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The economic distribution of power in a micro-grid by mixed integrated linear programming considering the uncertainty in load, wind turbines and photovoltaic systems

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Abstract

Using hybrid renewable energy is one of the best alternatives to supply the electrical energy at remote areas. Renewable energy sources are depended to weather conditions or other factors, so for supplying load with renewable sources appropriate capacity of these sources should be selected. In determining the capacity of renewable energy such as wind and solar, considering the stochastic nature of wind speed and solar radiation is very impressive.one of the problems of using energies like Wind and PV in micro-grid is their Intrinsic uncertainty and their random stochastic which made programming and predicting of such resources complicated.

In this Project, stochastic programming and probability scenarios are used in order to model uncertainty in both Wind and PV resources. Optimum programming of micro-grid which is connected to the main grid is considered by mixed integer programming in Gams software in which Virtual Power Producer manages optimum producing and load control by using main control system.

In order to solve the economic distribution of power in a micro-grid with different constraints, such as load and generation balancing, generation constraints, charging of storage resources in different scenarios and also the issue of unit commitment for sources of generation, the mixed integrated programming approach in this paper has been used.

Keywords: Renewable energy sources; Intrinsic uncertainty; Stochastic programming; mixed integer programming; Virtual Power Producer;

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 [17]. 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). These RESs include photovoltaic, wind farm, fuel cells, micro sized turbine, internal combustion engine generators, etc. 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 [5].

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 [15]. Due to these features, attentions both in industry and academia are increasingly focused on micro grids [1]. Keeping the balance between load and generation is the basic rule of all power systems Nowadays there is an upward tendency for using small isolated power systems, against central power producing system when regarding rural and distant places [11]. 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 [3]. Authors in [14], 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.

From power system point of view, the micro-grid can be considered as a controlled element that is connected to the main distribution system. The power may come in or out of the micro-grid. From the point of view of the consumer, the micro-grid can not only supply energy, it can also improve local reliability, reduce pollution, and with exploiting distributed resources, storages, and loads it can participate in providing cheap energy [18]. In order to achieve these benefits and provide energy in a reliable, economical and consistent way, several resources of distributed generation, storage and load should be exploited in a coordinated manner. To achieve this, the existence of a planning system for micro-grid is important. This planning system should anticipate the output of renewable resources and market prices, and consider technical constraints to plan, as well as specify the connection of the micro-grid to the main distribution system when participating in the electricity market. Significant efforts have been made to optimize planning and management of the micro-grid [6].

Although numerous studies have been done on cost reduction issues, most of them, regardless of the impact of storage optimization size, have been on reducing the operating costs of micro-grids. By using linear programming, the operating cost of the micro-grid has been optimized and the charging status of the storages has improved [16].

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 [8]. GA-based optimization method is used to obtain optimum power and price of the MG. Then, an objective function based on the total net present worth is considered and GA is employed to obtain the maximum net present worth of the micro-grid, during interconnected operation by optimizing the generation of local DGs and power exchanges with the main distribution grid [10].

Authors in [14], 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 algorithm, 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.

An algorithm for optimizing particles swarm in order to reduce the cost of operation in a micro-grid that has been applied to this problem [2].

By an adaptive mesh algorithm, the strategy and effective operating cost reduction for a micro-grid are estimated [9].

In [13], bee mating optimization algorithm is used to reduce the operating cost of a micro-grid, consisting of a photovoltaic system, a wind turbine, a fuel cell, regardless of the technology of storage batteries, in which active power losses and voltage drops and total energy costs are reduced.

In [12], an algorithm which is expressed as a multi-objective problem has been developed to minimize the cost and pollution of a grid.

2. The system under study

A micro-grid is considered as the study system, as shown in Figure 1. With the virtual production of power and the following development system, they seek to find the optimal capability in a small network. By virtual power plant and development of the following system, we are looking for optimal power in the micro-grid.

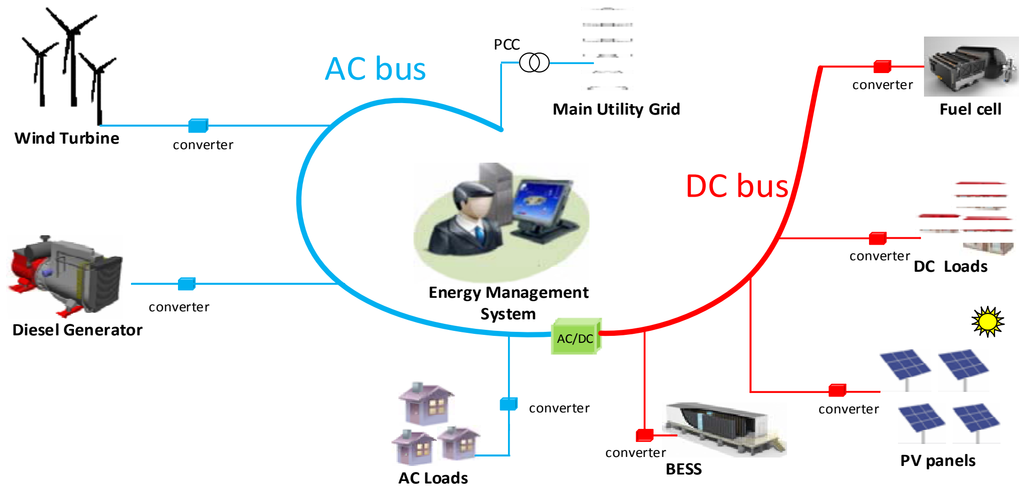

Fig.1 Under studied micro-grid

For optimal system utilization, virtual power producer or VPP needs the same information that should be considered to define the amount of energy generated by wind energy, photovoltaic energy, fuel cell and charge and discharge of battery. What to consider is as follows:

