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Techno-Economic Analysis of Stand-Alone Hybrid Energy System for the Electrification of Iran Drilling Oil Rigs

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Abstract

This paper explores the potential of use of stand-alone hybrid wind/solar energy system in electrification of calibrating equipment of drilling oil rig in Iran. To achieve this, different hybrid energy system configurations based on calibration equipment demand are proposed. This study puts emphasis on the energy production and cost of energy from both wind turbine and photovoltaic (PV) in the hybrid system. In addition, to make conditions more realistic, the real meteorological data is used for HOMER software to perform the technical and economic analysis of the hybrid system. Results indicate that the PV array shares more electricity production than the wind turbine generator if both wind turbine and PV array are utilized in the wind/solar hybrid system. Moreover, results show that the operational cost will be reduced by the suggested hybrid system.

Keywords*: hybrid energy system, drilling oil rig, HOMER, wind turbine, solar panels*

1. Introduction

Oil is the most important energy source in world and oil drilling rigs are used for oil extraction. However, oil rig location is not permanent and changes with oil well location [1]. Iran's oil rigs are scattered in south west which is desert and in inaccessible regions such as Masjed Soleyman [2]. Generally, electrification of oil drilling equipment is done by grid [3]. However, electrification is by grid and extension of the grid requires major big investment that does not generally fit with disperse regions with medium-low energy demand [4]. As a result, several technological alternatives are being implemented, mainly diesel generators, micro-hydro-turbines, wind-power generators, photovoltaic systems or some hybrid configurations [5]. Although the use of diesel generators is widely extended throughout the world, it has high maintenance and operation cost. In addition, the environmental concerns of fossil fuels at global and local level are taken into account in recent years [6]. Hybrid power systems combine the advantages of conventional and renewable power conversion systems. Renewable power sources, in opposition to conventional power sources, offer independence from fossil fuel and hence independence from world fuel pricing while increasing sustainability of the power supply. Conventional power sources, on the other hand, are independent from environmental conditions (irradiation, wind velocity, etc.) [7]. They can assist the renewable sources in situations of deficient environmental circumstances, thereby increasing the reliability of the entire power supply system. With this objective, hybrid energy is best solution for electricity generation in remote areas such as oil drilling rigs. On drilling oil rigs in Iran, calibrating units are fed by isolated diesel generator which is supported by UPS [8]. The capacity of this generator is negligible compared with the main one, and must be separated from the main generator because the controlling units are very sensitive to changes in power [9].

The main contribution of this paper is to identify a configuration among a set of systems that meets the desired system reliability requirements with the lowest electricity unit cost for electrification of calibrating equipment of drilling oil rig in Masjed Soleyman. In this regard,

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HOMER (Hybrid Optimization of Multiple Energy Resources) software that is developed by National Renewable Energy Laboratory (NREL) was used as the simulation and optimisation tool. To perform analysis with HOMER, Different combinations of PV, batteries, and wind turbine were selected in order to identify the optimal combination of the hydrogen based system.

2. Masjed Soleyman Wind and Solar Characteristics

The availability of renewable energy is the most important factor in energy utilization. Then, economical operation and reliability are evaluated precisely. In the desired location, wind energy, solar energy and solar-thermal energy are accessible. This study is focused on wind/PV/battery to support energy demand.

2.1. Wind Speed

Hourly wind speed and solar radiation data of desired area which has been measured in a year is extracted from NASA website [9]. Table 1 portrays the average wind speed in January, which is 4.8 m/s.

Table 1. Average wind and solar radiation

Month	Air Temperature (℃)	Wind Speed (m/s)	Daily Solar Radiation (kWh/m^2/d)
January	-4.7	4.8	1.16
February	-3.9	4.8	1.91
March	1.3	4.9	2.94
April	9.9	4.5	3.99
May	16.5	4.0	5.44
June	19.8	3.8	5.46
July	22.1	3.5	5.54
August	21.8	3.5	4.87
September	16.1	3.9	3.40
October	9.2	4.5	2.13
November	1.2	4.8	1.09
December	-3.8	4.8	0.91

Table 2. Electrical consumption of oil operation units

Application	Voltage (V)
Calibrating	24 DC
Oil Refining	380 AC
Pumps	220 AC
Lighting	220 AC
Air conditioning	220 AC

