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# Optimized Planning for Hybrid Microgrid in Grid-Connected Mode

Ashkan Nadimi*, Farid Adabi **‡

* Department of Electrical Engineering, Sanandaj Branch, Islamic Azad University, Sanandaj, Iran.

**Department of Electrical Engineering, Sanandaj Branch, Islamic Azad University, Sanandaj, Iran.

(ashkannadimi1369@yahoo.com, farid.adabi@ iausdj.ac.ir)

‡Corresponding Author; second Author, Department of Electrical Engineering, Sanandaj Branch, Islamic Azad University, Sanandaj, Iran., Tel: +98 87 33289430, farid.adabi@ iausdj.ac.ir

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**Abstract-**The emergence of the Distributed Generation (DG) units along with their application in the distribution system level has led to the establishment of microgrids. microgrids are a part of the distribution network in which, in addition to the loads, there are micro sources operating in two modes, i.e. grid-connected mode and island also known as standalone mode. In the grid-connected mode, the load is supplied through local DG units, and if necessary, power is exchanged with the upstream grid, concerned as well. Considering the development of DG units technology in recent years which in turn, has led to the expansion of microgrid concept, microgrid planning meaning determining the capacities of local DG units assumes an extraordinary significance, taking the technical, economic and environmental considerations into account. This research tries to study the optimized planning for a grid-connected hybrid microgrid. The case study was conducted in Razi University in Kermanshah, Iran (34°23'Nlatitude and 47°6'E longitude). Due to the stochastic behavior of renewable energies based DG units, the uncertainties about the amount of generated power from these resources are considered using appropriate probability density functions. The problem is a Mixed Integer Non-linear Program (MINLP), to be solved by means of GAMS software. In order to bring about optimized results, microgrid simulation is processed in assorted scenarios, both in probabilistic and deterministic modes. In the end, the results are compared to those resulted from Homer Energy software.

**Keywords-** Optimized Planning, Hybrid microgrid, Probability Functions, Uncertainty, Distributed Generation

## 1. Introduction

The need to supply electric load by DG units in the proximity to the load has led to the appearance of the microgrid concept in order to drop the costs, reduce the pollution, and minimize the losses and the like. microgrid, as the definition goes, refers to a part of the distribution network in which, in addition to the loads, there are power generation resources as well as Electrical Energy Storages System (EESS); in fact, a microgrid is an active distribution grid [1].

According to the declared statistical figures [2], the amount of energy consumption within 2008 was equaled to 474 E+18 joule, out of which 80 to 90 percent was supplied by fossil fuel resources – which are, in turn, known as exhaustible energy resources.

During the recent decades, human communities have faced three major crises which have influenced the overall policies as well as the technological advances. These three are namely "financial", "environmental" and finally "energy" crises. However, one may claim that energy could be influential on the two other ones [3].

Generally DG resources are divided into two main categories, i.e. fossil fuels-based and renewable energies-based units. Given fossil fuel resources are about to vanish and since the environmental concerns pertaining to extravagant consumption of such resources has led to grave worries, there has been ever-increasing tendencies toward renewable energy resources. However, renewable energy resources suffer from a couple of major setback factors, i.e. their doubtful economic justification in addition to the stochastic behavior of them. Though during the recent years, a good number of researches have focused their attention to tackle these impediments. Considering fluctuations and sharp rises in the prices of fossil fuels as well as due to the development of renewable energies-based generation units technologies in the years to come, we are going to witness more growth in the participation of renewable energies-based units.

However fossil fuel-based DG units are used in microgrids so as to encounter the uncertainties resulting from stochastic and unpredictable behavior of renewable energy resources, most particularly wind and solar energies. Thus, the requirements of grid are met when it is impossible to generate power in the renewable energy-based units. Such microgrids are called “hybrid microgrids”.

microgrids are operated in either “grid-connected mode” or “standalone mode” [4,5]. In “grid-connected mode”, the microgrids exchange power with their upstream grid according to the extents of their generation and internal consumption. Yet, in “standalone mode”, the design should have been made be in such a manner to make sure that the mircrogrids could supply the installed consumption load throughout all seasons of the year and in all climatic conditions, with the least possible load cuts while retaining the nominal frequency [6].

