# Design and Simulation of a Hybrid Micro-Grid for BishehVillage

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**Abstract-**In this paper, a gird-connected hybrid energy system for Bisheh village of environs the Khorramabad will be designed optimally with regard to the potential of wind and solar energy in this area. With annual average solar radiation of 5.521kWh/m$^2$/day and annual average wind speed of 4.2 m/s, this village has a great potential of utilization of the renewable sources. Simulation has been done byHOMER ENERGY which is developed by the U.S. National Renewable Energy Laboratory.In order to achieve the most optimal design for power generation, the simulation of the mentioned micro-grid will be made for 6 different scenarios.With comparing the results of these simulations, it is indicate that the best scenario is designing the hybrid micro-grid connected to the main grid.Also sensitivity analysis will be perform based on various parameters such as interest rate, the price of purchasing power from the main grid, fuel price, wind speed, solar radiation, and air temperature and acquired results will compare together.By analyzing the results, we found that, the use of renewable resources is more economical than diesel generators when the fuel price is close to the world prices or interest rate is high. In addition, production of power will be more economical than purchasing power from the main grid by using diesel generators with renewable resources when price of purchasing power from the main grid is similar to the world prices, so under these conditions, micro-grid doesn't have tend to purchasing power from the main grid.

**Keywords-** Distributed generation resources, Micro-grid, Optimal planning,Sensitivity analysis.

## 1. Introduction

The political instability in the Middle East is increasing the concerns over the security of supplies which is being felt in form of high prices. In order to mitigate greenhouse gas emissions, many types of renewable energy technologies will all require widespread deployment. The environmental concerns coupled with the volatility of the oil market (and so economic reasons) have led to a great attention to development of renewable energy based power generation by means of distributed generation (DG) units.Developing the DG units technology and utilizing them in a distribution network has created a new structure called micro-grid.Factually, the Micro-grid is an active distribution networkin which there are consuming loads, as well as power generation units.

Nevertheless, the most important problem in application of distributed generations based on renewable energies is treating uncertainties and discontinuities as well as their difficult compatibility with load variations. One way to overcome this problem is to commit gas generators during low power generation of renewable energy resources which led to formation of hybrid energy systems.

Planning of micro-grids is to determinethe capacity and types of DG units optimally considering economical and technical issues in orderto supply the predicted long-term and mid-term loads. In this way planning of a micro-grid is an optimization problem which is considered as one of research priority in literature.

C.Bhattacharyya [1] investigatesdifferent methodologies electrification to off-grid areas (independent of the main power grid) and express strengths and weaknesses of each approach. O.Erdinc, et al. [2] introduced available softwares and optimization techniques of micro-grid planning. The authors presentedoptimization techniques such as genetic algorithms (GA), Particle Swarm Optimization (PSO) algorithm, simulated annealing (SA), linear programming, neural networks, etc. and softwares such as Hybrid Optimization Model for Electric Renewables resources (HOMER), the Hybrid Power System Simulation Model (HYBRID2), etc.

Perera et al. [3] havepresented a new optimization method that is a combination of multi-criterion decision making (MCDM) technique and multi-objective optimization on a standalone renewable energy system. Using the HOMER Energy software, Silva et al. [4] designed a hybrid energy system, including photovoltaic panel, fuel cell and battery, to supply the electrical energy of a protected area, located in the state of Tocantins, Brazil. Also, in this paper, a comparative analysis of the costs of the hybrid system with different combinations after optimization with HOMER Energy is made. Using the multi-objective optimization, Perera et al. [5] designed a photovoltaic-wind-battery hybrid system, for optimal supply of an AC load. They presented the Levelized Energy Cost (LEC), the Initial Capital Cost (ICC) and the Green House Gas (GHG) emissions as objective functions. TaghipourRezvan et al. [6] proposed a model to determine the optimum capacity of combined heat and power (CHP) and absorbing chillers of the Distributed Generation (DG) system of Taleghani hospital (in Tehran, Iran). They have proposed an optimization technique based on the genetic algorithm for determining the optimum capacity of renewable energy generation units for buildings. The proposed model is determined by considering the uncertainty and assuming the fluctuation of the load. Castaneda et al. [7] presented a different sizing method and control strategy for the suitable management of a stand-alone hybrid system including photovoltaic (PV), fuel cell (FC), electrolyzer and hydrogen storage tank. By simulating this system, they showed that the combination of photovoltaic, fuel cells, electrolyzer and hydrogen tank provides the load with high reliability.ZongWoo Geem [8] is applied Branch-and-Bound (B&B) and Generalized Reduced Gradient (GRG) methods. In his research, the integer variables are selected by the B&B method, and then the GRG method is applied to find the optimal solution. Considering that the cost of wind turbines is cheaper than solar panels, the optimization algorithm, selects only wind turbines. Hakimiet al. [9] are presented an intelligent method to plan a hybrid power system such that supplying a village load in Kahnooj with a population of 2000 located in south-east Iran. Micro-grid components under study include fuel cells, wind turbines, electrolyzer, DC/AC converters, reactor and hydrogen tank. Results show that wind/fuel cell hybrid systemsare the most suitable solution. SandeepLalet al. [10] presented an optimization and sensitivity analysis of a PV/wind/diesel hybrid micro-grid system using the HOMER Energy software in the Fiji islands. This study indicates the most feasible system comprising of a 200 kW PV, 170 kW diesel generators and battery for the chosen location. GetachewBekeleet al. [11] investigated the possibility of load supplement in various areas by a wind-PV-hydro turbine hybrid system. They performed sensitivity analysis on the price of diesel and the initial investment and replacement cost of PV. The results of sensitivity analysis indicates efficient and practical different combinations with different levels of the penetration of renewable resources and NPC. ShafiqurRehman et al. [12] designed a hybrid micro-grid for a village in Saudi Arabia. The results of simulations show hybrid diesel/wind/PV is the most economical system for load supplement. In this paper the results of the sensitivity analysis show that each 0.5 m/s reduction of wind speed will result in 5% reduction in wind turbine production also with reduction of wind speed, cost of energy (COE) and the penetration of renewable resources (RF) will decrease linearly.

Saheb-Koussaet et al in [13] designed a hybrid system consisting of a wind turbine and PV for a desert environment which connected to the main grid. The determination of optimal size of each system's equipment also achieved by HOMEREnergysoftware. They showed that pollution extremely decrease and penetration percentage of renewable energies extremely increase when wind speed increase by sensitivity analysis on wind speed and solar radiation.

In this article, in order to choose the best equipment to supply Bisheh village's consuming load, a simulation with five wind turbine types is analyzed; incidentally, in order to achieve the best technical, economical design state of the micro-grid for the mentioned village, micro-grid is simulated in 6 different scenarios and the results are compared with each other. Also, sensitivity analysis performed to investigate the effects of problem uncertainties such as fuel price, interest rate, climate condition, purchasing price, etc.;that these matters with this expensiveness and accuracy are not found in the works considering micro-grid planning.