Wind speed remained constant in February and reached 4.9 m/s in March. The average wind speed decreases monthly from 4.5 m/s in April to 3.5 m/s in August. However, it has upward trend from September with 3.9 m/s and reached 4.8 m/s in December. The average wind speed during a year is 4.3 m/s. It is obvious that average wind speed is higher in winter than summer. Moreover, the maximum wind speed in January is 6.5 m/s; but it is minimum in June, a bit more than 4.7 m/s. The maximum wind speed usually occurs between 11 am to 16 pm. Therefore, the wind turbine generates maximum power around afternoon and power generation of wind turbine from midnight until dawn is significantly reduced. Weibull distribution function is used to explain the wind speed in the HOMER software [10]. This function contains ”c” and ”k” parameters which are used in software to extract wind profile [11]. The Weibull coefficients for the desired location are k=1.98 and c=4.87 m/s. The Weibull curves are widely used in statistical analysis. In wind energy analysis, it is used to represent the wind speed probability density function, commonly referred to as the wind speed distribution. The Weibull distribution function is given by [12]:

$$\tilde{v} = c.\Gamma(1 + \frac{1}{k}) \tag{1}$$

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \log_e v_i}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \log_e v_i}{n}\right)^{-1} \tag{2}$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{\frac{1}{k}} \tag{3}$$

Where $\tilde{v}$ is the average wind speed, $\Gamma(1+1/k)$ is gamma function,"c" is Weibull scale parameter, "k" is the unit less Weibull wind shape parameter, v_i is a particular wind speed. The calculation of Weibull coefficient is shown in Figure 1. The green bars illustrate the wind data and red line is the best-fit Weibull. The wind speed commenced with less than 1.00% frequency, but jumped up to 9.00% frequency at 3.5 m/s. The wind speed fluctuates and start to decrease to zero after 14 m/s. Therefore, the best-fit Weibull coefficient are calculated by HOMER software in Figure 2 are k=1.98 and c=4.87 m/s.

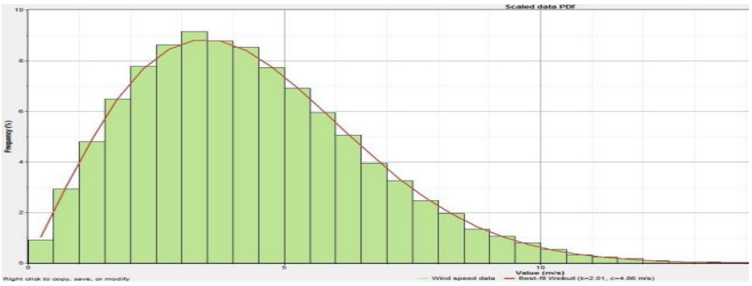


Figure 1. Weibull coefficients

2.2. Solar Radiation Ratio

Figure 2 illustrates daily radiation (bar graph) and clearness index (red line) simultaneously. The average daily radiation is a bit less than 2 kW/m2/d in January. It gradually increases from January and reached a high point of 5.54 kW/m2/d in July. However, daily solar radiation starts to decreases monthly to 0.91 kW/m2/d in December. Hence, the average daily solar radiation is slightly more than 3.24 kW/m2/d. Moreover, clearness index portrays that atmosphere is clean in January and December. The index is 1.00 for February and November, yet it is around 0.8 in March. The clearness index has gone down monthly and dropped to 0.6 in May, which shows the dirtiest atmosphere of the year. June and July are not clear months in the desired location and the index is around 0.65. The clearness index is gradually increased and reached 0.85 in October. Thus, the daily radiation is reflected by clearness index (Figure2). Because of oscillating in maximum power output of wind turbine and PV panel, the authors tried to utilize hybrid system to compensate and improve output power. System lifetime is considered as the lifetime of the solar array, which is 20 years.