1. Wind power generation depends heavily on the weather. The ability to produce for a 24-hour period can be well estimated. Wind energy will be dispatched during the period due to its price.
2. The production of photovoltaic is also predictable according to patterns of previous days and conditions of the sun in different hours.
3. The fuel cell has a limited output for a long period, but the total energy produced is determined by the amount of hydrogen fuel.
4. The discharge of the storage unit depends on the maximum discharge capacity and the amount of stored energy which is available.
5. Loads predicted by several different aspects, although most of the loads can be controlled within the desired range (DSM or demand side management)
6. To maintain system equilibrium, VPP can set up reservations. For example, VPP can limit the minimum reservations to 10% of the forecasted load

Energy storage applications deliver short-term power to improve quality, voltage support and frequency support for renewable generation smoothing and end user energy management [7].

The goal is to make an optimal power distribution with all the considerations mentioned. A case study is carried out on a micro-grid connected to the upstream grid. This micro-grid includes wind, photovoltaic, fuel cells, diesel generators and batteries. 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.

It is assumed that the load of micro-grid is well predicted. The amount of this load for a 24-hour period is shown in Figure2.

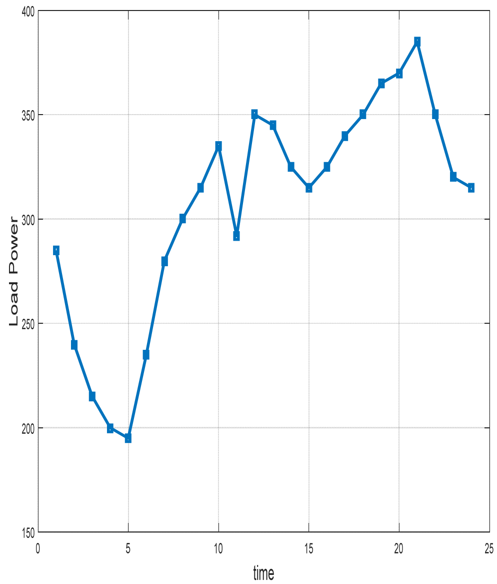

Fig.2 The micro-grid load pattern in 24 hours

The electricity selling tariff for a 24-hour period is shown in Figure 3. And the price of power generation by different units and the cost of undelivered energy are presented in Table 1. These values are assumed to be the same for all study hours and scenarios.

Table 1 Cost of generation power of units

Type of energy	*Price(€/kwh)*
Wind	0.4
PV	0.4
Fuel cell	0.9
Battery Charge	0.4
Battery Discharge	0.6
Undelivered Energy	1.5

Table 2 Specifications of the cost function of diesel generator

Coefficients	α_1	α_2	α_3	$P_{min(kw)}$	$P_{Max(kw)}$
Amount	1.112	1.22	3.03	0.1	0.81

The cost function of the diesel generator is as follows:

$$Cost = \alpha_1 \times P^2 + \alpha_2 \times P + \alpha_3 \quad (1)$$

For solving the problem, we consider it as a piecewise-linear, containing 100 pieces. The specification of the cost function factors and the minimum-maximum output of the diesel generator are presented in Table 2.

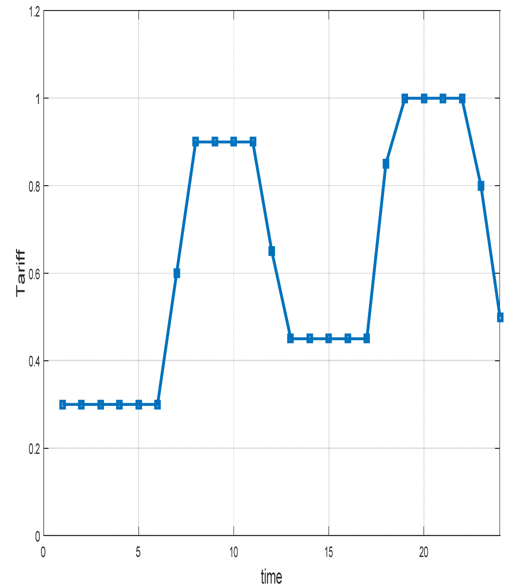

Fig.3 Power selling tariff

3. Problem Formulation

3.1. Random Variable

In stochastic programming, each variable with uncertainty is modeled as a random variable, and each random variable is expressed as a series of events or finite scenarios as follows:

$$\lambda(\omega) \quad \omega = 1, 2, ... \quad (2)$$

$$\lambda(ns) = \{\lambda(1), \lambda(2), ... , \lambda(ns)\} \quad (3)$$

Each scenario represented by $\lambda(\omega)$ is associated with a probability ($\pi(\omega)$) which is defined as follows:

$$\pi(\omega) = P(\omega | \lambda = \lambda(\omega)), \sum \pi(\omega) = 1 \quad (4)$$

The cumulative probability function of the scenarios can be defined as:

$$F(\eta) = P(\omega | \lambda(\omega) \leq \eta)$$

$$= \sum \pi(\omega), \quad \omega \in n \quad (5)$$

The above equations relate to discrete data. To calculate the probability of a discrete random variable, we can use the probability mass function, which is equivalent to the probability density function in the continuous space from the graphical point of view, Probability mass function or PMF is not suitable for displaying discrete variables, and it is recommended to use the adjusted Pdf (Probability density function).

