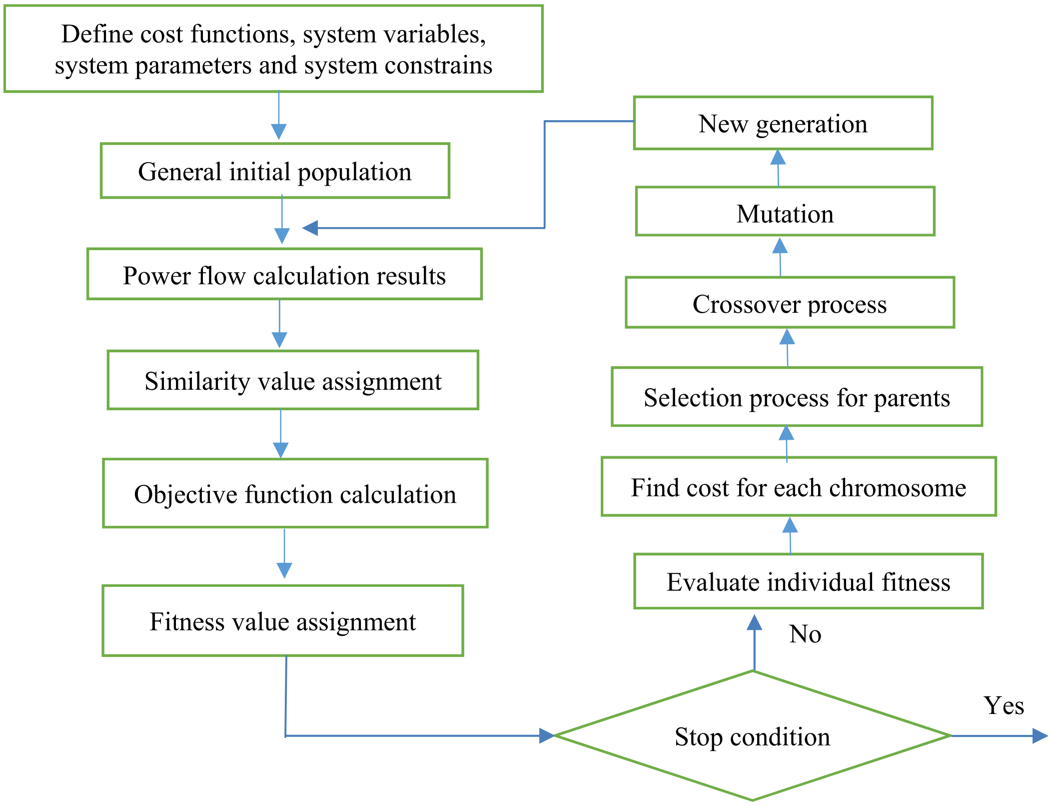

Fig. 7 GA implementation process for under study micro grid.

5. Simulation Results

Using the probability scenarios for wind and the sun and load, using the objective function, using existing data such as the proposed constraints for generating power and power generation tariffs simulation is done. Simulation performed on summer load and winter load is reviewed. The simulation results are as follows. The results of the optimal power distribution in the micro-grid in the winter is presented in Table 6.

The results of table 6 are for the optimal point of the beam with the minimum value of the objective cost function. In other words, the power values of each generation unit in the above table make the least cost. If objective cost function and objective pollution function are plotted for winter, Figure 8 is obtained, in other words, this figures shows the optimal beam for the two objective functions of cost and pollution.

Table 6 Result of optimal power distribution in the micro-grid for winter load

Hour	*Wind*	*PV*	*CHP*	*Fuel cell*	*Storage*	*Main Grid*
1	2.136	0	5.41	8.55	9.36	-43.96
2	3.66	0	11.18	7.75	-3.83	-47.44
3	2.48	0	6.56	4.73	15.93	-38.45
4	4.23	0	9.06	11.36	1.72	-35.39
5	3.31	0	9.78	7.54	3.68	-43.24
6	3.64	0	7.54	5.41	-11.54	-64.6
7	4.97	0	10.61	38.55	19.35	2.42
8	4.78	0	46.81	36.38	-11.83	-13.73
9	2.28	1.3	47.75	36.28	7.15	-0.52
10	3.2	1.5	47.66	36.44	5.03	0.4
11	2.11	1.9	46.99	36.8	1.01	5.27
12	2.26	3.72	9.92	36.44	9.08	-22.46
13	2.12	6.33	6.05	6.97	1.48	-66.21
14	3.12	7.58	6.93	4.99	1.14	-62.48
15	3.13	6.35	10.08	7.28	5.21	-52.57
16	4.25	2.98	6.57	7.38	-6.54	-71.84
17	2.67	1.98	6.32	8.17	15.12	-48.43
18	3.72	0.85	48.12	37.73	3.36	0.77
19	2.85	0	46.79	37.27	9.15	-3.66
20	3.59	0	48.79	35.11	10.26	-3.9
21	1.53	0	47.53	37.45	-3.12	-10.13
22	3.34	0	49.58	38.37	19.93	20.98
23	2.67	0	47.69	36.96	0.44	6.61
24	0.56	0	6.34	35.49	19.24	-18.3

Figure 9 shows how to supply load power by micro-grid and main grid in winter. All power is in kw. The results of the optimal power distribution in the micro-grid in the summer is presented in Tables 7.

