MODELLING AND PERFORMANCE ANALYSIS OF HYBRID ELECTRICAL POWER GENERATION SYSTEM FOR CONDENSATE FRACTIONATION PLANT

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Abstract:

Refinery industries are mostly installed at the rural area or distant islands considering the hazardous conditions and transportation facilities. However, more often than not these islands or rural areas have no grid connections to facilitate electrification for these kinds of plants. Even if a grid extension is possible, the availability of power cannot be guaranteed in such rural areas. In any case, disruption in power continuity is not allowed for keeping every subsystem (e.g., heating, reaction subsystem) of the refinery industries under running condition. So, having a standalone, failure free and robust power generation system is a prerequisite criterion before starting up such plants in those areas. Diesel generator is the inevitable choice to meet the demand of electricity in such situation, although the cost of running a diesel generator dependent power system to support these sophisticated plants has been quite a challenge. However, with the available modern technologies, it is possible to think of a stable renewable power generation system that can ensure power availability at any time with the lowest possible operating cost. In this paper, a hybrid power generation system is modelled for a Condensate Fractionation Plant (CFP). Optimization, performance analysis and validation of the proposed model are assessed by using HOMER simulation tool

1 Introduction

The crisis of electrical power has become a severe problem for the people around the world. Literature survey revealed that the conventional sources of power, mainly fossil fuels, are polluting our environment at an alarming rate. In addition, the deposit of these sources will eventually dry out by the next century. The increasing costs of line extensions and fossil fuels, combined with the desire to reduce foreign exchange charges, have encouraged many countries to consider small scale renewable energy technologies for rural electrification programs [1]. Therefore, Engineers and Explorers are looking into Renewable Systems as the potential source of energy. From detailed monitoring and evaluation of various pilot systems all over the world, a large discrepancy was found between the power produced by small wind turbines in a hybrid application and energy production estimates based on the site's climatic conditions and the turbine power curve. The reasons for this discrepancy vary but result in a 75% reduction in turbine output. Much research has been done in recent years to improve this discrepancy by employing Maximum Power Point Transfer (MPPT) and Output power levelling [2].

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Condensate is a low-density mixture hydrocarbon liquid found in the natural gas fields [3]. Fractionation of Natural Gas Condensate yields the fuel components like Naphtha, Special Boiling Point Solvent (SBP), Diesel, Kerosene, Jet fuel etc. Due to the high profit margin from these plants, investors have been attracted to this business over the years. But such plants have some constraints that must be met by the design of the process. Continuous power supply is one of the most important criteria for these plants since the start up procedure is very complex. If the plant shuts down for power interruption during the normal process run, the whole start up procedure must be followed all over again, which will take minimum of 3 days and the cost of repeating such procedure will increase the operating cost of the plant [4].

Normal practice is to have a dedicated grid connection for the plant. Unfortunately, even the most dedicated expressways in developed countries cannot provide a hundred percent guarantee of power continuity as we have seen many Blackout incidents in recent past [5]. The condition is much severe in developing countries like Bangladesh, India, and Pakistan. Besides, the distortions and oscillations caused by lightening induced surges in the power grid are harmful for the Process Control System and its associated instruments [6].

The prime objective of this research is to minimize the dependency of fossil fuel and develop a failure free yet low-cost hybrid power generation system using wind turbine, solar and diesel generator. The economic feasibility of that system is also analysed to find a suitable combination of renewable sources and at the same time compare it to other probable substitution for electrification like grid extension or standalone diesel generator. Although hybrid systems like have been developed previously but most of them are not reliable for continuous run and zero capacity shortage [7-8].

In this paper, HOMER software is used to optimize a Wind-Solar-Diesel Hybrid System for a remote area to attain the most practical, zero capacity shortage and cost-effective means of operation. The purpose of employing wind turbines and battery bank is to minimize the use of diesel generators [9-10]. We cannot depend only on wind power to supply our demand because no matter what the size of the wind turbine is we must have sustained wind velocity. Since sustained wind velocity cannot be guaranteed all the time, we have introduced a solar array into the system so that it increases the reliability of the system. The most probable situation is that when sustained wind velocity is not obtainable, we can still harness daylight using the PV module. And if both fail at the same time, we will have batteries to supply the peak load which will be charged when produced energy by the system is higher than demand. In the worst-case scenario when all the options for renewable sources fail, the diesel generator will take over the full load. But under normal condition of operation, the system will operate according to the optimized value found from HOMER calculations. We could think of a renewable based power plant instead but using a micro hydro or geothermal base plant will not be cost effective for such small loads. Moreover, finding the geological resources for those plants are not so easy.

2 Developing Hybrid Power Generation System

2.1 Assumptions and Constraints

Modelling the hybrid power generation system involves introducing non-conventional power sources into conventional power sources as done in [11-12]. The performance of such a system is solely dependent on the control system that would dictate the whole operation. There are various methods to control the performance of a hybrid renewable power system as shown in [13]. However, this model is designed for a condensate fractionation plant that has a peak load not more than 75 KW with 746 KWh per day. This load consists of pumps, heaters, instrument air compressors and coolers that are required for the process. In addition, the dc loads account for 11 KW (peak) coming from the Process Control Systems (PCS), instruments, surveillance cameras and other control panels. To meet these load demands both conventional and non-conventional sources are put into Homer to find out the most cost-effective combination.

Power generation by wind turbine is directly dependent on the wind velocity and availability. It is seen that a minimum of 4 m/s wind velocity is enough for a wind turbine to produce 16KWh power [14]. Similar conditions are applicable for photovoltaic arrays. Production from PV arrays would not reach the desired level if the weather were cloudy [15]. However, during the cloudy hours of the day, it is expected to have better wind velocity so wind turbines would generate most of the power. For any unforeseeable situations, high performance batteries are injected into the system to improve the reliability. All these constraints have been considered in HOMER calculation. In addition, we can set maximum allowable capacity shortage allowed by the system.