3.2. Objective Function

Choosing the appropriate objective function is the most important decision in the optimization problem. Electricity purchasing tariffs (or, electricity selling tariffs) are considered in objective function. The main purpose of the cost function is to provide the required power for load with the lowest operating cost. Also, the cost of the diesel generator as well as the cost of the electricity sent to the network is also considered. In addition, the objective function has been rewritten as a stochastic problem with probabilistic scenarios. This objective function is described as follows:

$$
\begin{aligned}
Cost = \sum_{t=1}^{24} \ \{ \sum_{s=1}^{Ns} \rho s \times (Qs(t) \\
+ P_{FC,S}(t) \times C_{FC} + P_{W,S}(t) \times C_{W} \\
+ P_{PV,S}(t) \times C_{PV} - P_{BSC,S}(t) \times C_{BSC} \\
+ P_{BSDC,S}(t) \times C_{BSDC} + P_{UE,S}(t) \times C_{UE} \\
- P_{EE,S}(t) \times C_{EE}) \} \qquad (6)
\end{aligned}
$$

Simulation is considered for each specific hour and Ns scenario. Q is the cost of generating power in diesel generator at time t and scenario s.

3.3. Constraints

At any time (t) and in each scenario(s) the balance of power between generators and the load and the grid must be maintained as follows:

$$
\begin{aligned}
P_{W,S}(t) + P_{PV,S}(t) + P_{BSDC,S}(t) + P_{FC,S}(t) \\
+ P_{D,S}(t) - P_{BSC,S}(t) - P_{EE,S}(t) \\
= P_{Load,S}(t) \qquad (7)
\end{aligned}
$$

Power of wind turbine should be less than the maximum wind turbine power at any time (t) and scenario (s).

$$P_{W,S}(t) \leq P_{W\ Limit} \qquad (8)$$

Power generation of PV should be less than the maximum photovoltaic output at any time (t) and scenario (s).

$$P_{PV,S}(t) \leq P_{PV\ Limit} \qquad (9)$$

Power generation of fuel cell should be less than the maximum fuel cell output at any time (t) and scenario (s).

$$P_{FC,S}(t) \leq P_{FC\ Limit} \qquad (10)$$

Power generation of diesel generator is between its minimum generation and maximum generation.

$$P_{D,S\ Min}(t) \leq P_{D,S}(t) \leq P_{D,S\ Max}(t) \qquad (11)$$

Battery capacity at any time (t) and any scenario (s) is less than its maximum capacity.

$$P_{SB,S}(t) \leq P_{SB\ Max} \qquad (12)$$

Battery discharge at any time (t) and any scenario (s) is less than the maximum discharge amount of the battery.

$$P_{BSDC,S}(t) \leq P_{BSDC\ Max} \times X(t) \qquad (13)$$

In which X (t) is a binary variable to indicate whether the battery can be discharged or not. Battery charge at any time (t) and any scenario (s) is less than the maximum charge amount of the battery.

$$P_{BSC,S}(t) \leq P_{BSC\ Max} \times Y(t) \qquad (14)$$

In which Y (t) is a binary variable to indicate whether the battery can be charged or not.

In order to eliminate the simultaneous charge and discharge of the battery, and to determine the energy stored in the battery as a time-dependent parameter, the following equation is used:

$$
\begin{aligned}
X_S(t) + Y_S(t) = 1 \\
X, Y \in \{0,1\} \qquad (15)
\end{aligned}
$$

In other words, at any time (t) and scenario (s), the battery cannot be charged and discharged at the same time.

The amount of battery discharge at the moment t and scenario s should be less than the battery storage in the moment before it.

$$P_{BSDC,S}(t) - P_{SB,S}(t-1) \leq 0 \qquad (16)$$

The amount of battery charge at the moment of t and scenario s plus the battery storage in the previous moment should be less than the maximum storage capacity of the battery.

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

The amount of battery storage at the moment t and scenario s is equivalent to the battery storage at the moment t-1 plus the battery charge at the moment t minus the battery discharge at the moment t (battery power balance).

$$
\begin{aligned}
P_{SB,S}(t) = P_{SB,S}(t-1) \\
- P_{BSDC,S}(t) + P_{BSC,S}(t) \qquad (18)
\end{aligned}
$$

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

$$P_{SB}(t=0)=P_{initial} \tag{19}$$

The undelivered power at the moment t and scenario s should be less than the amount of load.

$$P_{UE,S}(t) \leq P_{Load}(t) \tag{20}$$

4. Stochastic Scenarios in the Studied Micro-grid

Making decision is always a solution to an optimization problem. If the inputs of the optimization problem are definite, the decision is optimal and the decision can be made by solving this problem. But the input information is not always definite and it has uncertainties that can be described by the probability distribution function. In such cases, the making decision will not be clear. A solution is the use of expected values, which will be like a definite solution and may not lead to favorable outcomes. But the probabilistic distribution of input information can be estimated with a group of possible events Which is likely to occur. This type of programming is called stochastic programming. For example, three sets of input data with three probability occurrence rates, the sum of which will be equal to one, thus we have found an optimal response, this response, while not dependent on any of the inputs solely, is associated with and affects all of them. Since the input information has uncertainty, the objective function is uncertain too and random variables must be classified and each of them must be entered with the probability of its category. Another method for maximizing the objective function is to maximize the expected value for the target function in such a way that the variance is limited. The use of the above-mentioned problem answers is correct when the entire categories of input information are considered with their respective probability. This answer is not the best answer for each entry group, and only when all input groups are considered this answer will be the best answer. The main problem in the Stochastic Programming is its heavy calculations, and these calculations may lead to divergence.