It stands highly imperative to come up with an optimized design for microgrids to make optimal use of DG units as far as either economic or technical aspects are concerned. Accordingly, various authorities have proposed to optimal planning of hybrid microgrid, using miscellaneous algorithms and software applications including numerical [7, 8] and probabilistic [9] techniques, heuristic methods [10-15] and in the end, Mixed Integer Non-linear Program (MINLP) [16].Zong Woo Geem investigates an optimized planning for solar & wind-based energy system [17], in which the researcher primarily selects the integer variables via B&B[1] method; later searches for the optimized solution by GRG Algorithm in MATLAB software. In a condition that a constraint limit is not imposed on energy generation resources, the optimized design consists of 10 batteries along with 2 wind turbines (and without any photovoltaic cells), that will totally cost $5652.38. If such limits are not applied, the optimized design consists of 160 kW solar energy panels and 17 batteries, without resorting to wind turbines. From among the drawbacks of this article, one may refer to not considering the uncertainties of wind and solar energies and batteries charge and discharge in power balance constraint. M. Sadeghi, M. Kalantar investigated the optimized planning and later, allocating the solar unit in a typical 9-bus distribution system via mixed integer nonlinear programming (MINLP) through GAMS software [18]. The whole demanded energy is supplied by means of solar panels. Here in this research, in order to considering the uncertainties generated power modeled by use of Beta probability density function. The consequences resulted from the proposed "probabilistic method" are later compared to those of the "deterministic method" – which, in turn, indicates the proposed method has been acceptable. However, it is to be noted that, given the method was devoid of other generating power resources consideration, including both renewable and fossil-based, the results may not be operational. AngoSobu and Guohong Wu have conducted an optimized planning and operation for a solar and wind-based energy system in isolated mode [19]. This research models the uncertainties related to wind, solar energies and load by Weibull, Beta and Gaussian probability density functions respectively. Particles Swarm Optimization algorithm was adopted to solve the problem by MATLAB software. A.T.D Perera and colleagues make use of a multiobjective optimization framework for optimized planning of a solar and wind-based microgrid [20]. The objective functions, concerned, are enumerated as follow: Levelized Energy Cost (LEC), Initial Capital Cost (ICC), and finally Greenhouse Gases emission (GHG). Simulation results, through Pareto optimization illustrated that it would be easier to make decisions on ICC-LEC and GHG-LEC combinations rather than LEC, ICC and GHG. In this article, a gradual hybridization of renewable energy resources is suggested where it appears hard to bear the burden of higher initial capital costs. Dekker J and colleagues examined the feasibility of installing a hybrid energy system in 6 different geographical zones of South Africa [21]. In the end, a zone is identified as "ideal zone", which required the least costs. Its optimized equipment size consisted of a solar array of 5 kW, diesel generator of 5.5 kW, a convertor of 6 kW and 30 batteries with a Net Present Cost of $68801. The article employed Homer Energy software.

This article tries to conduct a research on a hybrid microgrid designing and programming in grid-connected mode, taking the possible existing uncertainties, concerned. Consumption load data pertaining to Razi University of Kermanshah, Iran were taken as the grid under study while the optimized planning problem solution was undertaken by means of GAMS software application. In the probabilistic method, as uncertainties had to be taken into account, firstly, the wind speed and solar radiation are modeled by Weibull and Beta probability density function respectively, in MATLAB software.Lastly, all the calculated values were considered as uncertainties in GAMS software.

## 2. The Microgrid Under Study

Figure 1 illustrates a schematic overview of the microgrid under study. As apparent, power generating units comprise solar panels, wind turbine as well as diesel generator; DC/AC converter is engaged to connect DC bus to the grid. Due to the fact that the solar and wind power generation suffers from fluctuations, batteries storage system is added beside the fossil fuel generator. In this research, the load of Razi University in Kermanshah was taken to be studied as the local load of the hybrid microgrid. Razi University in Kermanshah is located at the longitude of 34 degrees, 23 minutes and latitude of 47 degrees, 6 minutes on 1339 meters above sea level.

### *2.1. Consumption Load of the microgrid*

Considering the type of mirogrid load of a university, the consumption load is active power. In order to predict the load, a year is divided into 4 seasons; out of each season, a day has to be pinpointed as typical one. Ultimately, the pinpointed day would be later subdivided into 24 hours. Accordingly, the accurate load consumption is calculated within an hour, in regard with the installed equipment of university. Later on, the consumed load curve is provided for three different time pricing tariffs, i.e. peak, norm-peak and off-peak. Obviously,

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[1] Branch and Bound

peak consumption occurs while the grid is norm-loaded (Figure 2).