## 2. Methodology

### *2.1. Description of the Bisheh village*

Bisheh village, with the geographical location of 48 degrees and 52 minutes east longitude and 33 degrees and 20 minutes north latitude is located in the Sepyddasht area of the Khorramabad city and at an altitude of 1200 meters above sea level. This village has an average temperature of 15.2°C throughout the year and annual average wind speed of 4.2 m/s. Itconsists of 138 domestic consumers, 7 trade consumers and10 public consumersincluding schools, water and sewer room, health home, communication center, television satellite mast, police station, Post Bank,Basij base, train station and promenade to accommodate thetourists. Data on air temperature, solar radiation and wind speed of Bishehvillage are obtained through NASA's website [14]. This data is related to year 2014asshown in the Table 1.5% change compared to the annual average value is considered for each of the variables in order to do the sensitivity analysis to assume their uncertainty.

**Table 1.**The value of the atmospheric parameters of Bisheh village in 2014.

| Month | Wind Speed(m/s) | Air temperature(°C) | Clearness Index | Average Radiation(kWh/m$^2$/day) |
|---|---|---|---|---|
| January | 3.5 | 1.8 | 0.535 | 2.872 |
| February | 3.8 | 3.0 | 0.534 | 3.558 |
| March | 4.2 | 7.1 | 0.573 | 4.822 |
| April | 4.5 | 13.9 | 0.606 | 6.093 |
| May | 4.7 | 20.1 | 0.657 | 7.298 |
| June | 4.8 | 25.7 | 0.721 | 8.294 |
| July | 4.8 | 28.8 | 0.694 | 7.823 |
| August | 4.6 | 28.1 | 0.721 | 7.507 |
| September | 4.3 | 23.5 | 0.744 | 6.655 |
| October | 4.0 | 17.3 | 0.685 | 4.907 |
| November | 3.6 | 9.4 | 0.637 | 3.595 |
| December | 3.5 | 3.8 | 0.548 | 2.718 |

*2.2. HOMER Energy software input data*

*2.2.1. Load profile*

For doing careful planning, it is required thattheconsuming load be predictedwith the consideration of annual load growth.To do so, Bisheh village's consuming loads for 5 years areobtained from the Khorramabadelectricity distribution company[15].The results are shown in Table 2.

**Table 2.**Bisheh village's electricity consumption from 2010 to 2014 years [15].

| Year | Consumption (kW) |
|---|---|
| 2010 | 517328 |
| 2011 | 465701.04 |
| 2012 | 391075.08 |
| 2013 | 424864.28 |
| 2014 | 398090.704 |

Using the data in Table 2 and the regression analysis for consuming loads between 2010 to 2014years, the village's loads in 2015 with R2=0.87 would be equal to 440,000 kW.

In order to obtain accurate load prediction, micro-grid's consuming electricity are not considered identical for all days of the week, but the value of electricity consumption for working days and holidays are calculated individually. Considering the hourly data of the predicted load for 12 months of the year, the average annual consumption value is equal to 1228 kWh/d and the peak of load consumption is 146 kW. 5% random variability is considered for daily and hourly load.

Bisheh village's load consumption in a typical winter dayin 2015 is assumed as follows:

The total daily electricity consumption of the domestic consumers and trade consumers are about 5 kW and 3 kW, respectively. The total daily electricity consumption of the public consumers including health home, Basij base, communication center, school, television satellite mast, Post Bank, police station, water and sewer room, train station and promenade to accommodate the tourists is about 16 kW, 2 kW, 25 kW, 3 kW,2.5 kW, 11 kW, 7 kW, 78 kW, 110 kW, 25 kW, respectively. Furthermore, the village has 130 street light bulbs of which 36 numbers of these are 125 W, 26 are 23 W and 70 numbers are 70 W. Fig. 1 depicts the average daily load of Bisheh village for the year of 2015.

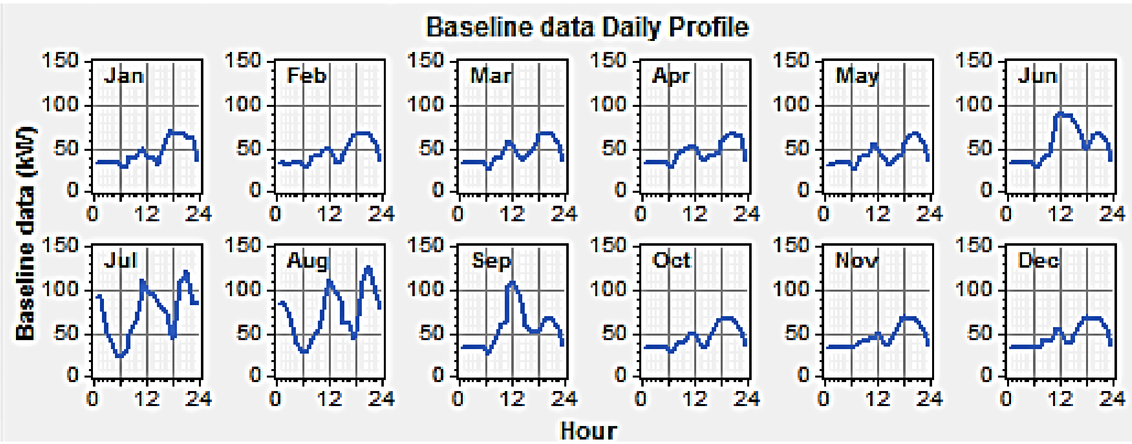



**Fig.1.**Average daily load of Bishehvillage for the year 2015.

*2.2.2. Economic inputs*

In this micro-grid, interest rate of 25%, the micro-grid fixed capital cost of $400, and project lifetime of 25 years are assumed, and for performing the sensitivity analysis the interest rate is assumed 6% once. The diesel generator's fuel price is 0.2 $/m$^3$ and to investigate the effect of actualizing the fuel price on the micro-grid it is assumed at0.45 $/m$^3$.

In this study, the social costs relating to environmental polluter emissions in the energy sector are considered. In Table 3, the cost for different greenhouse gases in terms of dollars per ton are given.

**Table 3.** Social costs of energy sector breakdown pollutant gases in terms of dollars per ton[16].

| Kind of gas | $NO_x$ | $SO_2$ | CO | SPM | $CO_2$ | $CH_4$ |
|---|---|---|---|---|---|---|
| The amount of cost | 1203.78 | 3661.5 | 376.18 | 8627.1 | 20.06 | 421.32 |

*2.2.3.Micro-grid's constraints*

Maximum annual capacity shortage of 5%, the minimum renewable fraction of 10%, hourly load of 10%, solar power output of 25% and wind power output of 50% are considered as operating reserve. The power exchange limit of the micro-grid with main grid in order to buy or sell power is assumed 150 kW.

*2.3. Description of system equipment*

In the studied micro-grid, we assume different components such as wind turbines, PV systems, energy storage systems. The utilized battery is the Surrette 6CS25P with nominal voltage of 6V, nominal capacity of 1156 Ah, nominal power of 6.94 kWh and operating lifetime of 9645 kWh.

In the HOMER Energy software, it is possible to select the type of wind turbine. The easiest method to determine the best kind of wind turbine is using a graph that shows the power output of the wind turbine at different wind speeds. But necessarily producing high power at low wind speeds, does not lead to reduced micro-grid costs. Since one of the most important goals of optimal planning is reducing micro-grid costs in an systems life time, 5 kinds of wind turbines producing more power at low wind speeds are selected to determine the best type of wind turbines; and simulation is done at the micro-grid's comparison state between connecting to the main grid and isolating of the main grid.