Since there is uncertainty in the sun and wind, stochastic scenarios are used to model power generation of wind turbine and photovoltaic. Power generation occurs with a certain probability at each scenario. The sum of these three probabilities is equal to 1. Three scenarios for wind power generation and three scenarios for solar power generation are selected as random scenarios. The scenarios for wind power generation are as shown in Fig 4. The scenarios for wind power generation are as shown in Fig 5.

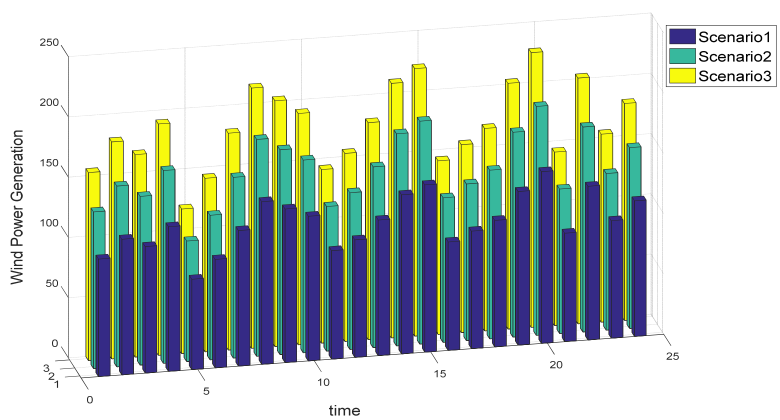

Fig.4 Wind power generation scenarios

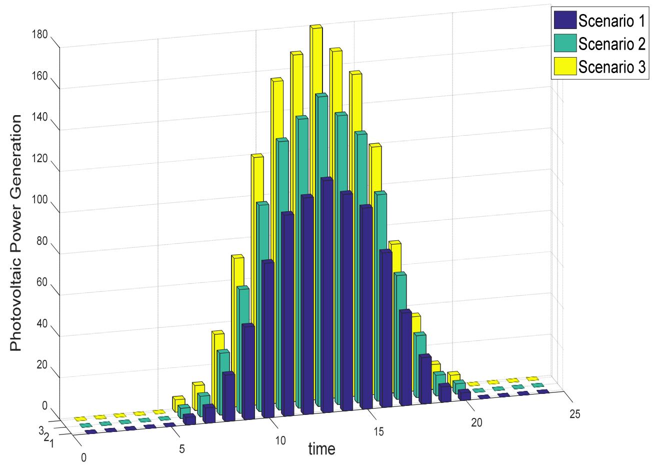

Fig.5 PV power generation scenarios

The probability of occurrence of each scenario is in Table 3.

Table 3 probability of occurrence of each scenario in each power generation unit

Wind scenarios	*probability*	*PV scenarios*	*Probability*
Scenario1	0.2	Scenario1	0.15
Scenario2	0.6	Scenario2	0.7
Scenario3	0.2	Scenario3	0.15

The new table will include nine scenarios in which probability of occurrence of each scenario is obtained from the product of the probability of previous scenarios in each other. These new scenarios and their probabilities are shown in table4.

The scenario 1 associated with the wind with the scenario 1 associated with the sun is defined as the new scenario 1 or scenario 1 associated with the wind with the scenario 2 associated with the sun is defined as the new scenario 2 and so on. New scenarios for Wind power generation is in Table 5. And new scenarios for PV power generation is in Table 6.

Table4 the probabilities of scenarios

Final Scenarios	*Probability of occurrence*
Scenario1	0.03
Scenario2	0.14
Scenario3	0.03
Scenario4	0.09
Scenario5	0.42
Scenario6	0.09
Scenario7	0.03
Scenario8	0.14
Scenario9	0.03

Table5 Wind power generation scenarios

	s1	*s2*	*s3*	*s4*	*s5*	*s6*	*s7*	*s8*	*s9*
t1	97.5	97.5	97.5	130	130	130	156	156	156
t2	112.5	112.5	112.5	150	150	150	180	180	180
t3	105	105	105	140	140	140	168	168	168
t4	120	120	120	160	160	160	192	192	192
t5	75	75	75	100	100	100	120	120	120
t6	90	90	90	120	120	120	144	144	144
t7	112.5	112.5	112.5	150	150	150	180	180	180
t8	135	135	135	180	180	180	216	216	216
t9	127.5	127.5	127.5	170	170	170	204	204	204
t10	120	120	120	160	160	160	192	192	192
t11	90	90	90	120	120	120	144	144	144
t12	97.5	97.5	97.5	130	130	130	156	156	156
t13	112.5	112.5	112.5	150	150	150	180	180	180
t14	132	132	132	176	176	176	211	211	211
t15	138.8	138.8	138.8	185	185	185	222	222	222
t16	90	90	90	120	120	120	144	144	144
t17	97.5	97.5	97.5	130	130	130	156	156	156
t18	105	105	105	140	140	140	168	168	168
t19	127.5	127.5	127.5	170	170	170	204	204	204
t20	142.5	142.5	142.5	190	190	190	228	228	228
t21	90	90	90	120	120	120	144	144	144
t22	127.5	127.5	127.5	170	170	170	204	204	204

t23	97.5	97.5	97.5	130	130	130	156	156	156
t24	112.5	112.5	112.5	150	150	150	180	180	180