Table 7 Result of optimal power distribution in the micro-grid for summer load

Hour	*Wind*	*PV*	*CHP*	*Fuel cell*	*Storage*	*Main Grid*
1	8.71	0	10.6	5.93	3.34	-38.44
2	4.5	0	6.55	6.64	15.67	-29.27
3	8.58	0	8.14	5.28	-7.13	-47.56
4	7.14	0	6.65	6.18	13.78	-27.01
5	7.19	0	8.5	5.64	4.24	-32.23
6	4.53	0	6.23	7.1	11.38	-33.34
7	3.24	0.58	48.81	38.07	6.41	27.51
8	3.67	2.21	45.87	38.07	13.59	33.73
9	4.12	4.22	48.2	35.44	-7.75	3
10	2.87	4.81	50.91	35.25	-8.9	-0.43
11	3.08	6.05	49.62	36.89	18.79	31.11
12	3.99	9.82	50.36	37.49	-0.58	12.69
13	4.88	10.5	48.48	36.2	9.08	13.6
14	3.55	9.71	47.38	36.77	-1.49	-0.59
15	2.86	9.77	47.39	36.17	14.2	18.98
16	1.9	9.66	47.97	38.6	-6.33	6.66
17	5.1	5.61	49.36	39.89	19.93	31.77
18	4.83	3.64	47.91	37.65	3.5	7.14
19	10.74	2.66	48.49	35.75	13.24	22.86
20	4.38	1.31	48	35.9	-1.84	-6.03
21	8.89	0	50.61	36.02	-0.99	3.77
22	12.46	0	45.51	36.75	-0.84	2.23
23	9.12	0	44.95	37.1	13.24	10.82
24	0.94	0	47.08	35.85	9.67	10.4

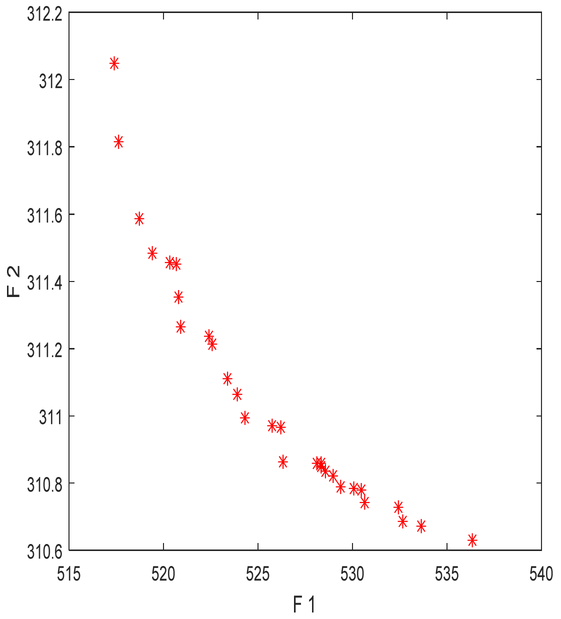

Fig.8 The optimal beam of two objective functions of cost and pollution for the winter

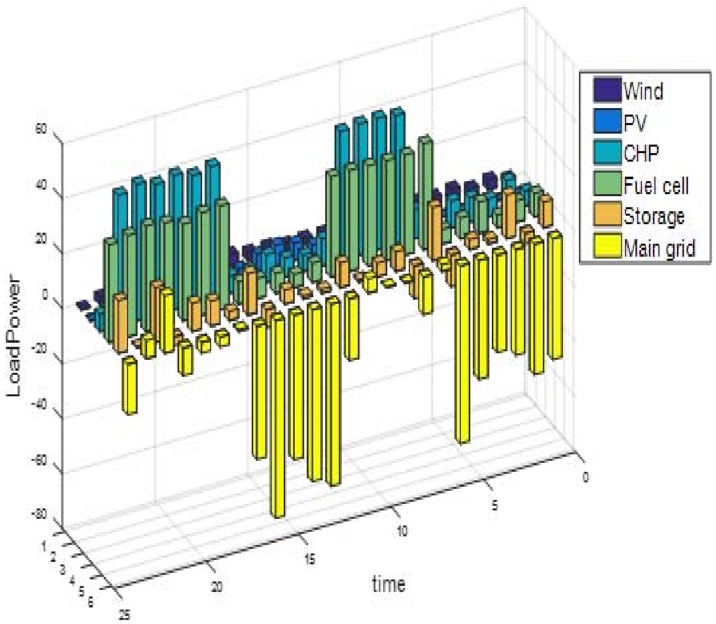

Fig.9 Supply of load power by the micro-grid and main grid in the winter.