The use of renewable energy sources in the generation of energy reduces the emission of CO_2, SO_2, and NOx in the atmosphere that helps to fight global warming. Estimation of yearly emissions from different combinations of power sources like wind-diesel-generator-battery, diesel-generator-battery, and wind-diesel-generator can be performed using HOMER as shown in [16].

2.2 Proposed Model

The proposed model of Hybrid power system is shown in Fig.1. In this system a traditional Diesel Generator and a Battery stack has been introduced in addition to PV array and wind turbine to improve reliability. The power generated by wind turbines and generators are alternating in nature, but the power of solar arrays is direct, so to use them in a combined system all the outputs are first converted into DC and thrown into a DC bus. A Maximum power tracking DC/DC converter in order to ensure increased efficiency of solar power conversion by allowing solar cells to operate at their ideal operating point regardless of changes in load, and radiation [13].

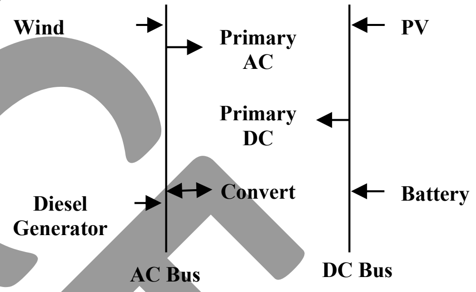


Fig.1 Grid configuration of a hybrid power system

The operation of such a hybrid system is not so straight forward. There must be a precise control system that would introduce different power sources as per demand requirement. In hybrid power generation, the generating units are designed to support different load conditions that may appear at any time of the day. Now, let us assume a scenario where demand power is less than that of combined generation of available sources at the system. In such conditions the excess power generated by the system either must be captured in a storing device or dumped into a dummy load. But, if the demand is so low that it can afford to omit a source from the system and it still run the loads properly, it should look to cut off the diesel generator.

Flow chart of the algorithm developed to control the proposed hybrid power system is Shown in Fig.2 Here, power generated by the diesel genset is P_{DL}; power generated by wind turbine is P_W; power generated by solar system is Ps; power stored in battery set is P_{Batt}; Total power generation by wind and solar system is P_{gen}; Base demand P_B; Peak demand P_P; Total demand is P_D.

Firstly the Total demand, P_D; Total power generation, P_{gen} and power stored in battery stack, P_{Batt} is measured. If Total demand, P_D is greater than power generated by wind and solar then the system should look for that excess amount from Battery stacks i.e. $P_D = P_{gen} + P_{Batt}$. If not, then the total demand will be met by diesel generator and total generation is saved into battery; meaning, $P_D = P_{DL}$. On the other hand, if $P_D \leq P_{gen;}$ then the excess power generated by wind and solar will be stored in the battery i.e. $P_{Batt} = P_D + P_{gen}$.

In Fig. 3, the proposed control system illustrated with an option to collect, manipulate and store data so as to facilitate the total control over the system [17-18]. Provison to supply both dc and ac power is also kept in the proposed model since refinary plants incorporates both large ac and dc loads. However the ac loads aree not directly fed from ac generators (namely; wind and diesel generators) rather a separate dc common bus is introduced to simplyfy optimization and control parameters. The dummy load attached the model would come in handy to keep the stability of the system when battery is fully charged and and system generation meets the demand comfortably.