Table 6 PV power generation scenarios

	s1	***s2***	***s3***	***s4***	***s5***	***s6***	***s7***	***s8***	***s9***
t1	0	0	0	0	0	0	0	0	0
t2	0	0	0	0	0	0	0	0	0
t3	0	0	0	0	0	0	0	0	0
t4	0	0	0	0	0	0	0	0	0
t5	0	0	0	0	0	0	0	0	0
t6	3.75	5	6	3.75	5	6	3.75	5	6
t7	7.5	10	12	7.5	10	12	7.5	10	12
t8	22.5	30	36	22.5	30	36	22.5	30	36
t9	45	60	72	45	60	72	45	60	72
t10	75	100	120	75	100	120	75	100	120
t11	97.5	130	156	97.5	130	156	97.5	130	156
t12	105	140	168	105	140	168	105	140	168
t13	113	150	180	113	150	180	113	150	180
t14	105	140	168	105	140	168	105	140	168
t15	97.5	130	156	97.5	130	156	97.5	130	156
t16	75	100	120	75	100	120	75	100	120
t17	45	60	72	45	60	72	45	60	72
t18	22.5	30	36	22.5	30	36	22.5	30	36
t19	7.5	10	12	7.5	10	12	7.5	10	12
t20	3.75	5	6	3.75	5	6	3.75	5	6
t21	0	0	0	0	0	0	0	0	0
t22	0	0	0	0	0	0	0	0	0
t23	0	0	0	0	0	0	0	0	0
t24	0	0	0	0	0	0	0	0	0

5. Flowchart of proposed approach

In the previous sections, the modeling of controlled production resources and renewable energy sources was discussed. For renewable energy sources that have stochastic generation, scenarios with the probability of occurrence of each scenario and the amount of production in each scenario are presented for the leading 24-hour period according to Tables 5 and 6.

In this section, the executive flowchart for energy management is presented in the method proposed in this article for a leading 24-hour period under the MILP method. After starting the microgrid energy management process, the microgrid energy management operator must enter the total input information of the microgrid at any time, including the information of the coefficients of the production cost function for the diesel generator units and the production cost coefficients for the fuel cell, solar cell, wind turbine and recharge and discharge the energy storage and other required information and based on the formulas provided in Equation (6) and the constraints governing the microgrid in Equation (7)-(20) and according to the MILP method to distribute power and do so Do it for the next 24 hours and finally announce the results of each production unit. This process is displayed in Flowchart.

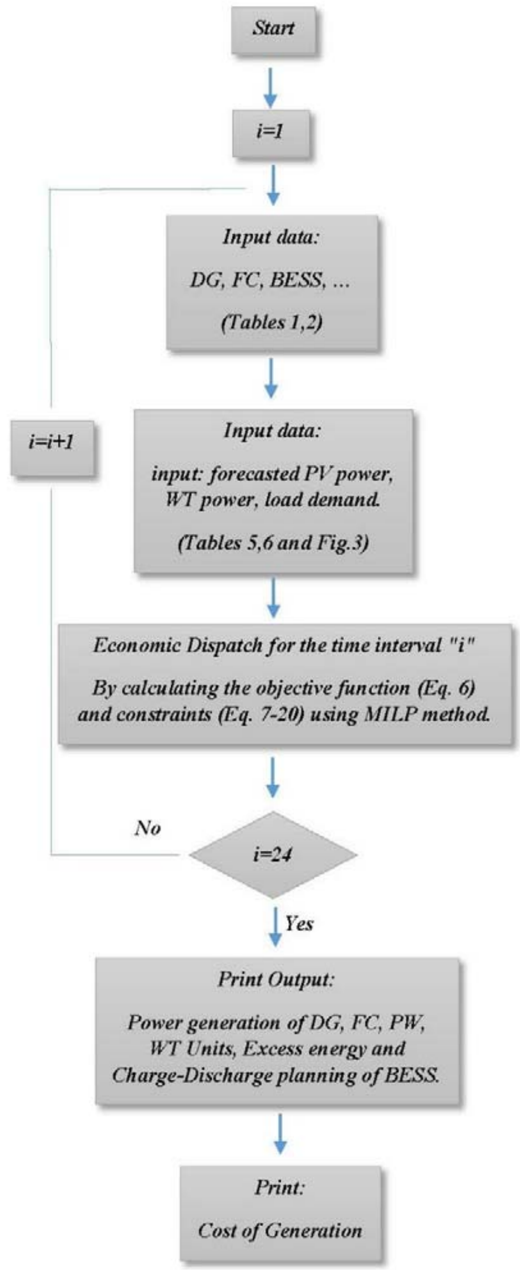

Fig.6 MILP implementation process for under study micro grid.

6. Simulation Results

Simulation is done by using data consist of probability scenarios for wind and the sun, using the objective function, existing data such as the constraints which are proposed power generation, the tariffs for power generation and load. As expected, the result consists of 9 scenarios. The optimal power generation planning in each scenario is based on the generation cost of each generator, which is diesel, wind, photovoltaic, discharger, fuel cell, respectively. In each scenario and at any particular time, all constraints, including the balance of power, are maintained. Power generation of each unit in the nine scenarios is shown in Figures 7-11. The wind and photovoltaic power generation has already been shown in table 5 and table 6. In all figures power units are in kilowatts.