According to the results from the simulation of the micro-grid with different turbines given in Table 4, it is defined that the Enercon E33 turbine with a nominal power of 330 kW is the most suitable option, compared to the other turbines. This turbine has a tower with a height of 50 meters.

**Table 4.**Resultant economic parameters of the simulation of micro-grid whit the various turbines.

| Turbine name | Initial capital cost ($) | Operating cost ($/yr) | NPC ($) | COE ($/kWh) | Breakeven grid extension distance (km) |
|---|---|---|---|---|---|
| Fuhrländer 250 | 232400 | 50342 | 433006 | 0.243 | 29.5 |
| Enercon E33 | 273400 | 39199 | 429603 | 0.241 | 29.1 |
| GE 1.5sl | 798400 | 20927 | 881791 | 0.495 | 81.4 |
| Vestas V82 | 865000 | 25564 | 966869 | 0.546 | 91.3 |
| WES 30 | 229400 | 61952 | 476270 | 0.267 | 34.5 |

The initial capital costs, replacement costs, maintenance costs, lifetime and search space considered for any of the componentsused in the micro-grid are given in Table 5.

**Table 5.** Characteristics of components used in designing of the optimal micro-grid.

| Component name | Initial capital cost ($) | Replacement cost ($) | O&M cost ($/yr) | Lifetime | Search space |
|---|---|---|---|---|---|
| Wind Turbine | 165000 | 41250 | 3300$/yr | 25 yr | 0, 1, 2, 3, 4 |
| Photovoltaic panel 1 kW | 1600 | 1600 | 20$/yr | 25 yr | 0, 50, 100, 150kW |
| Battery 6 V | 300 | 180 | 0.00 | 9645kWh | 0, 12, 24, 36, 48, 60 |

| | | | | | |
|---|---|---|---|---|---|
| Converter5 kW | 1600 | 1600 | 0 | 25 yr | 0, 5, 15, 30, 50, 70, 105kW |
| Diesel generator50 kW | 39600 | 39000 | 0.05$/hr | 40000 hr | 0, 50, 100, 150 kW |

### *2.4. Main grid*

When the micro-grid is connected to the main grid, it can exchange the power. So, the micro-grid can purchase its required power from the main grid if its local units are not able to supply the micro-grid's loads or if purchasing the power from the main grid is more economical. Also, if the generating power of local units is more than its loads, the micro-grid can sell its surplus power to the main grid. The prices of exchange power with the main grid are presented in Table 6. The starting and ending hours of different periods of electricity consumption for the mentioned area are shown in Fig. 2.

To perform the sensitivity analysis on price of purchasing power from the main grid, this rate is assumed 0.17 $/kWh having been the average electricity price of OECD countries in 2012.

**Table 6.** The prices ofexchange power with the main grid[17].

| Consumption time | Purchase ratefrom the main grid (Power Price)($/kWh) | Sale rate to main grid (Sellback Rate) ($/kWh) |
|---|---|---|
| Off peak | 0.023 | 0.111 |
| Normal | 0.031 | 0.111 |
| Peak | 0.049 | 0.111 |

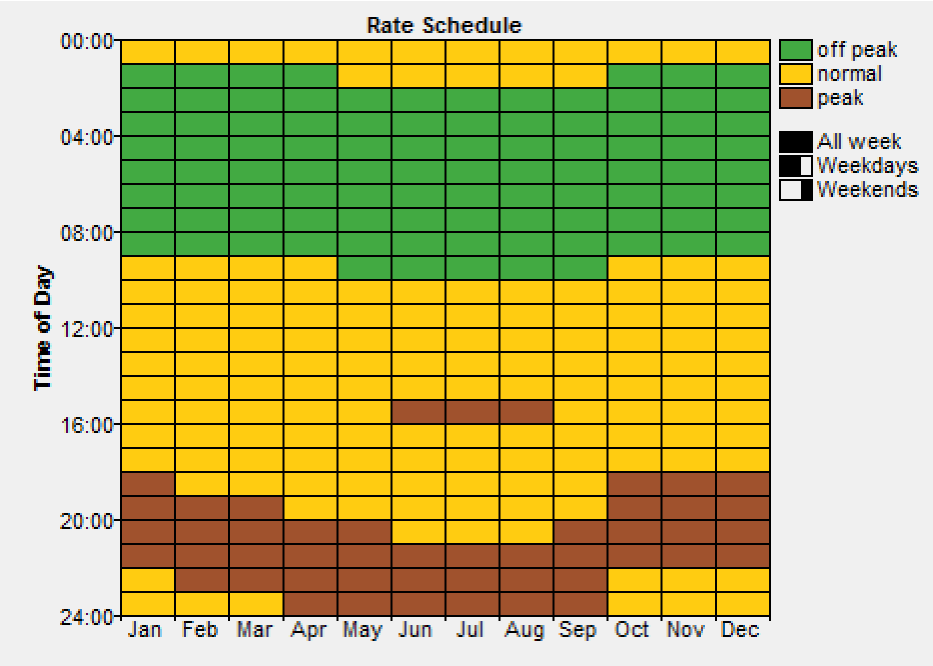



**Fig.2.** Starting and Ending times of different periods of power consumption.

### *2.5.Determining the bestscenario for micro-grid designing*

In order to achieve the most optimal design for power generation, the simulation of thementionedmicro-grid is made for 6 different scenarios and for each of themthe sensitivity analysis is performed on parameters such as interest rates, electricity purchasing pricefrom the main grid, and fuel price. Different modes of the sensitivity analysis are presented in Table 7. The 6 scenarios are as follows:

1) Micro-grid based on renewable resourcesisolated from the main grid

2) Micro-grid based on renewable resources connected to the main grid

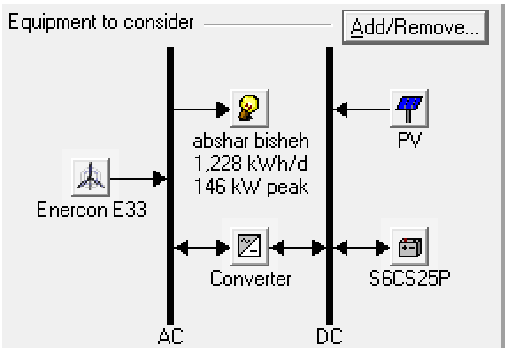
3) Micro-grid based on diesel generator isolated from the main grid

4) Micro-grid based on diesel generatorconnected to the main grid

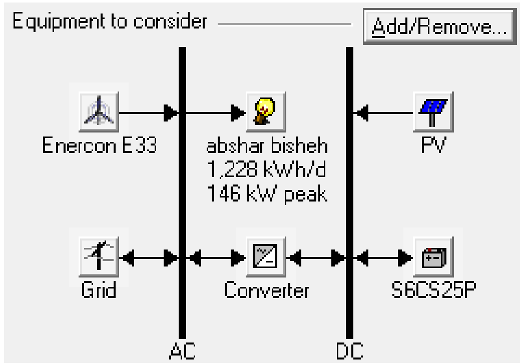
5) Hybrid micro-grid isolated from the main grid

6) Hybrid micro-grid connected to the main grid

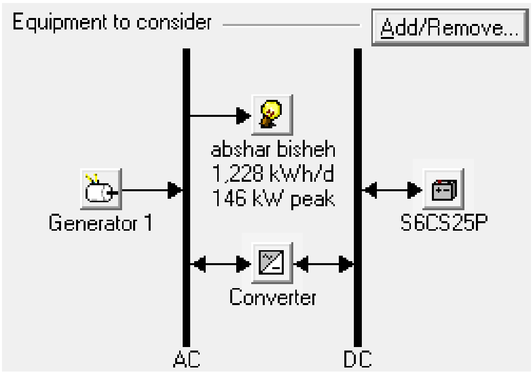
The overall diagrams of the above scenarios are shown in the Fig. 3.