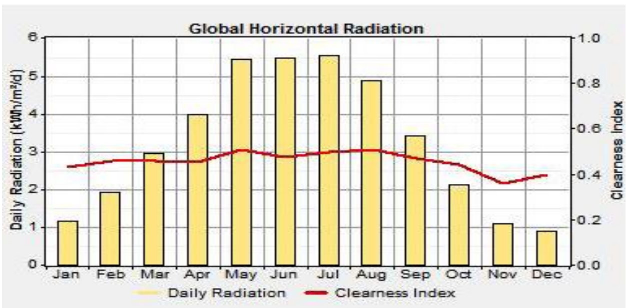


Figure 2. Profile of overall solar radiation

2.3. Oil Drilling Rig Specification

The desired location is an oil rig unit that is located at Masjed Soleyman at 32-degree North latitude, 49.3 East longitude and 867 meters above sea level. Oil rig units are built to extract oil and gas from the earth layers. Output oil from wells entered to refinery units and after passing few steps, the gas is separated from oil. Then gas and oil is sent via a pipeline to consumers or export. Oil and gas exploitation units have several power consumptions. Table 2 shows Electrical consumption of oil and gas operation units. DC power is used in oil rig units for calibrating equipment.

Table 3. Oil Rig Calibrators Consumption

Equipment	Voltage (V)	Number	Demand (W/h)
Transmitter	24	110	1440
Stablizer	24	15	432
Converter	24	30	345
Controller	24	50	576
Flow Computers	24	5	576
Gas Detector	24	100	1152
Relays and Switches	24	140	807
Other	24	-	673
Total			6001

The calibrating equipment needs constant power without fluctuating because DC power failure will cause disruption in extraction of oil process. Electrical consumption of oil drilling rig is for three applications: calibration, oil refining unit and public application. The calibrating equipment is using DC voltage of 24 V, but oil refining units are using 380 V_{AC}. Moreover, public units such as pumps, cooling and heating, AC equipment and lighting are using 220 V_{AC}.

2.4. Calibrators' Consumption of Oil Rig

Based on controlling technology, the power consumption in the oil rig unit varies. However, the voltage and current of calibration equipment does not exceed a few watts per day. The selected oil rig expenses are listed in Table 3. This equipment is used for extraction of 30,000 barrels oil per day. Transmitter, stabilizer, converter, flow computers, gas detectors, relay and switches used 24 V_{DC} voltages in calibration. The oil calibrating unit contains a maximum 140 relays and switches that consume a bit more power than 0.8 kW. However, there are only 5 flow computers and energy demand is 0.56 kW. On the other hand, the maximum power consumed by 110 transmitters is more than 1.4 kW, but the minimum power used is slightly less than 0.35 kW that is used for 30 converters. Transmitters, gas detector, relay and switching equipment exert effective power of around 1.4 kW, 1.2 kW and 0.8 kW, respectively. Combined equipment consumes close to 6 kW per day.

3. Economic Optimization of Hybrid System

This study tried to economically optimize hybrid system, increase reliability, reduce net investment, reduce greenhouse gas emission and use renewable energy in oil rig. The system cost is defined as sum of PV cost (C_{PV}), wind turbine cost (C_{WT}), battery cost (C_{BAT}) and converter cost (C_{CONV}) [13].

$$C_{SYS} = C_{PV} + C_{WT} + C_{BAT} + C_{CONV} \tag{4}$$

Cost of system components need to be deducted as:

$$C_{SYS} = N \times [C_C + C_R \times K + C_{O\&M}] \tag{5}$$

Where N is Number/size of component, C_C is Capital cost, C_R s Replacement cost, K is Number of replacement, $C_{O\&M}$ is Operation and maintenance cost.

4. Result and Discussion

The desired oil drilling rig is located onshore in a hot and windy region far from national grid; solar panels, wind turbine and battery are selected to feed the calibrating equipment. Wind turbine (BWC excel-R), solar panels (PV), battery (S6CS25P) and converter specifications are addressed in Table 4 to 6. Calibrators require DC power to control circuits and provide protection on instruments. The output power of wind turbine is a function of wind speed, while the output of solar panels is a function of sun radiation, clouds pattern, air pollution etc. Moreover, the output voltages of selected generation devices are not 24 V_{DC}. Hence, convertor between buses is used to control and regulate receiving end power and voltage. In Figure 3 is shown simulation system scheme in HOMER software.