Due to the dependence of the wind turbine and solar cell generation on weather and environmental conditions, there is an uncertainty of generation for these units. Thus, for the 24-hour intervals of each unit of wind turbine and solar cell, 9 scenarios are considered with different generations. Hence, the probabilistic combination of nine wind turbine and solar cell scenarios for 24-hour intervals and considering the probability coefficient of each scenario (Table 4), 9 new scenarios of production are obtained in terms of uncertainty. For each new scenario in each 24-hour interval, the objective function with all constraints is solved by the MILP method, and the simulation results are presented in Figures 7, 8, 9,10 and 11.

According to Table 5, it is found that power generation in the three scenarios 7, 8 and 9 for the wind turbine is as high as possible. And for solar cells at the beginning and the end times due to the lack of sunlight the output reaches zero and for the three scenarios 3, 6 and 9 it is the highest output compared to the other scenarios and at the time t = 13 the highest generation occurs for PV. Since the supply of micro-grid loads by PV and WT is prioritized due to lower generation costs, therefore, it is expected that in scenarios where PV and WT generation capacity is high, the output of controlled units such as DG will be less than other scenarios that is shown in Scenario 9 of fig. 7.

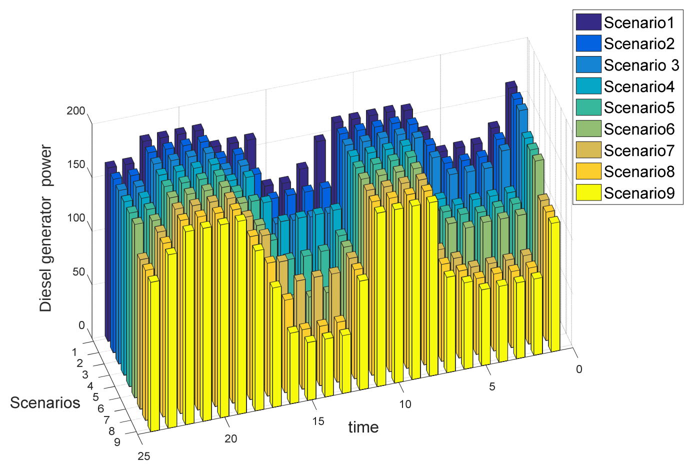

Fig.7 Optimal power generation programming for diesel generator unit

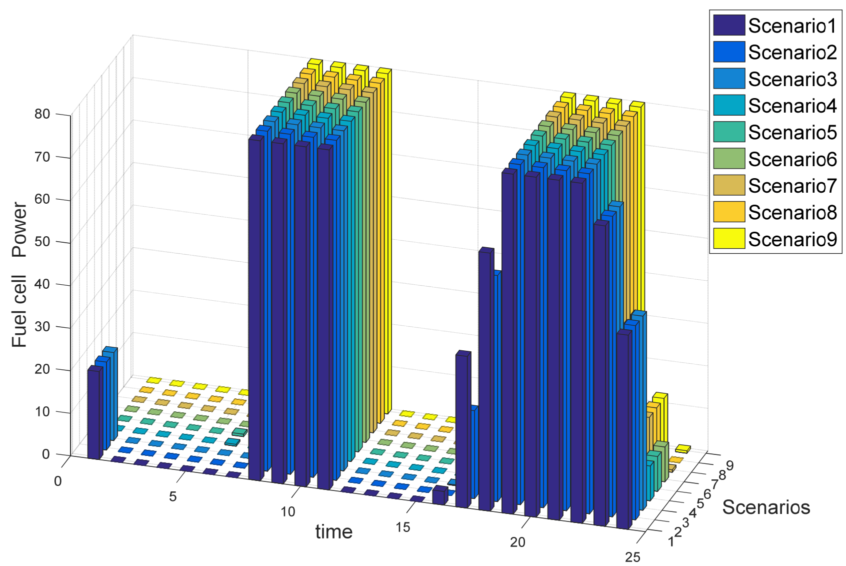

Fig.8 Optimal power generation programming for fuel cell unit

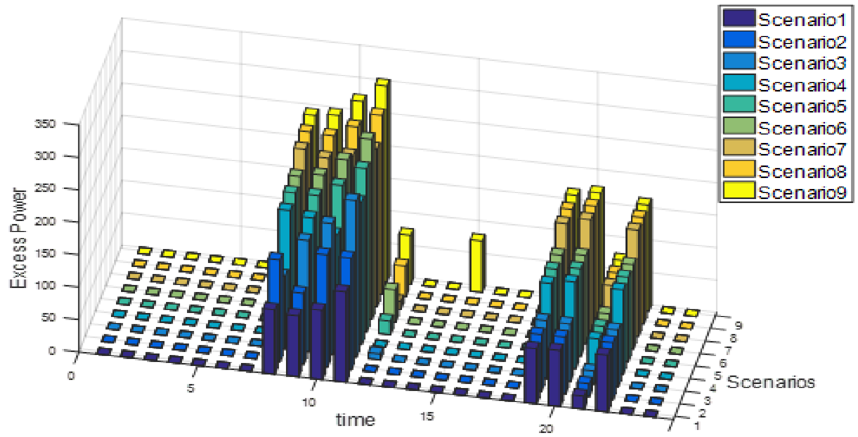

Fig.9 Excess energy (sell to grid) for all scenarios

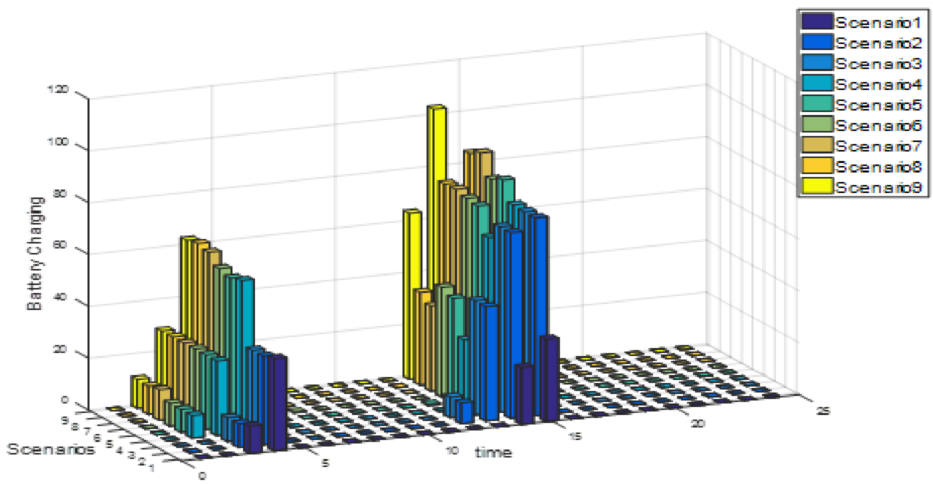

Fig.10 Optimal power generation programming for battery charging

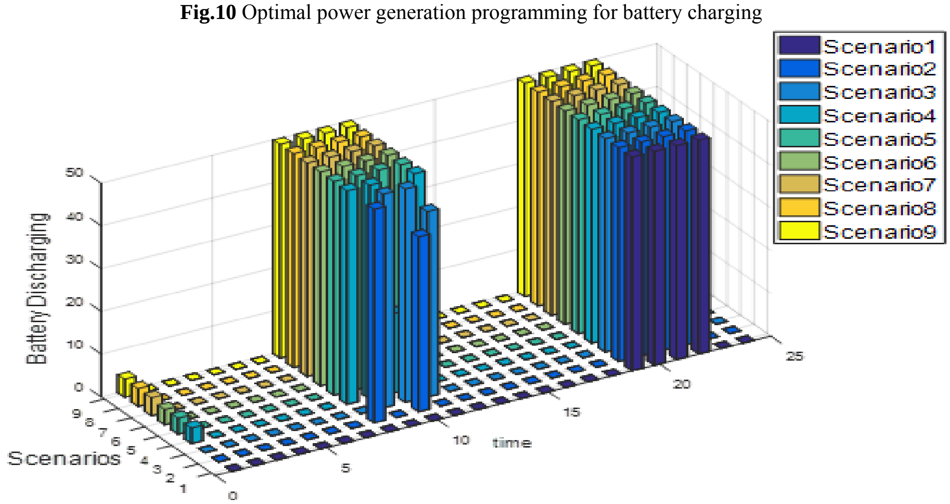

Fig.11 Optimal power generation programming for battery discharging