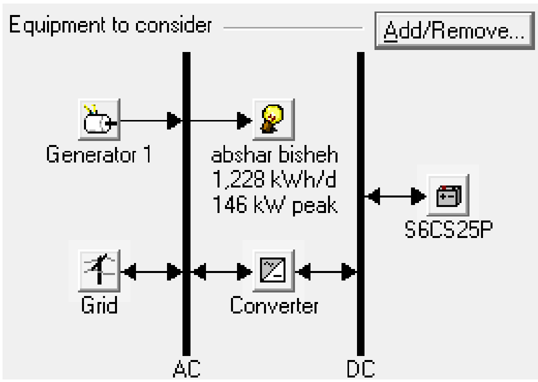

a)The overall diagram of the first scenario



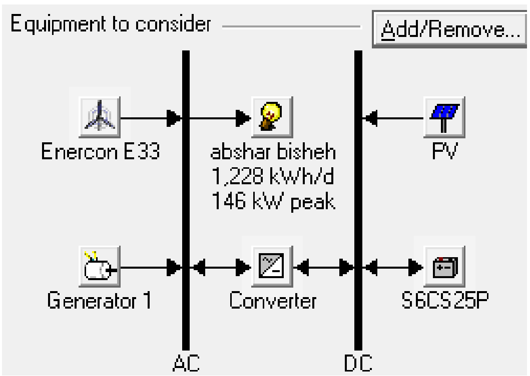

b)The overall diagram of the second scenario



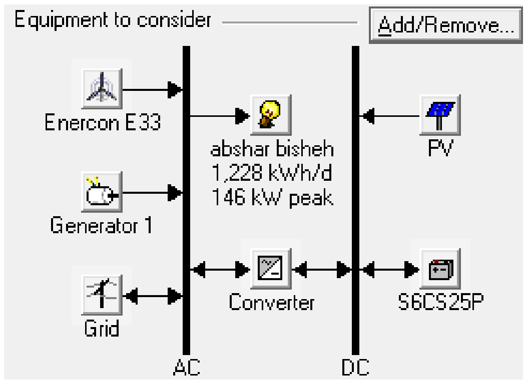

c)The overall diagram of the third scenario




d)The overall diagram of the fourth scenario




e)The overall diagram of the fifth scenario




f)The overall diagram of the sixth scenario

**Fig. 3.** Diagram of the mentioned micro-grid for 6 considered scenarios.

**Table 7.** Different cases of sensitivity analysis for simulation 6 scenarios.

| Case | Interest rates (%) | Purchasing rate from the main grid (Power Price)($/kWh) | Fuel price ($/m$^3$) |
|---|---|---|---|
| 1$^{st}$case | 25 | Present time prices | 0.2 |
| 2$^{nd}$ case | 25 | 0.17 | 0.2 |
| 3$^{rd}$ case | 25 | 0.17 | 0.45 |

| | | | |
|---|---|---|---|
| 4th case | 6 | Present time prices | 0.2 |
| 5thcase | 6 | 0.17 | 0.2 |
| 6th case | 6 | 0.17 | 0.45 |

The simulation results are shown in the Tables 8, 9, 10, 11, 12, and 13.

Regarding the results, it is indicated that in the second, fourth and fifth cases, the best plan is related to the micro-grid based on renewable resources connected to the main grid and in the third, fourth and sixth cases, the best plan is related to hybrid micro-grid connected to the main grid, and only in the first case, corresponding to the current state of Iran's economy, the fourth micro-grid, the micro-grid based on diesel generator connected to the main grid, is known as the best plan. Assuming that generating power from renewable resources depends on the data such as wind speed, solar radiation and air temperature, all having uncertainties, and if the amount of the data reaches a lower level, renewable resources will not be able to supply the micro-grid's loads alone and the shortage of the micro-grid’s power must be purchased from the main grid. With respect to the fact that generating power from diesel generator will be more economical than purchasing it from the main grid if electricity is sold to the micro-grid based on the world price, we conclude that designing the hybrid micro-grid, using renewable resources and diesel generator simultaneously, is more optimal for long-term planning is proposed.

**Table 8.**Results of simulation 6 scenarios in the first case.

| System's specifications | 1stscenario | 2ndscenario | 3rdscenario | 4thscenario | 5thscenario | 6thscenario |
|---|---|---|---|---|---|---|
| Initial capital cost ($) | 644800 | 90000 | 79600 | 400 | 274000 | 90000 |
| Operating cost ($/yr) | 10131 | 22595 | 72446 | 25646 | 39052 | 22605 |
| Total NPC($) | 685171 | 180039 | 368368 | 102598 | 429618 | 180080 |
| COE ($/kWh) | 0.393 | 0.101 | 0.209 | 0.057 | 0.241 | 0.101 |
| Renewable fraction (%) | 1 | 0.17 | 0 | 0 | 0.56 | 0.17 |
| Capacity shortage | 0.05 | 0 | 0.02 | 0 | 0 | 0 |

**Table 9.**Results of simulation 6 scenarios in the second case.

| System's specifications | 1stscenario | 2ndscenario | 3rdscenario | 4thscenario | 5thscenario | 6thscenario |
|---|---|---|---|---|---|---|
| Initial capital cost ($) | - | 495400 | - | 400 | - | 205000 |
| Operating cost ($/yr) | - | -64299 | - | 87082 | - | 19538 |
| Total NPC($) | - | 239176 | - | 347410 | - | 282857 |
| COE ($/kWh) | - | 0.065 | - | 0.195 | - | 0.122 |
| Renewable fraction (%) | - | 0.96 | - | 0 | - | 0.53 |
| Capacity shortage | - | 0 | - | 0 | - | 0 |

**Table 10.**Results of simulation 6 scenarios in the third case.

| System's specifications | 1stscenario | 2ndscenario | 3rdscenario | 4thscenario | 5thscenario | 6thscenario |
|---|---|---|---|---|---|---|
| Initial capital cost ($) | - | - | 79600 | 400 | 396400 | 330400 |
| Operating cost ($/yr) | - | - | 117858 | 87082 | 25402 | -11110 |
| Total NPC($) | - | - | 549250 | 347410 | 497624 | 286129 |
| COE ($/kWh) | - | - | 0.311 | 0.195 | 0.281 | 0.103 |
| Renewable fraction (%) | - | - | 0 | 0 | 0.84 | 0.88 |
| Capacity shortage | - | - | 0.02 | 0 | 0.03 | 0 |