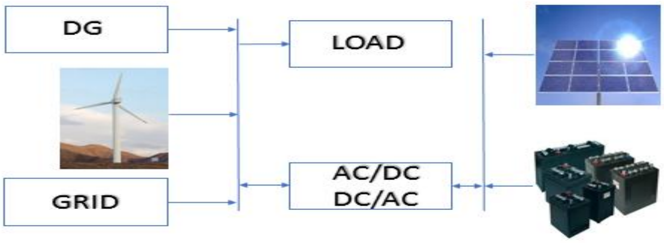


**Fig.1.** Schematic of the microgrid under Study

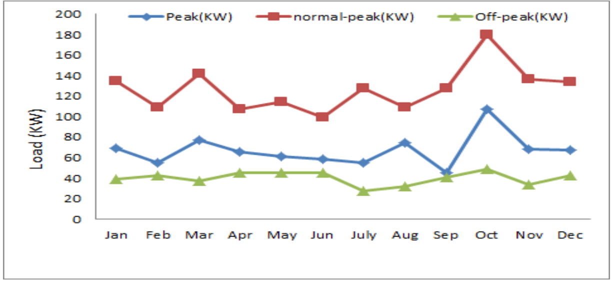


**Fig.2.** Microgrid predicted Load

## 2.2. Climate Data

On the microgrid concerned, it looks imperative to collect such related data as wind speed, solar irradiance, etc. as far as PV unit and wind turbine are installed. In 2014 (1393 Iranian calendar), average wind speed was 4.3 m/s for the year. The greatest wind speed belonged to September (4.8 m/s) while the least wind speed happened in the first two months of the winter (3.2 m/s). Moreover, average annual solar irradiance rated 5.588 kWh/m$^2$/d during the period; the most and least irradiance values occurred respectively in the first months of summer (8.301 kWh/m$^2$/d) and winter (2.2598 kWh/m$^2$/d). Figures 3 and 4 illustrate the average solar irradiance and wind speed curves in different moths of the year. Climate data of the region were gathered from NASA website [22].

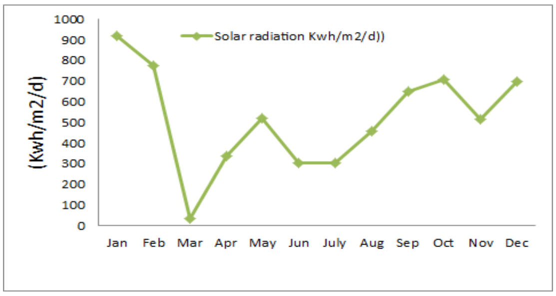


**Fig.3.**Average Solar Irradiance

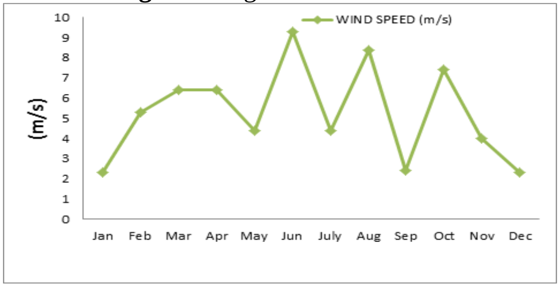


**Fig.4.** Average Wind speed

## 2.3. Economic Data

In this study, the costs, considered for the equipment are real and the equipment items installed in the microgrid are available in the producer companies. Initial capital costs include those of the equipment purchase, installation and transportation while O&M costs comprise those of fuel cost, repairing costs, and the like. Equipment life-time was assumed equal to that of the project itself. Therefore, none of the equipment items needs replacement within the life span of the project. Table 1 reveals the economic data, considered for each equipment item [17].

The electricity power price purchase from the upstream grid in three various times, including peak, norm-peak and off-peak according to general load tariff in Iran was taken into account respectively 0.2, 0.157 and 134 $/kWh. In the meantime, the power selling price to the grid was considered 0.153 $/kWh according to Iranian Ministry of Energy.

**Table 1.** Economic Data Considered in the Research

| Variable | Value |
|---|---|
| Annual interest rate(i) | 6% |
| Project life-time | 20 years |
| Solar panels purchase costs | 350 ($/panel) |
| Solar panels installation costs | 50 % of Purchase price |
| Solar panels repair & maintenance ($C_{mnt}^{pv}$) | 0.5 ($/kWh) |
| Wind turbine purchase costs | 20000 ($/turbine) |
| Wind turbine installation costs | 25 % of Purchase price |
| Wind turbine repair & maintenance ($C_{mnt}^{WT}$) | 0.4 ($/kWh) |
| Batteries purchase costs ($C_{CPT}^{BATT}$) | $170 |
| Batteries repair & maintenance costs ($C_{mnt}^{BATT}$) | 0.1($/ kWh) |
| Batteries' efficiency ($\eta_3$) | 85 % |
| Capacity of batteries ($S_{BATT}$) | 2.1 kWh |
| Fuel price ($C_F$) | $0.03 |
| Time unit($\Delta t$) | 1 h |

## 2.4. Equipment Mathematical Model

In order to determine the optimal size of the equipment used in the microgrid as well as to determine the Net Price Costs, firstly a mathematical model needs to be formulated before the optimization problem can be solved. The model goes as follows:

### 2.4.1 Wind Turbine

Stochastic behavior of the climate in the area causes hefty changes in the wind-generated power, introducing a good deal of intricacies to the system. Electric energy generation by wind turbines depends on the wind speed. Weibull probability function was made use of, to consider the uncertainties and errors of estimation according to the following relations [24]:

$$p^{ws}(v_t) = \frac{a}{b}\left(\frac{v_t}{b}\right)^{a-1}\exp\left(-\left(\frac{v_t}{b}\right)^{a}\right) \quad (1)$$

$$a = \left(\frac{\sigma^{ws}}{\mu^{ws}}\right)^{-1.086} \quad (2)$$

$$b = \frac{\mu^{ws}}{(1-a^{-1})} \quad (3)$$

Several models were presented so as to calculate the output power of the wind turbines. These models are generally categorized in tow groups: group 1 uses math relations and group 2 employs the curve of power per wind speed. Group 2 is further divided in two methods, namely "estimated curve" and "exact curve according to the producer company" [20]. The calculations in this article were conducted according to math models. The math relations are followed by a curve, indicating the power generated by the wind turbine in various wind speeds; the curve is illustrated in figure 5.