From the load curve presented in Fig. 2, it is found that the maximum load required for the microgrid occurs at the time interval t = 8-11 and t = 19-22. On the other hand, the highest revenue from the sale of energy to the upstream grid is shown in the fig. 3, will be paid at t =8-11 and t =19-22, though the sales revenue for t =19-22 will be slightly higher than t =8-11 due to peak hours. Therefore, it is expected that if energy management is implemented by the approach presented in this paper for the microgrid under study, diesel generator unit and FC generate the maximum of power output for these time intervals, and due to maximize the profits from the sale of power to the upstream grid, battery will be discharged at these times as shown in figs. 7-11 is clear.

In fig. 9, the upstream grid sales revenue for the time interval t = 8-11 is lower than the t = 19-22, but the power sales are higher. This is due to higher load demand over time t = 19-22. Therefore, the surplus power generated during this period is offered for sale to the upstream grid.

7. 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.

In this paper, the optimal planning of a micro-grid connected to the network using mixed-integer Programming is considered. This micro- grid includes renewable energy resources such as wind and solar, batteries and fuel cells. The simulation was carried out on a real sample at the University of Hungary and the results of the optimal planning of the units were obtained by minimizing the cost of the operation. In this plan, 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 GAMS software with mixed integer programming method, by using the CPLEX solver, answers are calculated by 276 iterations and during 0.05 second while in genetic algorithm, which all these processes were done by it, answers are calculated by 325 iterations. The operating cost for a 24-hour period, considering the scenarios proposed, is $ 3183(by CPLEX) and $ 3352(for genetic algorithm), by mixed integer method, 169$ is saved in generation costs in comparison with the Genetic algorithm.