**Table 11.**Results of simulation 6 scenarios in the fourth case.

| System's specifications | 1stscenario | 2ndscenario | 3rdscenario | 4thscenario | 5thscenario | 6thscenario |
|---|---|---|---|---|---|---|
| Initial capital cost ($) | 644800 | 844400 | 79600 | 400 | 407200 | 660400 |
| Operating cost ($/yr) | 10855 | -116450 | 75493 | 25646 | 17295 | -75752 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total NPC($) | 783559 | -644217 | 1044659 | 328247 | 628294 | -307960 |
| COE ($/kWh) | 0.14 | 0.041 | 0.184 | 0.057 | 0.111 | 0.022 |
| Renewable fraction (%) | 1 | 0.99 | 0 | 0 | 0.85 | 0.98 |
| Capacity shortage | 0.05 | 0 | 0.02 | 0 | 0.03 | 0 |

**Table 12.**Results of simulation 6 scenarios in the fifth case.

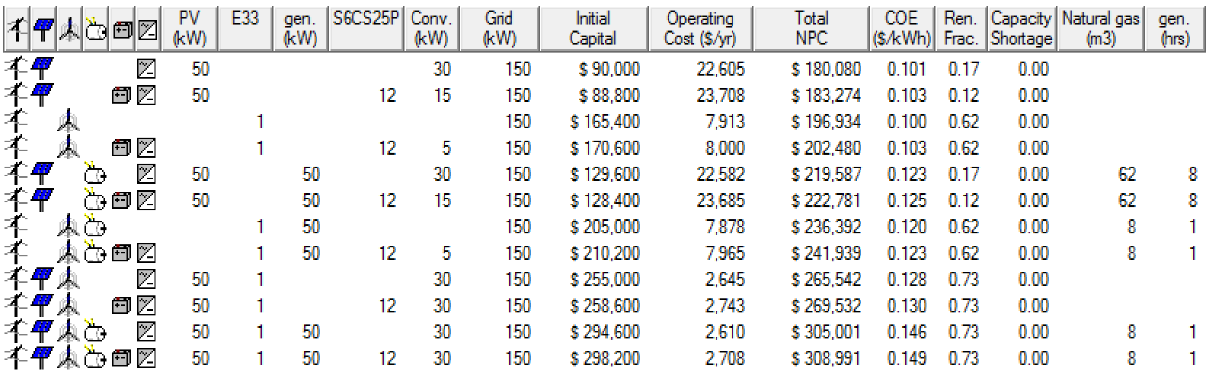
| System's specifications | 1stscenario | 2ndscenario | 3rdscenario | 4thscenario | 5thscenario | 6thscenario |
|---|---|---|---|---|---|---|
| Initial capital cost ($) | - | 844400 | - | 79600 | - | 750000 |
| Operating cost ($/yr) | - | -114311 | - | 71546 | - | -79402 |
| Total NPC($) | - | -616876 | - | 994198 | - | -265022 |
| COE ($/kWh) | - | 0.04 | - | 0.174 | - | 0.018 |
| Renewable fraction (%) | - | 0.99 | - | 0 | - | 0.98 |
| Capacity shortage | - | 0 | - | 0 | - | 0 |

**Table 13.**Results of simulation 6 scenarios in the sixth case.

| System's specifications | 1stscenario | 2ndscenario | 3rdscenario | 4thscenario | 5thscenario | 6thscenario |
|---|---|---|---|---|---|---|
| Initial capital cost ($) | - | - | 79600 | 400 | 418000 | 750000 |
| Operating cost ($/yr) | - | - | 120885 | 87082 | 22840 | -79402 |
| Total NPC($) | - | - | 1624919 | 1113594 | 709972 | -265022 |
| COE ($/kWh) | - | - | 0.287 | 0.194 | 0.125 | 0.018 |
| Renewable fraction (%) | - | - | 0 | 0 | 0.86 | 0.98 |
| Capacity shortage | - | - | 0.02 | 0 | 0.03 | 0 |

## 3. Results of hybrid micro-grid planning in grid connected mode

After the completion of simulating the grid connected hybrid micro-grid, the most optimal configuration is proposed by the HOMER Energy software including a 50 kW PV system and a 30 kW converter, as shown in Fig. 4. For this configuration, initial capital cost of $90000, operating costs of 22605 $/yr, total Net Present Cost (NPC) of $180080, final Cost of Energy (COE) of 0.101 $/kWh and renewable penetration of 0.17% are considered. In this configuration, all micro-grid loads are supplied; therefore, the annual capacity shortage is zero. Net Present Cost (NPC) of each component of the optimal configuration is shown in Table 14.



| PV (kW) | E33 | gen. (kW) | S6CS25P | Conv. (kW) | Grid (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage | Natural gas (m3) | gen. (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | | | | 30 | 150 | $ 90,000 | 22,605 | $ 180,080 | 0.101 | 0.17 | 0.00 | | |
| 50 | | | 12 | 15 | 150 | $ 88,800 | 23,708 | $ 183,274 | 0.103 | 0.12 | 0.00 | | |
| | 1 | | | | 150 | $ 165,400 | 7,913 | $ 196,934 | 0.100 | 0.62 | 0.00 | | |
| | 1 | | 12 | 5 | 150 | $ 170,600 | 8,000 | $ 202,480 | 0.103 | 0.62 | 0.00 | | |
| 50 | | 50 | | 30 | 150 | $ 129,600 | 22,582 | $ 219,587 | 0.123 | 0.17 | 0.00 | 62 | 8 |
| 50 | | 50 | 12 | 15 | 150 | $ 128,400 | 23,685 | $ 222,781 | 0.125 | 0.12 | 0.00 | 62 | 8 |
| | 1 | 50 | | | 150 | $ 205,000 | 7,878 | $ 236,392 | 0.120 | 0.62 | 0.00 | 8 | 1 |
| | 1 | 50 | 12 | 5 | 150 | $ 210,200 | 7,965 | $ 241,939 | 0.123 | 0.62 | 0.00 | 8 | 1 |
| 50 | 1 | | | 30 | 150 | $ 255,000 | 2,645 | $ 265,542 | 0.128 | 0.73 | 0.00 | | |
| 50 | 1 | | 12 | 30 | 150 | $ 258,600 | 2,743 | $ 269,532 | 0.130 | 0.73 | 0.00 | | |
| 50 | 1 | 50 | | 30 | 150 | $ 294,600 | 2,610 | $ 305,001 | 0.146 | 0.73 | 0.00 | 8 | 1 |
| 50 | 1 | 50 | 12 | 30 | 150 | $ 298,200 | 2,708 | $ 308,991 | 0.149 | 0.73 | 0.00 | 8 | 1 |

**Fig.4.**Resultsof simulating thesixth micro-grid in the first case.

**Table 14.**Net Present Cost (NPC) of each component in the first case.

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| PV | 80000 | 0 | 3985 | 0 | 0 | 83985 |
| Grid | 0 | 0 | 49919 | 0 | 0 | 49919 |
| Converter | 9600 | 0 | 0 | 0 | 0 | 9600 |
| Other | 400 | 0 | 36177 | 0 | 0 | 36577 |
| System | 90000 | 0 | 90080 | 0 | 0 | 180080 |

Also, the total system's cash flow and the annual cost of each component of the optimal configuration is shown in Fig.5and Table 15, respectively.