If objective cost function and objective pollution function are plotted for summer, Figure 10 is obtained.

Figure 11 shows how to supply load power by micro-grid and main grid in summer. All power is in kw.

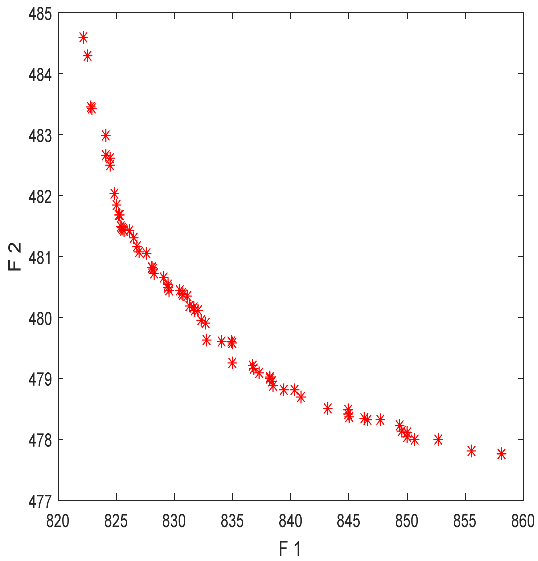

Fig.10 The optimal beam of two objective functions of cost and pollution for the summer

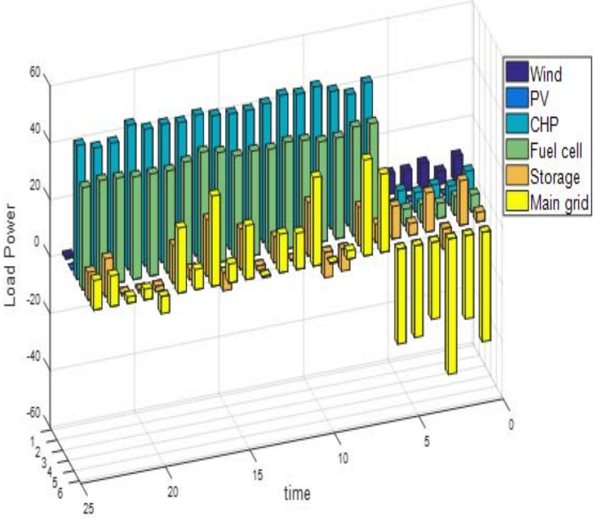

Fig.11 Supply of load power by the micro-grid and main grid in the summer

6. Conclusion

Hybrid power systems use a combination of different components, such as generation system, storage system, control system and power management system for generating electricity. Given the increasing use of micro-grids in the electricity industry, the power distribution issue among power generation units is one of the most important issues that should be considered when using micro-grids.

This paper has presented an optimization model to investigate the optimal power allocating for DGs, ESS and main grid. The optimization study takes into account the cost function, emission and power availability of renewable energy as the competitive objectives simultaneously. The proposed optimization model for micro-grid energy management is solved by Genetic algorithm. The efficient performance of the proposed methodology and its behavior is illustrated and analyzed in detail through a daily load demand variation considering the effect of seasonal weather on load demand profile. The virtual power plant or VPP uses a central control system to manage optimal generation and load control in the micro grid. The simulation was performed by using the Matlab software, by using the Genetic algorithm. and the operating cost for a 24-hour period, considering the scenarios proposed, is $ 3352 with 325 iterations.

7. Appendix

7.1. List of symbols

C_{DGi}	Cost of Power generation of each DG
C_{ESSj}	Cost of each power storage device
Cgr	Cost of power that is received from the network
Cs	Cost of the power given to the network
D	Binary variable
E	Pollution limit in Kg / Kwh
$P_{BSC,S}(t)$	The amount of power that is being charged in the battery at time t and scenario s
$P_{BSDC,S}(t)$	The amount of power that is being discharged from the battery at time t and scenario s
$P_{DGi}(t)$	The amount of power that is generated by each unit at time t and scenario s
$P_{ESSj}(t)$	The amount of power which is stored by storage device
$Pgr(t)$	The amount of power received from main grid at time t and scenario s
$Pgs(t)$	The amount of power sent to main grid at time t and scenario s
$P_{initial}$	The initial amount of power in battery
P_l	The amount of power which load needs
P_{SB}	Battery storage
$P_{SB\,Max}$	The maximum power that battery can store
$P_{SB,S}(t-1)$	The amount of battery storage at the moment t-1 and scenario s
SUC_{DGi}	Start-up cost of each unit
T	Duration of study
toff	The time that unit is off
Ug	Number of distributed generation units
Ul	Number of loads
Us	Number of storage devices
$X_s(t)$	Binary variable to indicate the battery discharge at time t and scenario s
$Y_s(t)$	Binary variable to indicate the battery charge at time t and scenario s
βi	Cost of cooling start-up s
τ	Constant of cooling time

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