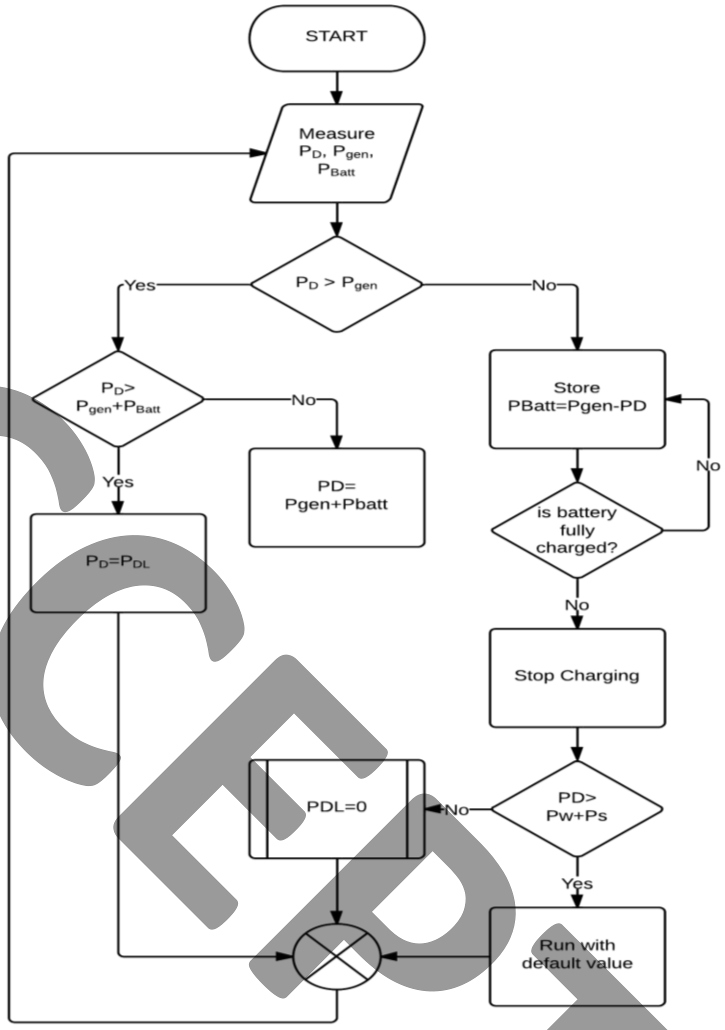


Fig. 2 Flow chart of the proposed control system

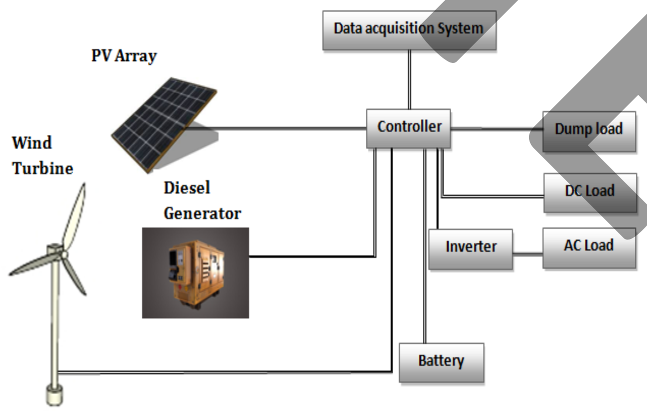
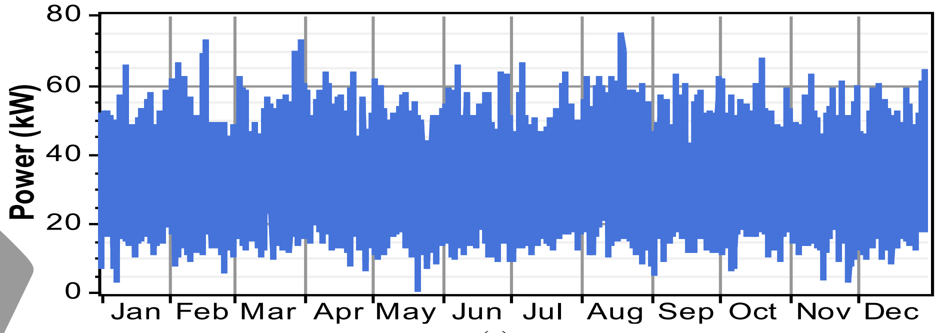


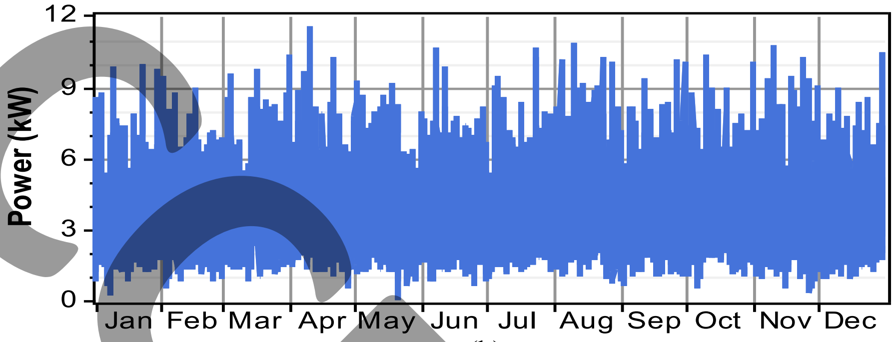
Fig. 3 Technological configuration of the system

2.3 Optimization of the Proposed Model

The proposed system is suitable for a remote condensate fractionate plant where capacity shortage cannot be accepted but power availability from the grid cannot be assured. The solar and wind profile used in this model is collected from a remote coastal area.



(a)



(b)

Fig. 4 Total demand profile of the system under consideration (a) Annual AC load profile, (b) Annual DC load profile.

Fig. 4 shows a demand chart for a typical condensate fractionation plant in one year. As shown in the seasonal profile the annual maximum AC load is 80 KW and annual maximum DC load is 11 KW. The red dots in the DMap signify that the demand has hit the peak load condition, and it is the upper limit of all the calculations that are done by HOMER. Fig. 5 shows the total solar radiation and clearness index over the year [19] which is used as solar resources for HOMER optimization.