Table 4. Battery and Convertor

Equipment	Size	Cost Capital($)	Replac($)	O&M($/yr)
Battery	1156(Ah)	833	555	15
Converter	1.5(kW)	700	700	10

Table 5. ARIA Solar Module Electrical

Peak power (W)	Output Current (A)	Output Voltage (V)	Area (cm^2)
120	4.88	24.6	84.88

Table 6. Wind Turbine Specification

Output Power (kW)	Output Voltage (V_{DC})	Wind Speed Start-up (mph)	Wind Speed Cut-in (mph)	Wind Speed Rated (mph)
7.5	48	7.5	8	31

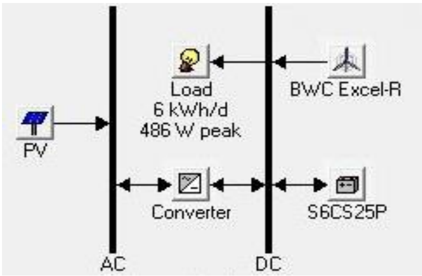


Figure 3. Scheme of proposed hybrid system

To supply oil rig calibrators' consumption, three different modes are as follows:

1. Wind turbine and battery.
2. Wind turbine, Solar panels, battery and convertor.
3. Solar panels, battery and convertor

In Table 4, size of battery is 1156 Ah, but capital and replacement cost for battery is around $830 and $550, respectively. Moreover, the operation and maintenance (O&M) expenditure is only $15/yr. Hence, convertor is chosen as 1.5 kW. This type of converter requires $700 for capital cost and $700 for replacement also. Finally, O&M cost is $10/yr. Although the converter lifetime is 15 years, it is something less than 1000 kWh for the desire battery. The PV panel is selected as Aria Solar module. The peak power for module is 120 W. Maximum output current and voltage are 4.88 A and 24.6 V, respectively which is tabulated in Table 5. The important electrical characteristics of wind turbine are reported in Table 6 on output power and voltage that are 7.5 kW and 48 V_{DC}, respectively. Furthermore, the generator of wind turbine uses a permanent magnet alternator. Two novels classified between 627 cases of simulation result are explained in this article, which is focused on economical price and finding the most reliable hybrid electrification. The economic scenario is selected based on less Net Present Cost (NPC) and minimizing initial capital cost. On the other hand, reliable system is chosen based upon atmospheric condition, selectivity and utilization of possible hybrid equipment in desire location.

4.1. Economic Hybrid System

In economic hybrid scenario, a wind turbine and five batteries are chosen. No converter is connecting the described system to calibrator equipment of drilling oil rig, although wind turbine generates DC voltage and the calibrating equipment of oil rig utilize DC voltage. Inherent fluctuation in voltage of wind turbine, depending on average wind speed per month, forced hybrid system customers to use converter between generation side and load. Moreover, wind turbine needs a rectifier with maximum generation of 7.5 kV, which is more than demand. The initial cost for reported system is slightly more than $19,150 and the system operating cost will be $555 per year. The cost of electricity generation by wind turbine and batteries is $0.938 /kWh, which is the minimum price compared to 672 other hybrid cases seen by HOMER software. Finally, total NPC for the economic system is around $26,260. The average power generation of wind turbine is shown in Figure 4. The panels will generate a bit more than 1.5 kW in January, but the generation is increased gradually in March, which is slightly more than 1.55 kW. The energy generations by wind turbine decrease from April until July, which is 1 kW to 0.7 kW. The wind turbine electricity generation slope is upward for August and September with 0.53 kW and a bit less than 0.8 kW, respectively. Wind turbine generation in March is the maximum of the solar energy generation in a year. The power generation is increased in October and reached 1.3 kW. The reduction is continued in November and December. The minimum generation is a bit less than 0.6 kW in July and August.