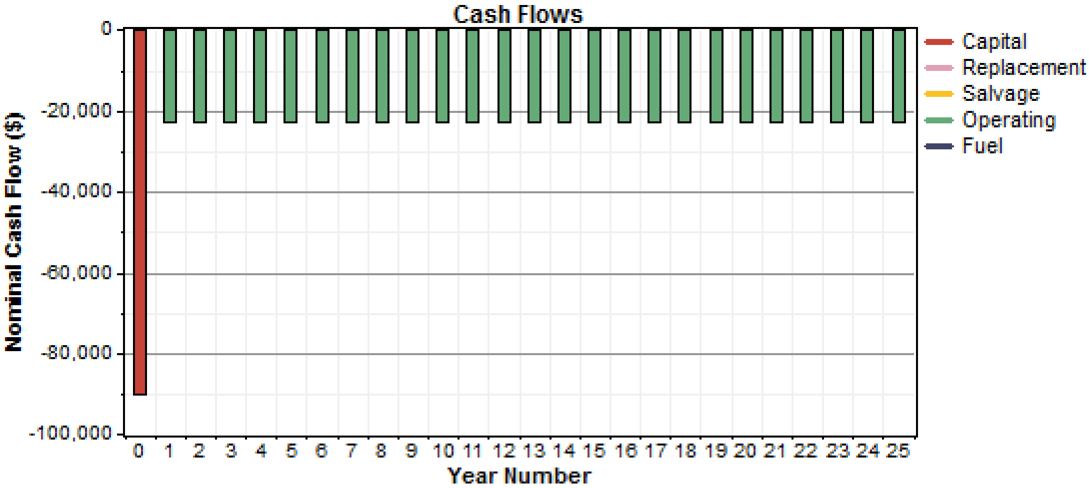



**Fig.5.**The system's cash flow inthe first case.

**Table 15.**Annual cost of each component in the first case.

| Component | Capital ($/yr) | Replacement ($/yr) | O&M ($/yr) | Fuel ($/yr) | Salvage ($/yr) | Total ($/yr) |
|---|---|---|---|---|---|---|
| PV | 20076 | 0 | 1000 | 0 | 0 | 21076 |
| Grid | 0 | 0 | 12527 | 0 | 0 | 12527 |
| Converter | 2409 | 0 | 0 | 0 | 0 | 2409 |
| Other | 100 | 0 | 9078 | 0 | 0 | 9179 |
| System | 22585 | 0 | 22605 | 0 | 0 | 45191 |

In the obtained optimal configuration, photovoltaic panels and the main grid generate the powers of 85515 kWh/yr and 374137kWh/yr, theshare of whichis 19% and 81% of the total micro-grid's productivity, respectively; that 448220 kWh/yrof this generated power supply the micro-grid's load and 279 kWh/yr is sold to the main grid.

In Fig.6,the diagram of the average value of electric energygenerationover one year is shown. In this case, the surplus amount of the system generates 2891 kWh/yrat 0.63%, and also the unmet electric load is zero.

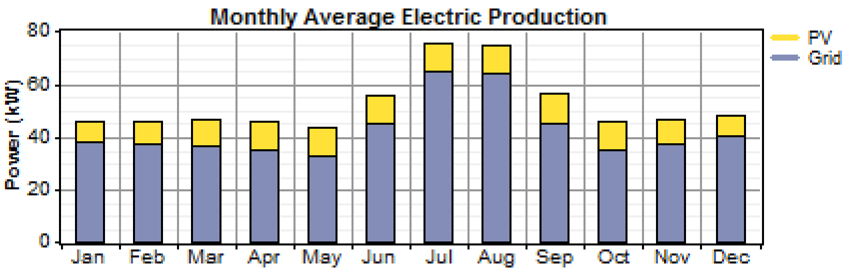



**Fig.6.**The diagram of the average quantity of electric energy generation.

In this system, the nominal capacity of photovoltaic panels is 50 kW and their mean output power is 9.76 kW which isequal to 234 kWh/d. These panels have been used for 4382hr/yr and their final Cost of Energy (COE) generation is 0.246 $/kWh. The output power for the photovoltaic panels over 24 hours is shown in Fig.7.

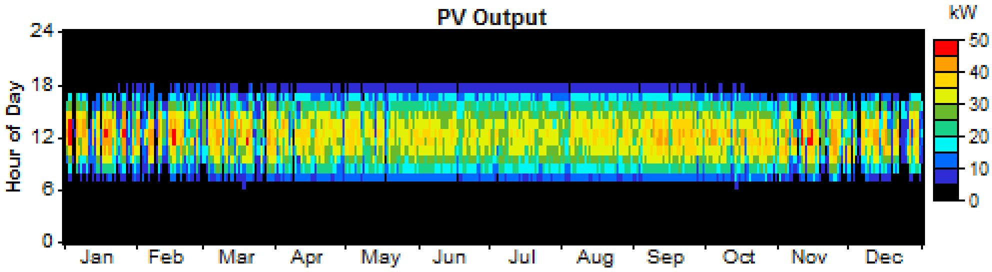



**Fig. 7.** Power output of photovoltaic panels.

In this case, the nominal capacity of both inverter and rectifier is 30 kW. The mean output power of the inverter andthe rectifier is 8.5 kW and zero, respectively. Maximum output powerof the inverter and the rectifier is 30 kW and zero, respectively. The inverterhas been used 4382 hours overone year and the rectifier has not been used. The input energy to the inverter is 82624 kWh/yr and output energy is 74362 kWh/yr.The loss of inverter is 8263 kWh/yrFig.8 shows the inverter's output power over one year.

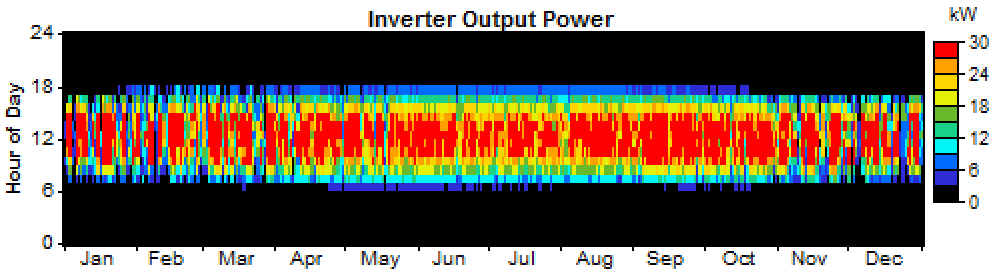



**Fig.8.** Inverter's output power.

The amount of pollutant gas emissions of this system is shown in the Table16.