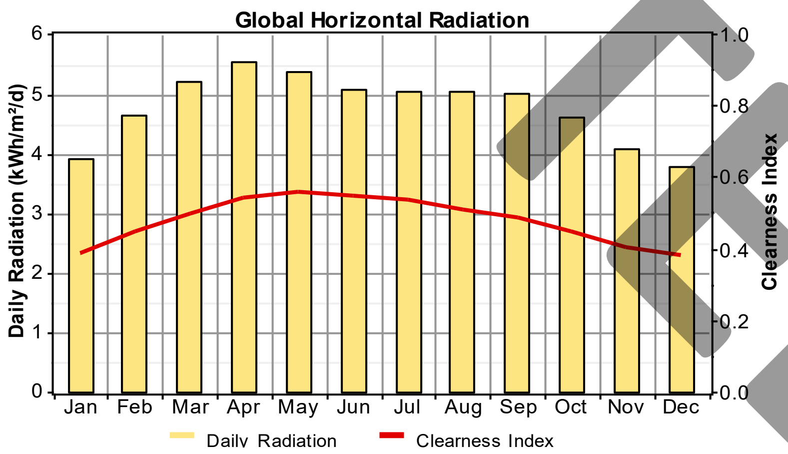


Fig.5: Solar radiation and clearness index

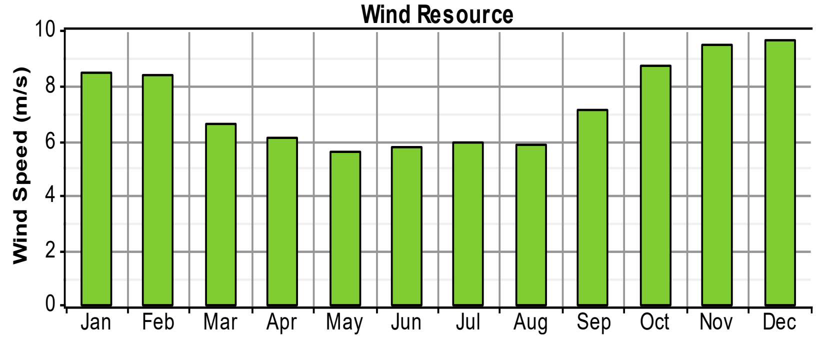


Fig.6 Annual wind profile

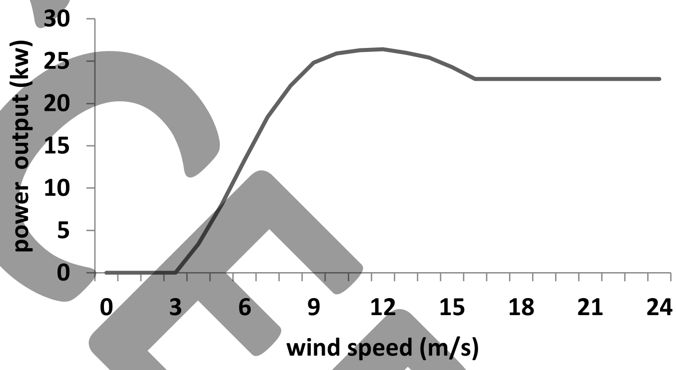


Fig.7 Wind speed Vs Power curve of PGE 20/25 Wind energy Conversion System

The variation of wind speed in m/s over the year is shown in Fig. 6 [20]. The average wind velocity is 7.3 m/s. Because of such low average wind velocity, PGE 20/25 manufactured by Energie PGE is suitable as it has a cut-in speed of 3.5 m/s, a cut-out speed of 25 m/s and a rated speed of 9 m/s along with an efficiency of typically 40% and 25 years a life span; making it the turbine of choice by the US Department of Energy (DOE) [21-22]. So, with 40% efficiency for wind turbines, the dependency of wind turbine on wind velocity is shown in Fig. 7. The solar and wind profile are the optimization resources for HOMER. Some constraints are also added into HOMER input that must be met by the system e.g., maximum capacity shortage, load factor, operating reserve as percentage of renewable sources. For the convenience of the system a few battery banks or flywheels should be added. In this case Trojan L16P (manufactured by Trojan Batter Company; Nominal specifications 6 V, 360 Ah, 2.16 KWh) are introduced.

Another fact which needs to be considered in wind turbines is Dump wind energy. An extra resistive load is added to the system to prevent turbine runway. When the battery bank is not already fully charged, a DC-based power system uses excess renewable energy to charge it. As the battery bank charges the internal resistance of the bank increases, leading to a reduction in charge acceptance. The effects of increased internal resistance are most noticeable during periods of high charging current or during charging at high states of charge. In both situations, the battery bank voltage is driven up, in some cases up to the regulation voltage. This effect is exaggerated in systems with weak or small battery banks. For weak battery banks, the internal resistance is higher. For smaller battery banks, the effective charge currents are higher. A converter must be installed in the system to facilitate both the AC and DC loads of the plant. In the “sizes to consider” column four different converters (ranging from 15 KW to 45 KW) are used so that HOMER can find out the optimal size that is suitable for the system.

3 Results and discussion

With the above-mentioned inputs, HOMER tried and tested a total of 4,200 different configurations with different sub-systems of the proposed model and by meticulously observing sensitivity, reliability, and optimization parameters it found out only four to be practical and applicable in the real world where all the subsystems perform nominally. With Net Present Cost in mind the one with the lowest operating cost is shown in Table-1. The annual energy production from the system is shown in Table-2. A total of 379,349 KWh electricity would be produced from the system and 85 percent of that comes from the wind turbines.

Table1. System Architecture.

Equipment	Specifications
PV Array	0.5 kW
Wind turbine	2 PGE 20/25
Generator 1	35 kW
Battery	122 Trojan L16P
Inverter & Rectifier	25 kW
Dispatch strategy	Cycle Charging

Table 2. Annual Energy Production

Production Sources	KWh/yr
PV array	695
Wind Turbine	322,704
Generator 1	55,950

Table 3. Annual Load Statistics

Quantity	Value	Unit
Excess electricity	65,338	kWh/yr
Unmet load	0.240	kWh/yr
Capacity shortage	23.4	kWh/yr
Renewable fraction	0.815	-

Table 4. Generator Parameters for Hybrid System

Quantity	Value	Unit
Hours of operation	2,175	hr/yr
Number of starts	885	starts/yr
Operational life	6.90	yr
Capacity factor	18.2	%
Fixed generation cost	10.0	$/hr
Marginal generation cost	0.200	$/kWh
Electrical production	55,950	kWh/yr
Mean electrical output	25.7	kW
Min. electrical output	10.5	kW
Max. electrical output	35.0	kW
Fuel consumption	20,078	L/yr
Specific fuel consumption	0.359	L/kWh
Fuel energy input	197,563	kWh/yr
Mean electrical efficiency	28.3	%

It is worth mentioning that only the best operating conditions are shown here. Fig. 9 shows the cost summary of the entire system. It is seen that although the capital cost is high like most of the renewable systems, the operating cost is still reasonable. What adds to the advantage of the system is the reliability and continuity of power supply from this system. The proposed system would produce around 65,000 KWh surplus electricity in a year and possible capacity shortage is almost zero percent as shown in Table-3. Although it is possible to reduce the amount of surplus electricity by adding some more battery units to the system but that significantly raises the capital cost and operating cost of the system.