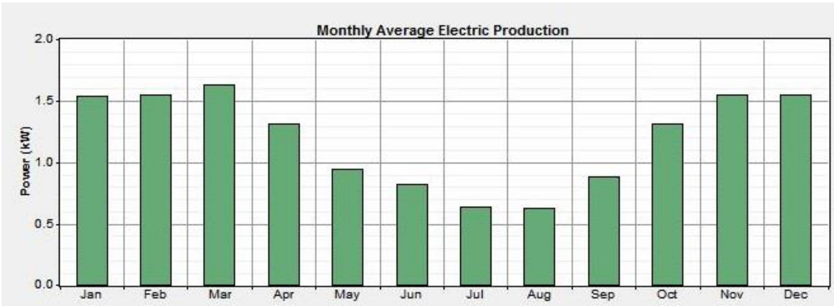


Figure 4. Average Power Production of PV modules

Therefore, the batteries are required to provide remained power for calibration equipment of oil drilling rig. Battery output power (S_{BAT}) is calculated by:

$$S_{BAT} = I_{MAX} \times V \tag{6}$$

Where I_{MAX} is maximum discharge current while V is input voltage. Battery output power in 24 V_{DC} is 27.744 kW and will be 4 times more economical for the described system. In the worst-case scenario of July and August, the wind turbine generates something less than 0.6 kW and one of the batteries can cover 5.2 kWh. Figure 6 focused on cash flow of initial cost of the economic system scenario. It is shown that wind turbine capital cost is $15,000 and it required a bit less than $5,424 in replacement cost. The salvage of wind turbine is $10 and total cost is around $19,670. The capital costs of batteries are 3 times less than wind turbine. However, the batteries replacement cost is only 50% less than wind turbine. The operating and maintenance (O&M) cost of batteries is $770 and $259 for O&M of wind turbine. The total cost of batteries salvage is $593. Wind turbines are designed to exploit the wind energy that exists at a location. Aerodynamic modelling is used to determine the optimum tower height, control systems, number of blades and blade shape. Wind turbines convert wind energy to electricity for distribution. Conventional horizontal axis turbines can be divided into three components:

1. The rotor component, which is approximately 20% of the wind turbine cost, includes the blades for converting wind energy to low speed rotational energy.
2. The generator component, which is approximately 34% of the wind turbine cost, includes the electrical generator, the control electronics, and most likely a gearbox (e.g. planetary gearbox), adjustable-speed drive or continuously variable transmission component for converting the low speed incoming rotation to high-speed rotation suitable for generating electricity.
3. The structural support component, which is approximately 15% of the wind turbine cost, includes the tower and rotor yaw mechanism

4.2. Reliable Hybrid System

In this scenario, both wind and solar energy are utilized to provide energy for calibration equipment of oil drilling. This system is highlighted in Figure 5.

				PV (kW)	XLR	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
					1	5		$ 19,165	555	$ 26,266	0.938	1.00	12.0
				1	1	2	1.5	$ 22,716	516	$ 29,318	1.048	1.00	12.0
				4		6	1.5	$ 26,048	400	$ 31,158	1.113	1.00	12.0

Figure 5. Sensitive Result of HOMER Software

The addressed system is a DC wind turbine, a PV panel and two batteries that are connected with a converter to load. The initial cost of hybrid system is slightly less than $22,700, which is 1.8 times more than proposed economical system. Operating cost is $516 per year, which is close to first scenario. Moreover, cost of electricity generation and total NPC are 1.11 times more than proposed economical scenario and reached $1.046/yr and a bit less than $29,000, respectively. Figure 6 portrays wind/PV average energy generation per year.

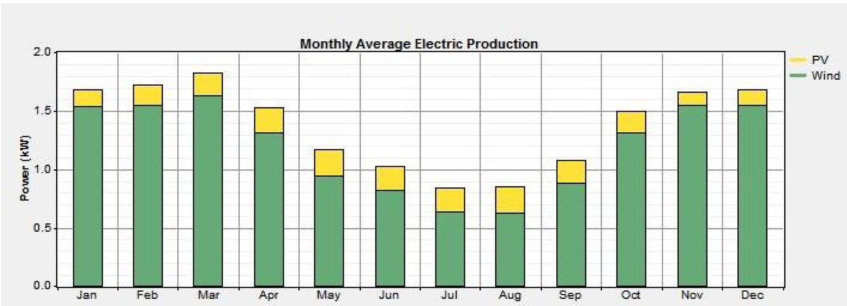
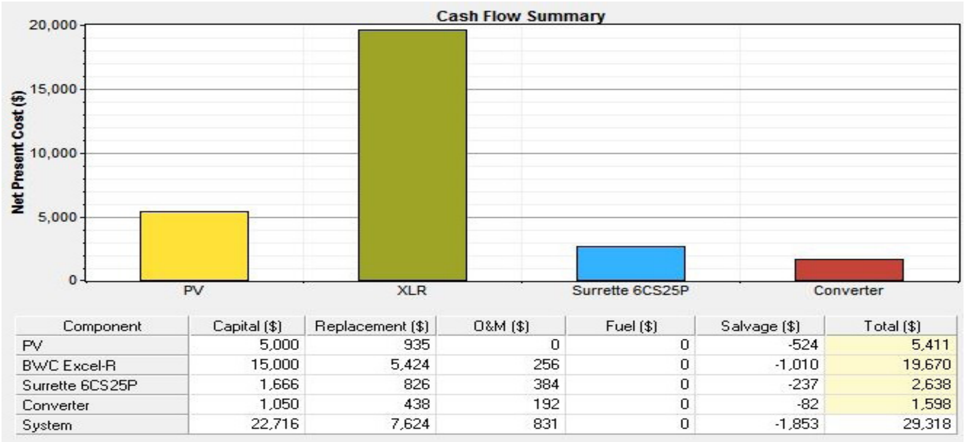