$$P_t^{wd}(V_t) = \begin{cases} 0 & 0 \le v_t \le v_{ci} \\ \left(\frac{v_t - v_{ci}}{v_r - v_{ci}}\right)^3 P_r^{wd} & v_{ci} \le v_t \le v_r \\ P_r^{wd} & v_r \le v_t \le v_{co} \\ 0 & v_t \le v_{co} \end{cases} \quad (4)$$

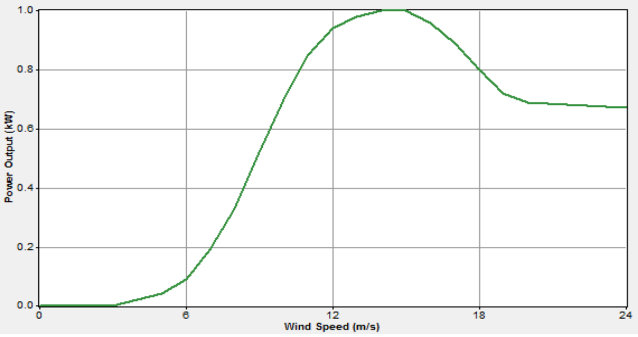


**Fig.5.** Electricity Generation Power of the Wind Turbine pge11/35 in different Wind speeds

The values Vci ، Vco,Vr were considered respectively 4.8, 25 and 14 meter per second.

Statistical methods were used so as to determine the wind potential energy and to estimate the output energy in the area, concerned. Wind speed data were measured for the height of 10 meters above the earth level with the time distance of 1 hour for a period of 1 year. Table 2 shows the wind speed and wind power-related parameters.

**Table 2.** Parameters related to Wind Speed and Power at a Height of 10 Meters

| | |
|---|---|
| Average wind speed (m/s) | 4.13 |
| Wind speed standard deviation(%) | 3.89 |
| Most and least wind speed(m/s) | 3.2 / 4.8 |
| Weibull probability density function coefficients | a= 1.87 and b= 5.5 |

### 2.4.2 *Solar Arrays*

Power generation through solar arrays is intensively influenced by solar irradiance and its value could be calculated by the equation 5 as follows:

$$P_{spv}(t) = G_B(t) \times \eta_1(t) \times A_{pv} \times P_{pv} \times \eta_{c-spv}$$

$$\eta_1 = P\left[q\frac{G_B}{G_{B,O}} + \left(\frac{G_B}{G_{B,O}}\right)^m\right].\left[1 + r\frac{\theta_{cell}}{\theta_{cell,o}} + s.\frac{AM}{AM_O} + \left(\frac{AM}{AM_O}\right)^U\right] \quad (5)$$

Constant values existing in the relations above are illustrated in the tables 3 and 4 [20].

**Table 3.** Constant Values for Calculating Solar Panel's Efficiency

| technology | P | q | r | s | m | U |
|---|---|---|---|---|---|---|
| monocrystalline | 23.6 | -0.2983 | -0.093 | -0.979 | 0.019 | 0.98 |
| polycristalline | 15.3 | -0.1770 | -0.097 | -0.899 | 0.079 | 0.93 |
| amorghous | 36.2 | -0.7576 | -0.097 | -0.143 | 0.66 | 1.03 |

**Table 4.** Constant Values for Standard Test Condition

| $G_{B,O}(\frac{w}{m^2})$ | $AM_O$ | $\theta_{cell,o}$ |
|---|---|---|
| 100 | 1.5 | 25 |

Beta probability density function is presented in the equation 6 [24].

$$P^{sr}(ci_t) = \frac{\Gamma(k+c)}{\Gamma(k)\Gamma(c)}(ci_t)^{k-1}(1-ci_t)^{c-1}$$

$$k = \frac{(\mu^{sr})^2(1-\mu^{sr})}{(\sigma^{sr})^2} - \mu^{sr} \quad (6)$$

$$c = \frac{k(1-\mu^{sr})}{\mu^{sr}}$$

Related constant values are presented in table 5.

**Table 5.** Solar Irradiance Data

| | |
|---|---|
| Average solar irradiance(kWh/m$^2$/d) | 5.588 |
| Standard deviation | 2.78 |
| Most/Least solar irradiance | 8.301 / 2.2698 |
| Beta probability density function coefficients | c=4.7 and k=1.01 |

### 2.4.3 *Batteries*

Batteries used in this study are SURRETTE-6CS25P with a nominal voltage of 6V and nominal capacity of 1156Ah [25]. The following equations are employed to calculate the number of batteries required in each design [17].

$$N_{batt}(P_{PV}, N_{wind}) = \text{roundup}\left\{\frac{S_{req}}{\eta \times S_{batt}}\right\} \tag{7}$$

$$S_{req}(P_{PV}, N_{wind}) = \sum_{t=1}^{maxt}[P_{PV}(t) + P_{wind}(t) - P_{demand}(t)]\,\Delta t - \sum_{t=1}^{mint}[P_{PV}(t) + P_{wind}(t) - P_{demand}(t)]\,\Delta t \tag{8}$$

Roundup method was used in order that the of battery number end up in an integer.