Figs.10-12 show loading on wind generator and battery. As shown in Fig. 12, the batteries will be loaded highly, which is expected from a wind-solar hybrid system as these systems depend heavily on unpredictable natural forces and the control system involves battery stacks when power demand does not meet total generation. But Homers calculations ensures this heavy loading of battery does not affect the sensitivity, reliability, and sustainability of the total system. If the battery packs fail, the diesel generators are present to take up the load. However, due to heavy loading batteries may require more frequent replacement and the cost of replacement of the storage bank is significantly smaller compared to others [Fig. 9]. The generator parameters are shown in Table-4. As seen from the table, per unit cost of electricity production from the generator is about 0.2$ and mean efficiency of generator is 28.3%. The amount of gas emission from the generator is presented in Table-5. Environmental protection agencies around the world have enforced cost effective regulations to reduce harmful air pollution from the oil and natural gas industry. But the cost associated with polluting gas emission is neglected here since they are not applicable in many countries.

Table 5. Generator Emissions for Hybrid System

Pollutant	Emissions (kg/yr)
Carbon dioxide/Carbon monoxide	52,871
Unburned hydrocarbons	14.5
Particulate matter	9.84
Sulfur dioxide	106
Nitrogen oxides	1,164

Fig. 13 shows the comparison of electrification cost of the proposed system with the grid extension. The grid extension cost increases linearly with distance and the breakeven point of grid extension is 153 Km. That means if the site is located at a distance more than 153 Km from the main grid the proposed model is more suitable. However, even if the plant is near to the grid the system, it will still be vulnerable to load shedding and power surges. For a sophisticated process as Condensate Fractionation such power interruptions will cause high opportunity cost. It is seen in sub continental countries that the grid voltage is often higher than the nominal voltage. If the nominal line to line voltage is 400V, the supply voltage varies in the range 375 V- 470 V. Using Automatic voltage regulator (AVR) is a common practice in such situations but having precise voltage regulator is costly and is not reliable. So, in places where supply continuity and quality cannot be guaranteed, it is better to have a standalone system. One probable substitution is standalone diesel generator. Although installation of a diesel generator is very straight forward and instant but the cost of running a diesel generator is very high as shown in Fig.14 compared to a renewable hybrid system. It is evident from the comparison result between a standalone diesel generator and the proposed hybrid system, as shown in Fig. 15, that having a standalone Hybrid power system is a far better option than a diesel generator.

The renewable penetration of the proposed system is 0.815. Renewable penetration refers to the fraction of energy produced by the renewable sources with the total available generation capacity. High penetration renewable sources ensure minimal dependency on fossil fuel which was the primary target of this research work. The total electrical load supplied by the system and the total renewable power generated by the system are shown in Fig.16 (a) and (b) respectively. If the two figures are compared it becomes obvious that most of the electrical power is supplied by renewable sources thus reducing fossil fuel consumption and the cost associated with it.