Figure 6. Average power generation of Wind/PV hybrid system

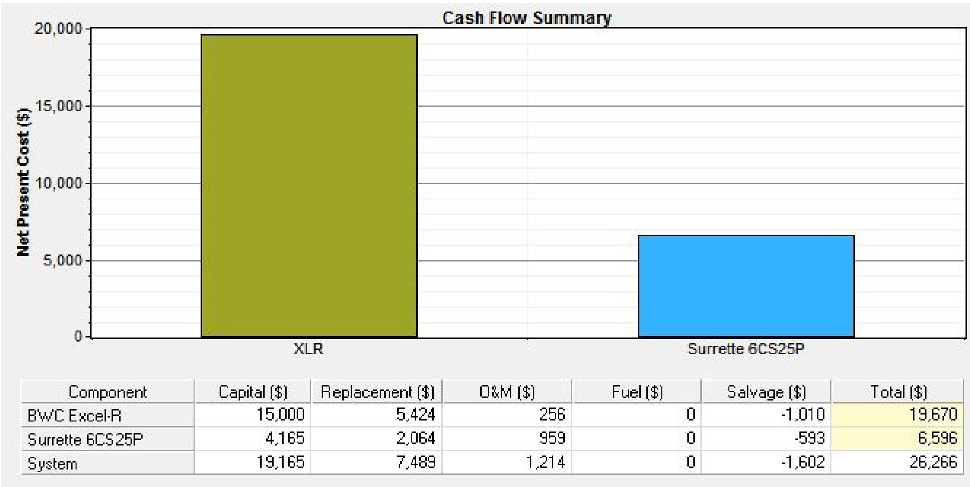
The average generation is 1.8 kW in January and jumped to maximum generation of a bit less than 2.0 kW in March. The generation is reduced to 0.9 kW until July, yet it fluctuated in August and touched 1.8 kW in November and December. Although wind power penetration is more dominant in all months, it is not constant and oscillates significantly. The average wind generation is 1.1 kW per year, reaching a peak in March with 1.7 kW. Furthermore, the minimum wind generation occurred in July with 0.65 kW. The PV panel generation in July is 0.25 kW. Hence, July is seen as the worst-case scenario of this hybrid system. Two batteries will support the proposed system by maximum output power of 55.488 kWh. In this proposed reliable hybrid system, PV penetration is 13% and wind turbine is 87%. Figure 7 illustrates the cash flow of PV/wind/ battery system. This cash flow is similar with cash flow of Figure 8.

In this scenario, the highest initial cost is $15,000 for installation of wind turbine. The replacement cost is around 3 times less than capital cost and O&M cost is $256. Therefore, the wind turbine total cost is slightly more than $19,600. However, PV panel cost must be divided by two to compare with economic scenario because only a PV is installed. Furthermore, the batteries expenditure is two times less than previous scenario, because the batteries are reduced to 2. Hence, initial capital cost for this system is $22,716 and the total cost by adding replacement O&M and salvage is more than $29,000.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	5,000	935	0	0	-524	5,411
BWC Excel-R	15,000	5,424	256	0	-1,010	19,670
Surrette 6CS25P	1,666	826	384	0	-237	2,638
Converter	1,050	438	192	0	-82	1,598
System	22,716	7,624	831	0	-1,853	29,318