### *2.4.4 Diesel Generator*

Nominal capacity of the generator is 10 kW and it consumes natural gas fuel. Following equation is used to calculate the amount of fuel that the generator consumes [26]:

$$F = (F' \times Y_{GEN}) + (F'' \times P_{GEN}) \tag{9}$$

It is assumed that the number of generator has no limitations and could compensate for all the lacking power to feed the load.

### *2.4.5 Research Constraints*

The purpose is to minimize the objective function, considering the research constraints such as technical constraints, power balance constraints.

**Power Balance Constraints**

$$\sum_{t=1}^{T}(P_{PV}(t) \times \eta_1 \times \Delta t) + \sum_{t=1}^{T}(P_{wind}(t) \times \eta_2 \times \Delta t) + \sum_{t=1}^{T}\left(\frac{P_{disch}^{batt}(t)}{\eta_3} \times \Delta t\right) + \sum_{t=1}^{T}(P_{grid}^{in}(t) \times \Delta t) + \sum_{t=1}^{T}(P_{DG}(t)) \geq \sum_{t=1}^{T}(P_{charge}^{batt}(t) \times \eta_3 \times \Delta t) + \sum_{t=1}^{T}(P_{demand}(t) \times \Delta t) + \sum_{t=1}^{T}(P_{grid}^{out}(t) \times \Delta t) \tag{10}$$

**Generator's Technical Constraints**

$$P_{DG}^{min} \leq P_{DG}(t) \leq P_{DG}^{max} \tag{11}$$

## 3. Problem Optimization Formulas

The purpose of this study is to plan (determine the optimal size of installed equipment) for a hybrid microgrid with minimum costs on the condition that problem constraints are met. Therefore, objective function is composed of all the costs related to the microgrid. The objective function of this study is explained according to equations 12 and 13.

$$\text{Min } j = \sum_{t=1}^{T} C_{total} \tag{12}$$

$$C_{total} = C_{CPT} + C_{MNT} \tag{13}$$

$C_{CPT}$ and $C_{MNT}$are calculated according to the equations 14 and 15; It should be noted that total annual maintenance costs is calculated assuming a year equal to 365 day and total capital costs is presented in annual form using capital recovery factor (equation 16).

$$C_{CPT} = \frac{A}{P}[C_{PV} \times P_{PV} + C_{WT} \times N_{WT} + C_{DG} \times P_{DG} + C_{BATT} \times N_{BATT} + C_{CON} \times P_{CON}] \tag{14}$$

$$C_{MNT} = \left[C_{MNT}^{WT} \times \sum_{t=1}^{24} P_{wind}(t) \times \Delta t + C_{MNT}^{PV} \times \sum_{t=1}^{24} P_{PV}(t) \times \Delta t + C_{MNT}^{DG} \times \sum_{t=1}^{24} P_{DG}(t) \times \Delta t + C_{MNT}^{BATT} \times \sum_{t=1}^{24} P_{BATT}^{t} \times \Delta t + C_{MNT}^{CON} \times \sum_{t=1}^{24} P_{CON}^{t} \times \Delta t + \text{Cemission} \times \sum_{t=1}^{24} P_{DG}(t) \times \Delta t\right] \times 365 \tag{15}$$

$$\frac{A}{P} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{16}$$

In equation 16, i is interest rates. The item Cemission shows the emission penalty resulted from diesel generator power generation per kWh. The equation17 is used for calculating carbon emission costs [26].

$$\text{Cemission} = \frac{C_{CO2} \times M_{CO2}}{1000} \tag{17}$$

## 4. Simulation

This article uses GAMS software application to solve the problem. As it said, in order to consider the uncertainties, first considering Weibull and Beta probability density function for wind speed and sun irradiation, the probability of related power of various wind speed and sun irradiation were calculated in MATLAB software; later the problem was solved through GAMS in accordance to the following algorithms. Eventually, the results would be compared to those of HOMER ENERGY.

### *4-1- Findings resulted from GAMS Software*

Due to the nature of the problem, simulations are carried out using MINLP method in GAMS. Results for the microgrid under study in both probabilistic and deterministic modes are hereafter presented in table 6 through table 10.

In order to evaluate the results, simulation has been carried out in the following cases and the obtained results are compared:

1. Applying limitations and in the deterministic mode;
2. Without limitations and in the deterministic mode;
3. Applying limitations and in the probabilistic mode;
4. Without limitations and in the probabilistic mode;
5. Renewable energy based microgrid without limitations and in the probabilistic mode.

Here limitations refer to the restrictions applied on generator output and imported power from main grid.