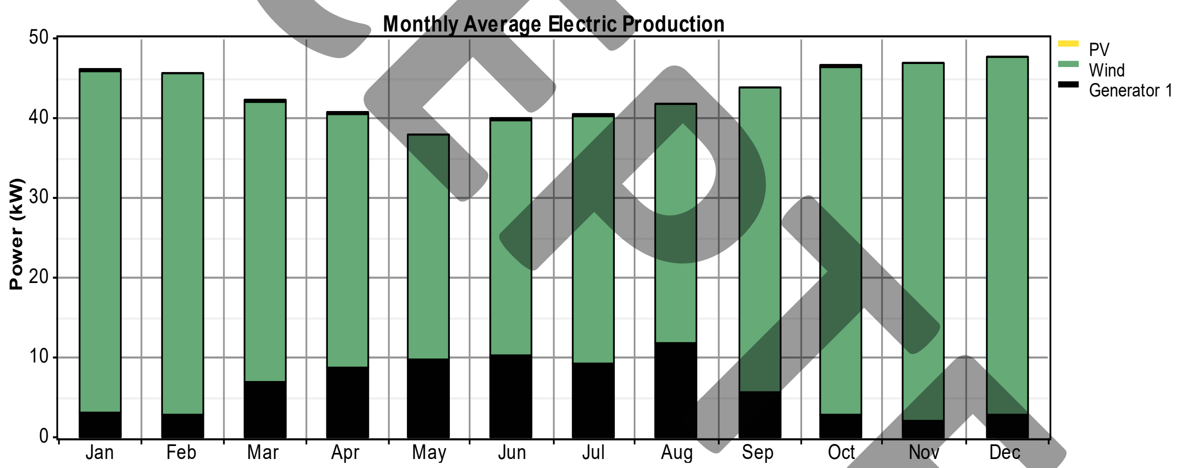


Fig. 8 Monthly energy production by various sources of the system

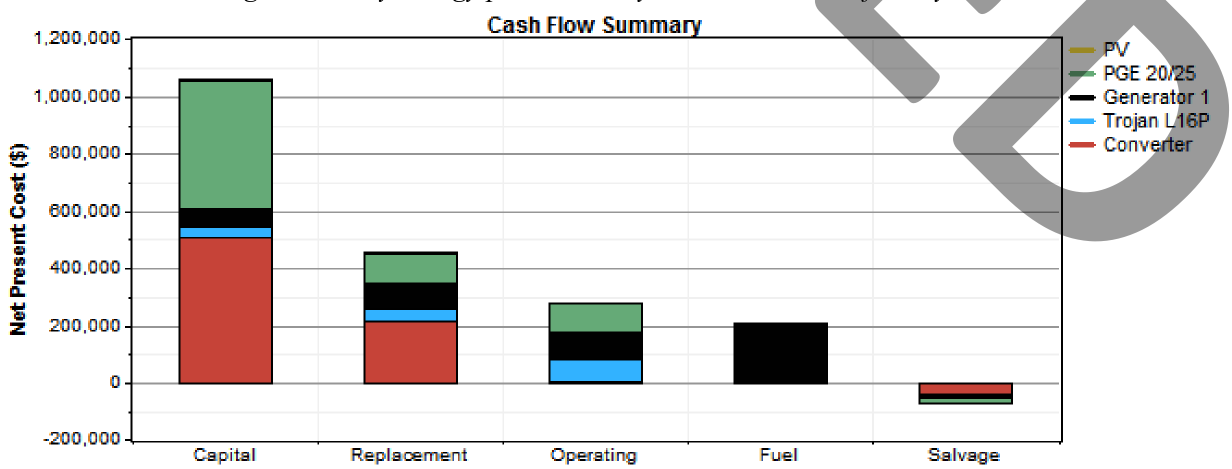


Fig. 9 Total cash flow summary of the proposed system

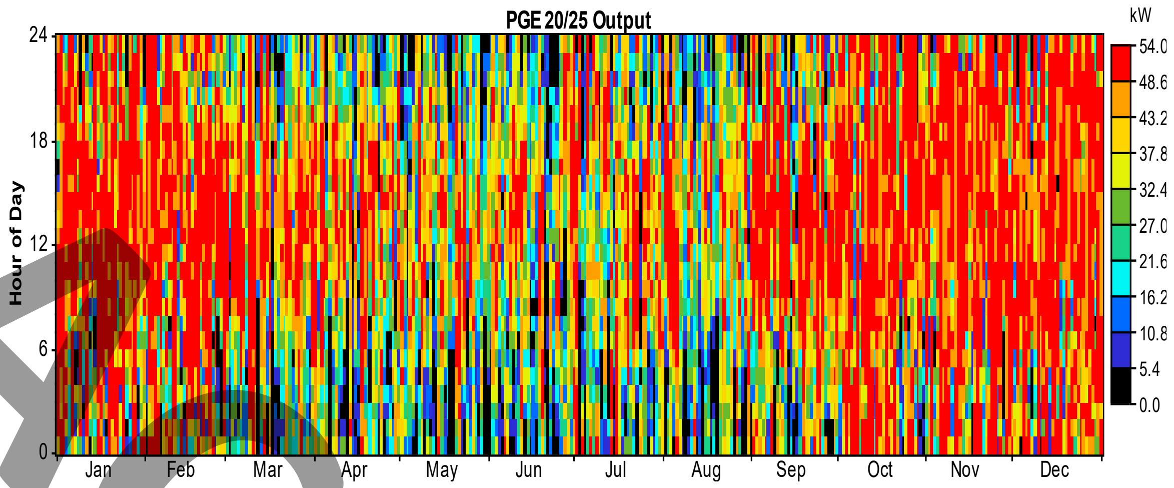


Fig. 10 Annual Wind turbine output of the system

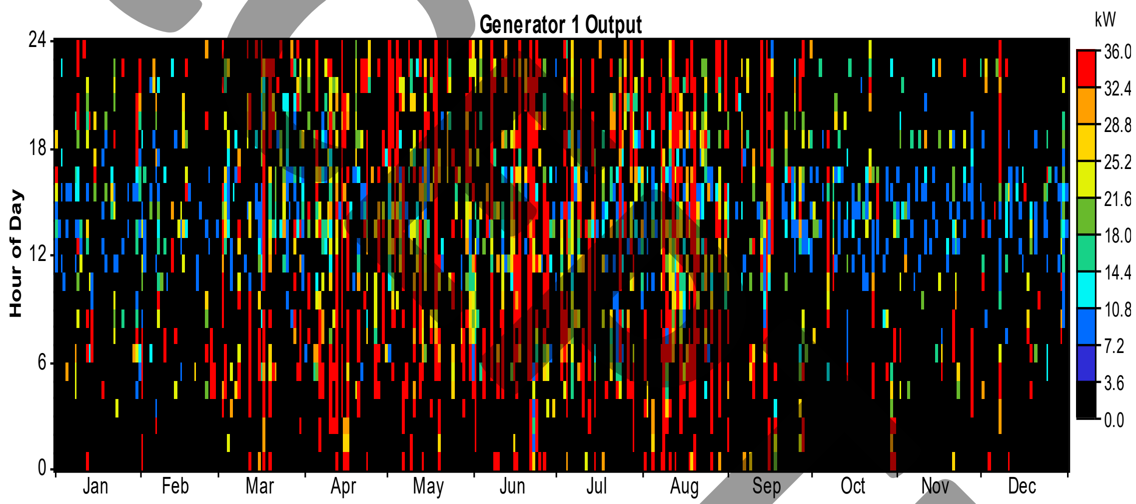


Fig. 11. Annual Generator output of the system

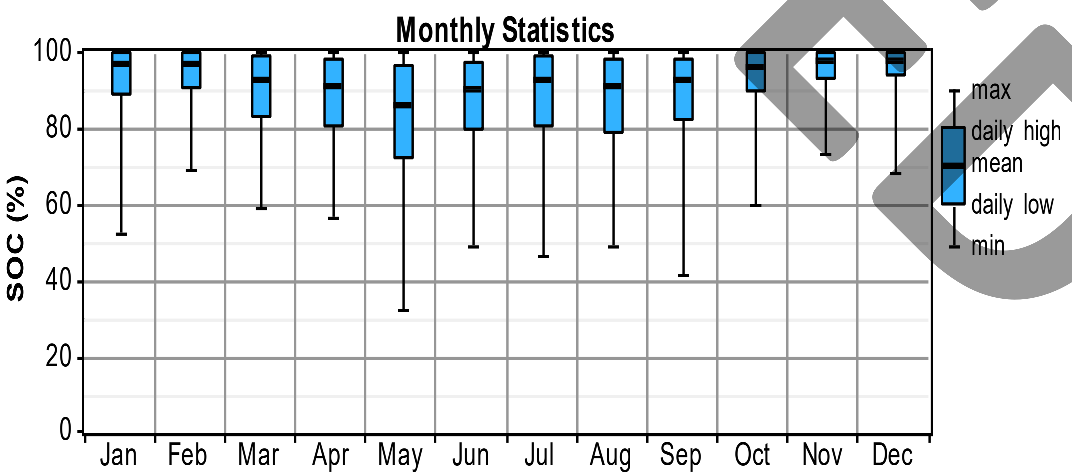


Fig. 12 State of Charge of Trojan L16

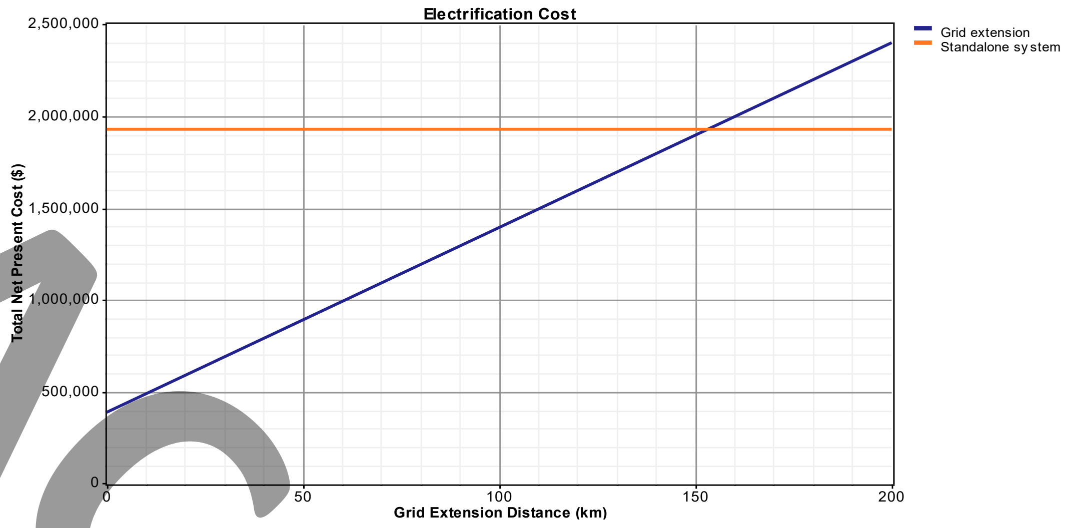


Fig. 13 Comparison of electrification cost by grid extension and proposed system

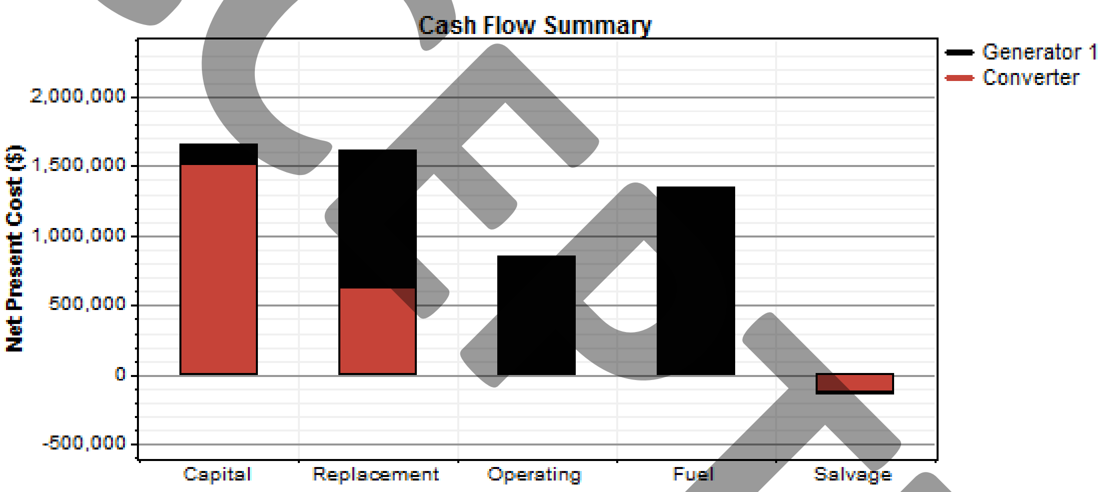


Fig. 14 Cost associated with standalone Diesel Generator

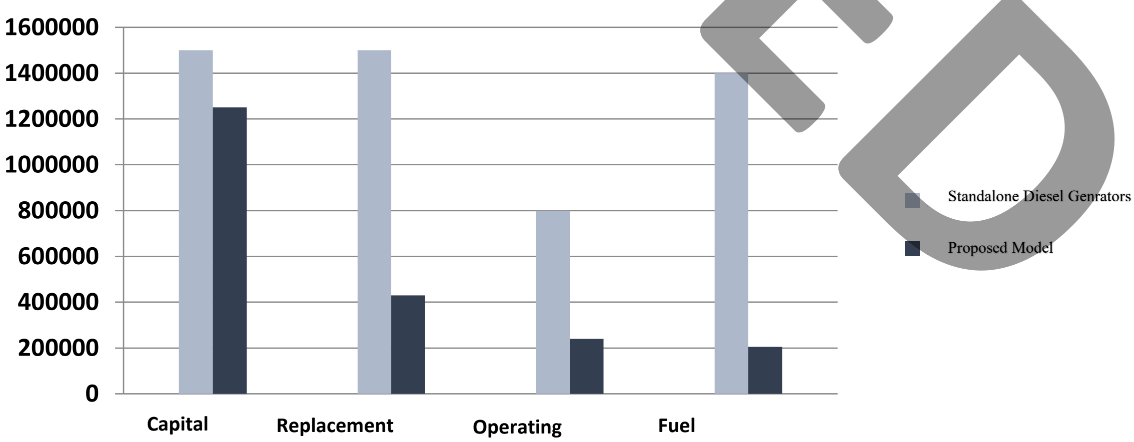
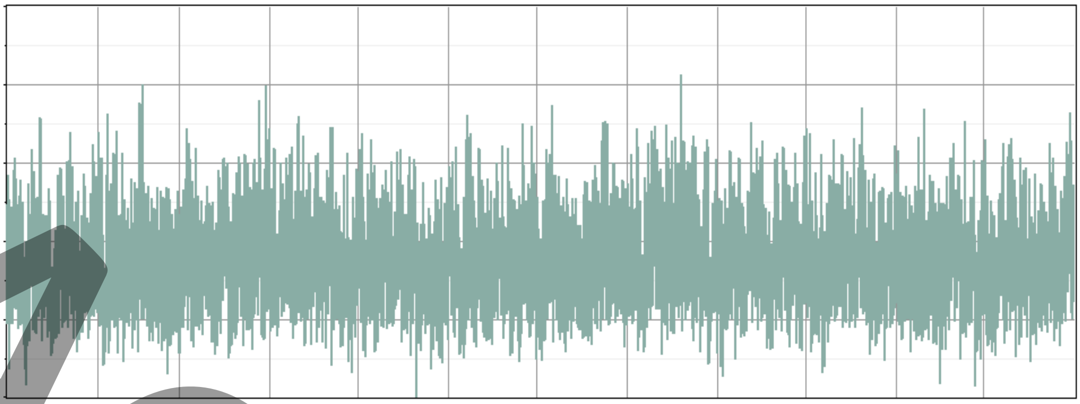
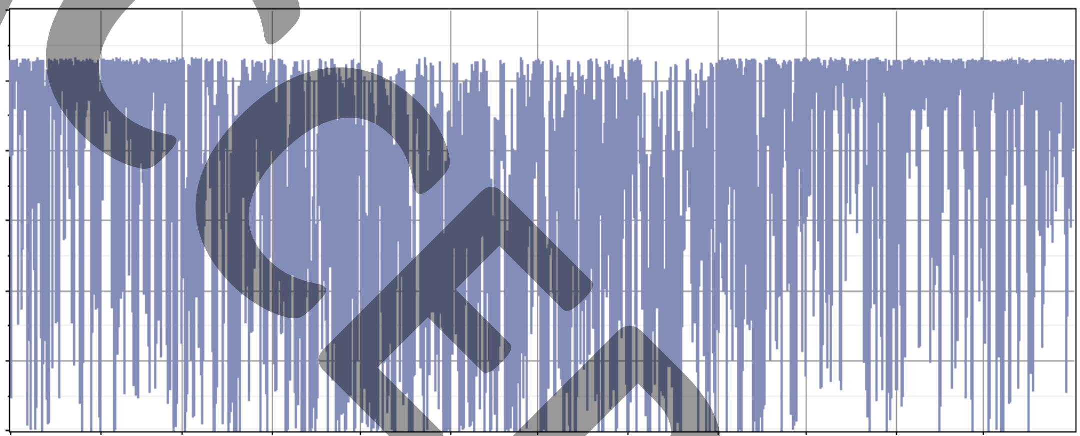


Fig. 15 Cost comparison between Standalone diesel generator and proposed model



(a)



(b)

Fig. 16 (a) Total electrical load supplied from the system (b) Total Renewable power produced by the proposed system