Figure 7. Cash flow of Reliable scenario



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
BWC Excel-R	15,000	5,424	256	0	-1,010	19,670
Surrette 6CS25P	4,165	2,064	959	0	-593	6,596
System	19,165	7,489	1,214	0	-1,602	26,266

Figure 8. Cash flow of Economic scenario

4.3. Supplying Equipment with National Grid

In this section, it is assumed that an oil rig is supplied by national grid. For this reason, overhead line or cable is needed for electrification of oil rig equipment. Distance of oil rig to national grid, soil properties and the nearest substation determine initial cost of electrification by grid. Designer of grid is required to clarify the number of towers and insulators, type of tower and insulator and length of cable/wire. Finally, a step down transformer will reduce the voltage to desired level and a converter will convert it to DC power. The information and price of related equipment are extracted from Iran, Ministry of Power and Energy/distribution voltage. The initial cost of a normal 25 kVA transformer is around $4,000 and initial cost on national grid is $50,000/km. Now, assume that oil rig distance to national grid is "L". The system cost (C_{SYS}) is summation of national grid cost (C_{NG}) multiplied by length of national grid, transformer cost (C_T) and converter cost (C_{CON}) as follows:

$$C_{SYS} = C_{NG} \times L + C_T + C_{CONV} \quad (7)$$

The capital cost analysis has illustrated that national grid is very expensive for a period of oil drilling and even can be replaced with expensive hybrid electrification such as two wind turbines. Moreover, O&M cost is must be added to calculated value. From calculation, the largest cost is on grid construction and this grid is undesired when extraction of oil process is complete.

4.4. Single Generator and Pollution Analysis

This section discusses the comparison of electrification of oil calibrating equipment with a diesel generator instead of hybrid system. A generator is selected to provide 6 kW for calibrating equipment in series with a converter. The initial cost for an AC generator is $2,400 and operating cost expenditure is $8,600/yr. Moreover, the electricity cost by this method is $4.401/kWh. Initial cost of converter is $800 and the system total NPC is $113,137. Although the initial cost of diesel generator is less than hybrid system and grid, operating cost of diesel generator in comparison with suggested system makes customers reluctant. Furthermore, this generator has burned 8147 liters diesel to generate 6 kW electrical powers. Analysis of pollutant emission by HOMER software portrays the desired hybrid system as decreasing greenhouse gases. The rate of carbon dioxide emission for supplying calibrator's equipment of oil drilling rig (6 kW/h and 21.9 MW/h/yr) by diesel generator is portrayed in Table 7.

Table 7. Pollutant analysis

Pollutent	Emission (kg/yr)
Carbon dioxide	21,453
Carbon monoxide	53
Unburned hydrocarbon	5.87
Particular matter	3.99
Sulfur dioxide	43.1
Nitrogen oxide	472

Emission of carbon dioxide and carbon monoxide due to burning diesel are 21,453 kg/yr and 53 kg/yr respectively. The rate of other pollutant such as nitrogen oxide, sulfur dioxide, unburned hydrocarbon and particular matter are 472 kg/yr, 43.1 kg/yr, 5.87 kg/yr and 3.99 kg/yr, respectively. Providing energy for calibrating equipment of oil drilling rig by hybrid system is preventing environmental pollutant release that is around 22 tons/yr. Hybrid system utilization helps to green energy and save fossil fuel resources for future generation.

5. Conclusion

Due to increase in energy demand, resource limitation and increasing environmental pollution of fossil fuel combustion, penetration of renewable energy in generation is enhanced. This paper is focused on effective cost analysis of oil rig calibrators consumption by HOMER software. The result analysis has shown that two effective scenarios need to be described, economic scenario and reliable scenario. In economic scenario, wind turbine/ battery hybrid system is used to feed calibration equipment of oil drilling rig with $19,165 for initial cost and $0.938/kWh on cost of electricity generation. In the other case, wind/PV/battery provides energy. Although the initial cost and cost of electricity generation is increased by around 18%, hybrid energy use is more reliable. Wind generation supports PV generation between sunset and sunrise. Moreover, wind/PV/battery hybrid system dependency on battery is 50% reduced.

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