8. Appendix

8.1. List of symbols

C_{BSC} Cost of energy charged in storage

C_{BSDC} Cost of energy discharged in storage

C_{EE} Cost of power sent to main grid

C_{FC} Cost of Power generation of fuel cell

Cost Total cost consists of power generation in units and storage

C_{pv} Cost of Power generation of photovoltaic

C_{UE} Cost of undelivered power

C_w Cost of Power generation of wind turbine

$F(\eta)$ Cumulative probability function

$P_{BSC,S}(t)$ 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

$P_{D,S}(t)$ Power generation of diesel generator at time t and scenario s

$P_{D,S\,Max}(t)$ Maximum Power generation of diesel generator at time t and scenario s

$P_{D,S\,Min}(t)$ Minimum Power generation of diesel generator at time t and scenario s

$P_{EE,s}(t)$ The amount of power sent to main grid at time t and scenario s

$P_{FC,S}(t)$ Power generation of fuel cell at time t and scenario s

$P_{Load,s}(t)$ The amount of power which load needs

$P_{pv,s}(t)$ Power generation of photovoltaic at time t and scenario s

P_{SB} Battery storage

$P_{SB,S}(t-1)$ The amount of battery storage at the moment t-1 and scenario s

$P_{UE,S}(t)$ The amount of undelivered power at time t and scenario s

$P_{W,S}(t)$ Power generation of wind turbine at time t and scenario s

$X_s(t)$ 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

$\alpha_1.\alpha_2.\alpha_3$ The coefficients related to power generation in diesel generator

$\lambda(\omega)$ Random variable

$\pi(\omega)$ Probability function of each scenario

ω Number of each scenario

9. References

[1] Agrawal M, Mittal A, Azad M (2011). "Micro grid technological activities across the globe: a review." ***International Journal of Research & Reviews in Applied Sciences 7.***

[2] Anvari Moghaddam A, Seifi A, Niknam T (2012) "Multi-operation management of a typical micro-grids using particle swarm optimization: a comparative study." ***Renewable and Sustainable Energy Reviews*** 16:1268. doi: 0.1016/j.rser.2011 .10.002.

[3] Bhadoria A, Kamboj V.K, Sharma M. et al. (2018). "A Solution to Non‑convex/Convex and Dynamic Economic Load Dispatch Problem Using Moth Flame Optimizer." ***INAE Lett*** 3: 65.doi:10.1007/s41403-018-0034-3

[4] Fadlullah Z.M, Kato N (2015). "On Optimally Reducing Power Loss in Micro-Grids with Power Storage Devices." ***In: Evolution of Smart Grids. Springer Briefs in Electrical and Computer Engineering. Springer, Cham.*** doi:10.1007/978-3-319-25391-6_6

[5] Gupta P, Bhatia R.S, Jain D.K, Ruchika (2018). "Active Islanding Detection Technique for Distributed Generation." ***INAE Lett*** 3: 243. doi: 10.1007/s41403-018-0054-z.

[6] Gu W, Wu Z, Bo R. et al. (2014). "Modeling, planning and optimal energy management of combined cooling, heating and power microgrid: A review." ***International Journal of Electrical Power & Energy Systems*** 54:26. doi: 10.1016/j.ijepes.2013.06.028.

[7] Hussain A, Amin M, Khan R.D. et al. (2018). "Optimal Allocation of Flexible AC Transmission System Controllers in Electric Power Networks." ***INAE Lett 3***: 41. doi:10.1007/s41403-018-0035-2

[8] Kamboj V.K, Bhadoria A, Gupta N (2018). "A Novel Hybrid GWO-PS Algorithm for Standard Benchmark Optimization Problems." ***INAE Lett 3***: 217. doi:10.1007/s41403-018-0051-2

[9] Mohamed F.A, Koivo H.N (2010). "System modelling and online optimal management of microgrid using mesh adaptive direct search." ***International Journal of Electrical Power & Energy Systems*** 32:398. doi: 10.1016/j.ijepes .2009.11.003

[10] Mohammadi M, Hosseinian S.H, Gharehpetian G.B (2011). "GA-based optimal sizing of microgrid and DG units under pool and hybrid electricity markets." ***International Journal of Electrical Power & Energy Systems 35***. doi: 10.1016/j.ijepes.2011.09.015

[11] Morais H, Kadar P, Faria P. et al. (2010). "Optimal scheduling of a renewable micro-grid in an isolated load area using mixed-integer linear programming." ***Renewable Energy*** 35:151. doi: 10.1016/j.renene.2009.02.031

[12] Niknam T, Azizipanah-Abarghooee R, Narimani M.R (2012). "An efficient scenariobased stochastic programming framework for multi-objective optimal microgrid operation." ***Applied Energy*** 99:455. doi: 10.1016/j.apenergy.2012. 04.017

[13] Niknam T, Kavousifard A, Tabatabaei S. et al. (2011). "Optimal operation management of fuel cell /wind /photovoltaic power sources connected to distribution networks." ***Journal of Power Sources*** 196. doi: 10.1016/j.jpowsour.2011.05.081

[14] Roofegari Nejad R, Moghaddas Tafreshi S.M (2014). "Operation Planning of a Smart Microgrid Including Controllable Loads and Intermittent Energy Resources by Considering Uncertainties." ***Arab J Sci Eng*** 39: 6297. doi:10.1007/s13369-014-1267-4

[15] Seo J.T (2016). "Towards the advanced security architecture for Microgrid systems and applications."

The Journal of Supercomputing 72: 3535. doi:10.1007/s11227-016

[16] Sharma S, Bhattacharjee S, Bhattacharya A (2016). "Grey wolf optimization for optimal sizing of battery energy storage device to minimize operation cost of microgrid." ***IET Generation, Transmission & Distribution*** 10. doi: 10.1049/iet-gtd.2015.0429

[17] Shukla A, Singh SN (2016). "Multi-Objective Unit Commitment with Renewable Energy Using GSA Algorithm." ***INAEL*** 1: 21. doi:10.1007/s41403-016-0004-6

[18] Tsikalakis A.G, Hatziargyriou N. D (2008). "Centralized Control for Optimizing Microgrids Operation." ***IEEE Transactions on Energy Conversion*** 23:1. doi:10.1109/PES.2011.6039737