The capital cost, operating cost, replacement cost and salvage value of the proposed PV-Wind hybrid power system, it is quite apparent that the proposed model is far superior to grid extension beyond 153 KM or standalone diesel generators of any capacity as evident from Fig. 13 and Fig. 15. So, from pure economic sense, it is wise for an investor of a condensate refinery plant to venture into a hybrid power system rather than waiting for grid connection. It is noteworthy, that even with a grid connection, the usual practice is to have a backup diesel generator so that the vital machinery of the refinery is running during power outage. So, the cost of conventional grid connection would go even higher. Moreover, if we count the carbon footprint into consideration the renewable hybrid system has to be the most feasible option.

In an ideal hybrid renewable system, the absence of one renewable source is compensated by the other. This adds to the system's reliability and as a result the system would be able to supply power if the peak voltage does not cross the set limit. In order to make a complete renewable system, we must add a base load plant that only uses renewable sources. Micro hydro or geothermal plants are most reliable to meet the base load of the system. But such plants have geographical and cost management issues. One could also think of super capacitors as storage devices instead of batteries. Of the two competing technologies, the battery stands for a slow but steady energy supplier in case of large energy demands, and the super capacitor is more suitable for more dynamic load.

4 Conclusion

With increasing the load demand and reducing the storage of fossil fuel, Hybrid Power System (HPS) seems to be the only solution to meet the present and future power crisis. The objective here was to observe the performance of the wind/diesel/battery hybrid power system under different wind speed, sunlight deviation and load demand conditions, which can be seen in the simulation results. Obviously, before implanting this system into reality, site selection factors must be observed, since renewable energy is largely dependent on that. This paper has presented the performance of a generic model using HOMER software and shown the advantages of having a standalone renewable system for condensate fractionation plant.

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