**Table 16.**The amount of pollutant gas emissions ofthe optimal configuration in the first case.

| Pollutant gas | Emissions (kg/yr) |
|---|---|
| $CO_2$ | 236278 |
| CO | 0 |
| UHC | 0 |
| PM | 0 |
| $SO_2$ | 1024 |
| $NO_x$ | 501 |

The amount of pollutant gas emissions of other possible configurations that can supply the micro-grid's load is given in Table 17.

The HOMER Energy software ranks possible configurations based on total Net Present Cost (NPC); i.e., the configuration with the lowest NPC is placed at the top row. Carefully looking at Table 17, we see that some configurations located lower than the optimum configuration have totally lower pollution, as the configuration at row 9 which has the lowest pollution, including 50 kW photovoltaic panels and a wind turbine. In this configuration, the NPC is $265542. The share of photovoltaic panels, wind turbines and the main grid is 16%, 58% and 26% of the total micro-grid's productivity, respectively; that 86% of the total power production supplies the micro-grid's local loads.

If both criteria of low NPC and value of pollution are considered, the most optimal configuration is one located at row 3 consisting of only one wind turbine and related NPC is $196934. In this configuration, the wind turbine and the main grid have a power generation of 308307 kWh/yr and 186845 kWh/yr, the share of which is 62% and 38% of the total power generation, respectively; and 448220 kWh/yr of this generated power is 91% of the total power production supplies local loads and the other 9% is sold to the main grid.

## 4. Sensitivity analysis

For sensitivity analysis on some of the system input data and considering Iran's grid conditions, different cases are considered which listed in Table 18.

**Table 17.**The amount of pollutant gasemissions of possible configurations in the first case.

| Row | Grid (kW) | PV (kW) | E33 | Gen. (kW) | 6CS25P | Conv. (kW) | NPC ($) | $CO_2$ (kg/yr) | $SO_2$ (kg/yr) | $NO_x$ (kg/yr) | Total emissions (kg/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 150 | 50 | 0 | 0 | 0 | 30 | 180080 | 236278 | 1024 | 501 | 237803 |
| 2 | 150 | 50 | 0 | 0 | 12 | 15 | 183274 | 248432 | 1077 | 527 | 250036 |
| 3 | 150 | 0 | 1 | 0 | 0 | 0 | 196934 | 88425 | 383 | 187 | 88995 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 150 | 0 | 1 | 0 | 12 | 5 | 202480 | 88636 | 384 | 188 | 89208 |
| 5 | 150 | 50 | 0 | 50 | 0 | 30 | 219587 | 236322 | 1024 | 504 | 237850 |
| 6 | 150 | 50 | 0 | 50 | 12 | 15 | 222781 | 248475 | 1077 | 530 | 250082 |
| 7 | 150 | 0 | 1 | 50 | 0 | 0 | 236392 | 88430 | 383 | 188 | 89001 |
| 8 | 150 | 0 | 1 | 50 | 12 | 5 | 241939 | 88641 | 384 | 188 | 89213 |
| 9 | 150 | 50 | 1 | 0 | 0 | 30 | 265542 | 41428 | 180 | 88 | 41696 |
| 10 | 150 | 50 | 1 | 0 | 12 | 30 | 269532 | 41464 | 180 | 88 | 41732 |
| 11 | 150 | 50 | 1 | 50 | 0 | 30 | 305001 | 41433 | 180 | 88 | 41701 |
| 12 | 150 | 50 | 1 | 50 | 12 | 30 | 308991 | 41469 | 180 | 88 | 41737 |

**Table 18.**Different cases of hybrid micro-grid analysis when connected to the main grid.

| Case | Interest rates (%) | Purchasing rate from the main grid (Power price) ($/ kWh) | Fuel price ($/m$^3$) | Average wind speed (m/s) | Average radiation (kWh/m$^2$/d) | Air temperature (C°) |
|---|---|---|---|---|---|---|
| 1stcase | 25 | Present time prices | 0.2 | 4.19 | 5.52 | 15.3 |
| 2ndcase | 25 | Present time prices | 0.2 | 4.4 | 5.8 | 16.1 |
| 3rdcase | 25 | Present time prices | 0.2 | 3.98 | 5.24 | 14.5 |
| 4thcase | 6 | Present time prices | 0.2 | 4.19 | 5.52 | 15.3 |
| 5thcase | 25 | Present time prices | 0.45 | 4.19 | 5.52 | 15.3 |
| 6thcase | 25 | 0.17 | 0.2 | 4.19 | 5.52 | 15.3 |
| 7stcase | 25 | 0.17 | 0.45 | 4.19 | 5.52 | 15.3 |
| 8ndcase | 6 | 0.17 | 0.2 | 4.19 | 5.52 | 15.3 |

Actually, the first case is related to the present conditions of Iran.The first to third cases have an interest rate assumed to be 25%, power purchase price from the main grid equivalent to the current prices which is listed in Table 6 and fuel prices equivalent to delivered gas current prices of $0.2 to the power plants are considered at the first case. Each wind speed, solar radiation and air temperature data are real data in 2014 which extracted from NASA [13]. Second case is simulated considering5% increases in scaled annual average wind speed, solar radiation and air temperature. In the third case, it is simulated considering 5% decreases in scaled annual average wind speed, solar radiation and air temperature.

In the fourth to the eighth cases, wind speed, solar radiation and air temperature data are considered as the same as real data in 2014. In the fourth case, it is simulated considering economicconditions changed and interest rate reached to 6% with the same purchasing power rate from the main grid and fuel price. In the fifth case, interest rate is considered 25%, power purchase rate equal to present prices and fuel prices equal to the world price which considering Iran is the exporter of oil and gas itself, fuel price 0.45$/m$^3$ is considered the price of the export gas. In the sixth case, interest rate and fuel price are considered according to the present conditions (interest rate of 25% and fuel price of 0.2 $/m$^3$), in this case purchasing power rate from the main grid is considered as 0.17 $/kWh which is the mean power price of countries in OECD in 2013. The seventh case is simulated with 25% interest rate and considering fuel price and power purchase rate from the main grid is 0.45$/m$^3$ and 0.17$/kWh, respectively. The eighth case is simulated with interest rate of 6%, and fuel price is 0.45$/m$^3$, at a purchasing power price of 0.17$/kWh.

*4.1.Sensitivity analysis Results*

Obtained results of these simulations are listed in Table 19.