In the restricted mode i.e. first and third case, it is presumed that it is not possible to purchase more than 450 kW power from the main gird. Likewise, there is a restriction of power generation for the generator with a maximum of 200 kW. On the other hand, while no limitation applied, it is supposed that each generation unit can supply the load by itself. In this mode, maximum power generation of each generating unit is supposed to be more than the amount of total microgrid load.

Tables 6 present the results of optimized planning in the deterministic mode while the amount of generator output power and imported power from main grid are limited. This consists of three wind turbines with 35 kW of AC output power in addition to a set of 36 batteries. The exchange of power is practiced exclusively in one way, i.e. power is only purchased from the grid but not sold to it. In such a mode, the upstream grid takes the role of the major supplier of the electric consumption load to the microgrid.

Tables 7 and 9 show that in the second and 4th case, the most economical design is the one which the load is supplied by the generator and the grid due to the high amount of capital costs of renewable energy based unit. But this design surely emits more pollutants, compared to the previous one as this mode merely utilizes fossil fuel.

Emission is decreased in first case due to the use of renewable energy resources. In this mode, it is observed that employing renewable energy resources, installing more solar energy panels and wind turbines lead to higher initial capital costs along with more maintenance expenditures.

**Table 6.** Results for the first case

| | |
|---|---|
| No. of WT | 3 |
| PV (kW) | 55 |
| GENERATOR | 100 |
| BATTERY | 36 |
| GRID IN (kW) | 430 |
| GRID OUT | 0 |
| Total capital costs: $496017 | |
| Total maintenance costs :170547 $/yr | |
| Net present cost: $2816000 | |

**Table 7.** Results for the second case

| | |
|---|---|
| No. of WT | 0 |
| PV (kW) | 0 |
| GENERATOR | 175 |
| BATTERY | 33 |
| GRID IN (kW) | 435 |
| GRID OUT (kW) | 0 |
| Total capital costs: $98500 | |
| Total maintenance costs :190000$/yr | |
| Net present cost: $2487590 | |

**Table 8.** Results for the third case

| | |
|---|---|
| No. of WT | 8 |
| PV (kW) | 70 |
| GENERATOR | 90 |
| BATTERY | 38 |
| GRID IN (kW) | 300 |
| GRID OUT | 0 |
| Total capital costs: $611758 | |
| Total maintenance costs :140010 $/yr | |
| Net present cost: $3045254 | |

**Table 9.** Results for the 4th case

| | |
|---|---|
| No. of WT | 7 |
| PV (kW) | 60 |
| GENERATOR | 200 |
| BATTERY | 45 |
| GRID IN (kW) | 350 |
| GRID OUT (kW) | 0 |
| Total capital costs: $690315 | |
| Total maintenance costs: 220515 $/yr | |
| Net present cost: $3187957 | |

**Table 10.** Results for the 5th case

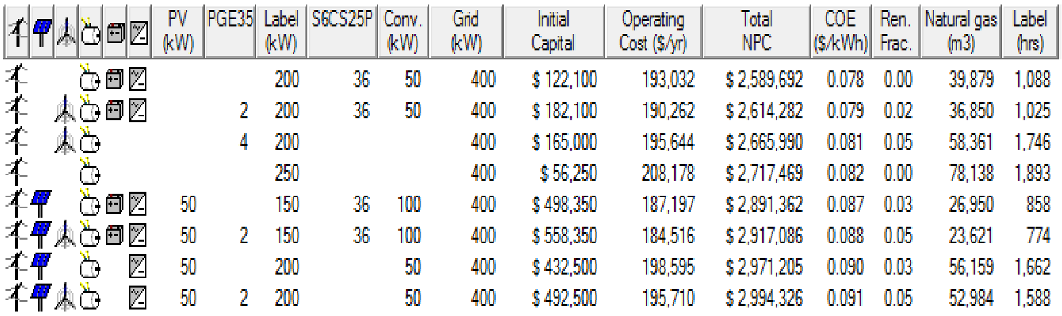
| | |
|---|---|
| No. of WT | 48 |
| PV (kW) | 350 |
| BATTERY | 156 |
| GRID IN | 400 |
| GRID OUT | 0 |
| Total capital costs: $4249100 | |
| Total maintenance costs :158357 $/yr | |
| Net present cost: $2900124 | |

In tables 8 and 9, the findings resulted from the optimized planning in the probabilistic mode will be illustrated. Here, as it said we made use of Weibull and Beta probability density functions so as to demonstrate the power generation uncertainties existing in the wind and solar energy resources. Similar to deterministic mode, the total costs increased while limitations applied. Moreover, maintenance costs increase owing to more use of fossil fuels for the generator.

The last case is related to the situation in which among DG units, only renewable energy base units used to supplying the load. Also no limitation applied on exchanged power with upstream grid. This case simulated in probabilistic mode. In this mode, the amount of initial capital costs increases, but the maintenance costs decrease because the fuel costs of the generator are omitted.

### *4.2. Findings resulted from Optimized Planning in HOMER ENERGY Software*

Here the results of planning through HOMER software are introduced and at the end, the results will be compared together. Fig. 6 shows the results for the under study system. The most three economical design are presented in table 11.



| PV (kW) | PGE35 | Label (kW) | S6CS25P | Conv. (kW) | Grid (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Natural gas (m3) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 200 | 36 | 50 | 400 | $ 122,100 | 193,032 | $ 2,589,692 | 0.078 | 0.00 | 39,879 | 1,088 |
| | 2 | 200 | 36 | 50 | 400 | $ 182,100 | 190,262 | $ 2,614,282 | 0.079 | 0.02 | 36,850 | 1,025 |
| | 4 | 200 | | | 400 | $ 165,000 | 195,644 | $ 2,665,990 | 0.081 | 0.05 | 58,361 | 1,746 |
| | | 250 | | | 400 | $ 56,250 | 208,178 | $ 2,717,469 | 0.082 | 0.00 | 78,138 | 1,893 |
| 50 | | 150 | 36 | 100 | 400 | $ 498,350 | 187,197 | $ 2,891,362 | 0.087 | 0.03 | 26,950 | 858 |
| 50 | 2 | 150 | 36 | 100 | 400 | $ 558,350 | 184,516 | $ 2,917,086 | 0.088 | 0.05 | 23,621 | 774 |
| 50 | | 200 | | 50 | 400 | $ 432,500 | 198,595 | $ 2,971,205 | 0.090 | 0.03 | 56,159 | 1,662 |
| 50 | 2 | 200 | | 50 | 400 | $ 492,500 | 195,710 | $ 2,994,326 | 0.091 | 0.05 | 52,984 | 1,588 |

**Fig.6.** Results of Optimized Planning in HOMER

Having analyzed the results, we come to the conclusion that the first design is economically optimal and would impose the least costs; however it stands more pollutant than the second design.

**Table 11**. Results of Three Major Simulation Designs in HOMER in the First Mode

| Designs | Design 1 | Design 2 | Design 3 |
|---|---|---|---|
| Photovoltaic Cells | - | - | - |
| Wind Turbine | - | 2 | 4 |
| Diesel Generator(kW) | 200 | 200 | 200 |
| Batteries | 36 | 36 | - |
| Converter(kW) | 50 | 50 | - |
| Total Net Costs($) | 2589692 | 2614282 | 2665990 |
| Energy Price(/kWh$) | 0.078 | 0.079 | 0.081 |

Our purpose here is to consider both economic as well as environmental objectives; consequently, we opt for the second design as it is a more proper design regarding both costs and emission. The selected design supplies 95 percent of the consumption electric load coming from the grid, 2 percent by the wind turbine and three remaining percent through the generator. The amount of emission in the selected design equals 1618185, which is less than those of other designs. The following figure (Fig. 7) illustrates the generation value of each unit in the selected design. Black parts indicate the power generated by the generator; the green color is related to wind turbine and meanwhile, the blue-gray color shows the amount of electric power purchased from the grid.

As wind speed and solar irradiance are behave stochastically, it would be highly critical to take this fact into consideration as an integral part of optimized planning studies. It could be concluded that the results of an optimized planning for consumption load supply through GAMS software outstands more reliable than other methods as it takes the uncertainties into account.

## 6. Conclusions

The main purpose of this study was to determine the optimized size of equipment needed for designing a grid-connected hybrid microgrid with the aim partly supplying consumption power in Razi University in Kermanshah, Iran. Hybrid power generating systems use various energy resources such as wind and solar energies which work together in a collaborative effort. Sun and wind are two of the most prevalent resources of renewable energy. As far as any region needs a special combined system with certain number of components favorable to the local climatic conditions and fitted to electric load it demands, it would be imperative to conduct the feasibility studies of every region exclusively. Size and number of components have to be chosen in a way that the energy is supplied with the least costs and pollution. The selected design would be able to supply 630 kW power at peak hour and 7.1 MWh consumption energy needed in Rzai University. If the selected design (including wind turbine, internal combustion generator, batteries and converters) is operated, the electric load can be supplied with the least costs and the minimum emissions.