**Table 19.**Results of sensitivity analysis.

| System's specifications | 1stcase | 2ndcase | 3rdcase | 4thcase | 5thcase | 6thcase | 7stcase | 8ndcase |
|---|---|---|---|---|---|---|---|---|
| Initial capital cost ($) | 90000 | 165400 | 90000 | 660400 | 90000 | 205000 | 330400 | 750000 |
| Operating cost ($/yr) | 22605 | 2870 | 22760 | -75752 | 22605 | 19538 | -11110 | -79402 |
| Total NPC($) | 180080 | 176835 | 180696 | -307 | 180080 | 282857 | 286129 | -265022 |
| COE ($/kWh) | 0.101 | 0.085 | 0.101 | -0.022 | 0.101 | 0.122 | 0.103 | -0.018 |
| Renewable fraction (%) | 0.17 | 0.69 | 0.16 | 0.98 | 0.17 | 0.53 | 0.88 | 0.98 |
| PV production (kWh/yr) | 85515 | - | 81374 | - | 85515 | - | - | 85515 |
| PV production (%) | 19 | - | 18 | - | 19 | - | - | 6 |
| Wind turbine production(kWh/yr) | - | 361640 | - | 1233227 | - | 308307 | 616613 | 1233227 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Wind turbine production (%) | - | 69 | - | 98 | - | 53 | 89 | 93 |
| Diesel generator production(kWh/yr) | - | - | - | - | - | 250750 | - | - |
| Diesel generator production (%) | - | - | - | - | - | 43 | - | - |
| Grid purchases (kWh/yr) | 374137 | 158874 | 376839 | 25047 | 374137 | 23993 | 79996 | 18641 |
| Grid purchases (%) | 81 | 31 | 82 | 2 | 81 | 4 | 11 | 1 |
| Grid sales (kWh/yr) | 279 | 72295 | 209 | 668117 | 279 | 134830 | 245610 | 718136 |
| Grid sales (%) | 0 | 14 | 0 | 60 | 0 | 23 | 35 | 62 |

The above results indicate that:

In the second case, considering 5% increases in wind speed, solar radiation and air temperature, initial capital costs will increase 83.77% compared to the first case which increases due to the use of wind turbines for power generation, operating cost, the Net Present Cost (NPC), the cost of energy (COE) will decrease 87.3%, 1.8%, 15.84% respectively, compared to the first case. Also in this case, the participation of renewable resources in power generation is increased 305.88%, due to better weather conditions, and especially higher wind speeds.

In the third case, considering 5% decreases in wind speed, solar radiation and air temperature, the cost of initial capital is unchanged, that is due to the use of photovoltaic panels to generate power in both cases. In this case, operating cost, and Net Present Cost (NPC) are increased 0.68% and 0.342% respectively, compared to the first case.Also in this case, the Cost of Energy (COE) didn't change, but the participation of renewable sources in generated power due to a decrease in the atmospheric parameters is decreased 5.88 % compared to the first.

In the fourth case, all the conditions are the same as the first case and only interest rate have decreased to 6%, the initial capital costs are increased 633.77%, compared to the first, it is because of the use of wind turbines for power generation.Operating cost,the Net Present Cost(NPC) and the cost of energy (COE) are decreasing 435.11%, 271.01%, 121.78% respectively, compared to the first. Also in this case, the participation of renewable sources in power generation is increased 476.47% compared to the first case, because in this case interest rate is lower than wind turbine while the use of wind turbines with the same weather conditions of the first case is economical, so wind turbineshave a greater share in power generation, as in this case, only 2% of the micro-grid consumption power from the main grid is purchased.

In the fifth case, which all of the conditions are the same as the first case and fuel price only is assumed 0.45$/m$^3$, the most optimal suggested configuration by the HOMER Energy software is the same combination of the first case, so this case is unchanged rather than the first case.

In the sixth case, all the conditions are the same as the first case and only the price purchase power from the main grid is considered at 0.17$/kWh.The initial capital cost is increased to 127.77%, compared to the first case, meaning this increase is due to the use of wind turbines for power generation.Operating cost is decreased 13.56% and Net Present Cost (NPC). The Cost of Energy (COE) is increased to 57.07% and 20.79% respectively, compared to the first case.The reason for this increase is the increasing cost of purchasing power from the main grid. Also, in this case the participation of the renewable resources in power generation are increased 211.76% compared to the first case. That's why purchasing power rate from the main grid are increased compared to the first case, with same weather conditions and fuel prices of the first case power generation from wind turbine and micro turbine are more economical than purchasing power from the main grid as in this case when 53% is supplied to the micro-grid by the wind turbine, 43% by diesel generators and only 4% of the main grid is purchased.

In the seventh case, with the same weather conditions of the first case and considering purchasing power rate from the main grid, the fuel price and interest rates are simulated 0.17$/kWh, 0.45$/m$^3$, 25% respectively, and the initial capital cost is increased to 267.11% compared to the first case.This increase is due to the use of wind turbines for power generation.Operating costs decrease to 149.14%.The Net Present Cost (NPC), and the Cost of Energy (COE) are increased to 58.88%, 1.98% respectively, compared to the first case. The reason for this increase is more expensive price of purchasing power from the main grid. Also, in this case the participation of the renewable resources in power generation has increased to 417.647% compared to the first case that the reason of this matter is more expensive price of purchasing power rate from the main grid than the first case, as in this case it was supplied 89% of the micro-grid's generated power by the wind turbine, and only 11% purchased of the main grid.

In the eighth case, with the same weather conditions of the first case considering fuel price of 0.45 $/m$^3$, the power purchase rate from the main grid of 0.17$/kWh, and interest rate of 6% simulated, the initial capital cost of 733.33% increasesunlike the first case, The reason for this increase is the use of a wind turbine and photovoltaic panel for power generation.The operating costs, the Net Present Cost (NPC) and the Cost of Energy (COE) are decreased to451.25%, 247.169%, 117.82% respectively, compared to the first case.The major reduction in the micro-grid's cost is due to lower interest rates. Also, in this case the participation of the renewable resources in power generation is increased to 476.47% compared to the first case.The reason for this is due to the more expensive price of purchasing power rate from the main grid and lower interest rate compared to the first case. In this case 93% of the micro-grid's generated power by the wind turbine, 6% by the photovoltaic panelsis supplied, and only 1% of main grid is purchased.

## 5. Conclusion

In this paper,ahybrid energy system is designed and planned for Bisheh village inKhorramabad by the HOMER Energy software. In order to high accuracy and using the most appropriate components for supplying the mentioned village's loads, the simulation was performed with five wind turbine models. Regarding the results of simulatingthese wind turbines, it was indicated that, due to the area's wind speed, the wind turbine Enercon E33 was more optimal than others. Also, in order to achieve the best state of the micro-grid (the best configuration of micro-grid components), the simulation was performed in 6 different cases. With comparing the results of these simulations, it was indicated that the best case is designing a grid connected hybrid micro-grid.

Since the time horizon of the planning problem is considered 25 years and during this time a lot of project's economic data such as the fuel price, the cost of purchasing power from the main grid, interest rate and meteorological data such as wind speed, solar radiation, air temperature may be changed,so the sensitivity analysis has been performed with regard to the 8 different cases of Table 18 and the results of the were analyzed.

By comparing the obtained results of the simulation we indicate that:

The highest initial capital cost is related to case eight, the lowest operating cost is related to case eight, the best Net Present Cost (NPC) is related to the fourth case, the lowest Cost of Energy (COE) is related to the eighth case, the maximum participation of renewable resources in supplying power are related to the fourth and eighth cases, the highest value of selling power and the highest value of purchasing power from the main grid is related to the eighth case. As it can be seen according to the above results the best case of different economic analysis for the micro-grid is the eighth and fourth cases, that interest rate equal to 6% and purchasing power price is equivalent to the world power price of $0.17.

According to the obtained results, it’s clear that until electricity price is lower than its real price (because of government subsides), it is not feasible to use renewable energy DG units in the country. This said, if electricity sold at its real price and with lower interest rates construction of micro-grid is optimal having benefits not just environmentally but also technically.

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