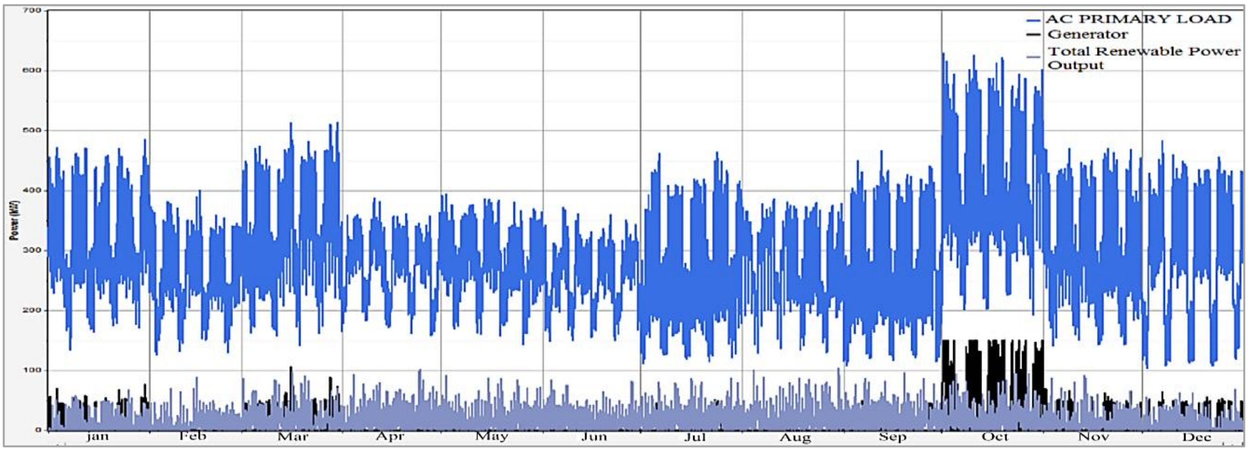


**Fig 7.**The Share of each Equipment Item in Supplying the Load

| | | | |
|---|---|---|---|
| k,c | Beta probability function coefficients | $N_{wind}$ | Number of wind turbines |
| $S_{req}$ | Required power for storage | F' | Fuel curve intercept coefficient by (L/hr/kW) and equal to 0.08 |
| $S_{batt}$ | Nominal capacity of each battery | $a, b$ | Weibull probability function coefficients |
| $P_{PV}(t)$ | PV generation within t time | $v_t$ | Wind speed within t time |
| $\sigma^{sr}$ | Solar irradiance standard deviation | $\sigma^{ws}$ | Wind speed standard deviation |
| $\mu^{sr}$ | Solar irradiance median value | $\mu^{ws}$ | Wind speed median value |
| $\theta_{cell}$ | Temperature in real environment | $v_{ci}$ | Wind turbine lower cut-off speed |
| $\theta_{cell,o}$ | Temperature standard condition | $v_{co}$ | Wind turbine upper cut-off speed |
| $N_{batt}$ | Number of batteries | $V_r$ | Nominal wind speed |
| $P_{PV}$ | Required size of solar panels | $P_r^{wd}$ | Nominal wind turbine power |
| $P_{wind}(t)$ | Wind turbine generation within t time | $G_B(t)$ | Solar irradiance value on the panels at each time step (kW/m$^2$)within t time |
| $P_{demand}(t)$ | Load consumption within time t | $G_{B,O}$ | Solar irradiance value on the panels at each time step in standard experimental conditions(kW/m$^2$) |
| F'' | Slope of generator fuel curve by (L/hr/kW) and equal to 0.25 | $C_{MNT}^{BATT}$ | Batteries maintenance cost (as per one battery) |
| $P_{GEN}$ | Generator's output power at each time step | $C_{MNT}^{CON}$ | Converters' maintenance cost |
| $Y_{GEN}$ | Generator's nominal capacity and equal to 10 kW | $C_{CO2}$ | Pollution emission penalty |
| $\eta_1$ | PV efficiency and equal to 0.9 | $C_F$ | Fuel price in us dollar |
| $\eta_2$ | Wind turbine efficiency and equal to 0.9 | $A_{pv}$ | The area of PV panel and equal to 1.22m$^2$ |
| $C_{PV}$ | Initial cost of PV system ($/kW) | $ci_t$ | Transparency index of PV panel |
| $C_{WT}$ | Initial cost of each wind turbine($) | $\eta_{C-PV}(t)$ | Loss value of solar panels |

| | | | |
|---|---|---|---|
| $C_{DG}$ | Initial cost of diesel generator($/kW) | $A_M$ | Air density in real environment condition |
| $C_{BATT}$ | Initial cost of each battery($) | $A_{M,O}$ | Air density in standard condition |
| $C_{CON}$ | Initial cost of converter | $P_{WT}$ | Power generated by wind unit |
| $P_{DG}$ | Diesel generator capacity(kW) | $P_{grid}^{in}$ | Power purchased from the grid at each time step |
| $P_{CON}$ | Converter capacity(kW) | $P_{grid}^{out}$ | Power Sold to the Grid at each Time Step |
| $P_{DG}(t)$ | Generated power of diesel generator within t time (kW) | $P_{disch}^{batt}$ | Discharged power of the batteries |
| $C_{CPT}$ | Total initial capital cost | $\eta_3$ | Batteries' efficiency coefficient and equal to 0.85 |
| $C_{MNT}$ | Total maintenance cost | $M_{CO2}$ | Produced $CO^2$ (kg) |
| $C_{MNT}^{WT}$ | Wind turbines' maintenance cost (as per one wind turbine) | $P_{demand}$ | Load demand at each time Step |
| $C_{MNT}^{PV}$ | PVs' maintenance cost (as per each kW of generated power) | $P_{charge}^{batt}$ | Charged power of batteries |
| $C_{MNT}^{DG}$ | Diesel generator's maintenance cost (as per each kW of generated power) | $P_{dlmax}$ | Maximum Interruptible Load (10 percent of the Load) |

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