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Assessment of utilizing stand-alone renewable energy scenarios to feed a passenger service station in Saudi Arabia

Abstract *This paper is directed to simulate, analyze and assess different off-grid renewable supply options to feed a proposed passenger services station on Al-Nafud dessert / Saudi Arabia. The results show that wind only and off-grid hybrid wind/PV schemes are technically visible and economically vital. Stand-alone wind energy scenario becomes the most preferable option; having the lowest NPC, if diesel price is increased to 0.3$/l. Moreover, the utilization of such renewable energy supply option will eliminate great amount of gas emissions produced by diesel generator.*

Streszczenie. *W artykule analizowano możliwości wykorzystania źródła energii odnawialnej do zasilania stacji obsługi pasażerów na pustyni Al-Nafud.* ***Analiza możliwości zastosowania zasilania ze źródeł energii odnawialnej stacji obsługio pasażerów na pustyni***

Keywords: solar energy, wind energy, renewable energy
Słowa kluczowe: ogniwa fotowoltaicznej, energia wiatrowa

Introduction

Nowadays, the implementation of renewable energy (RE) resources, like wind and solar, has received a great concern due to their advantages over conventional energy sources. Since Saudi Arabia has a high solar insolation level and acceptable level of wind speed, utilization of these energy resources to contribute in supplying electric load demand will be feasible and vital. As far as the authors concern, the literature lacks to an extensive study dealing with the implementation of various solar/wind supply options to feed electrical loads in Saudi Arabia. The current study investigates the technical feasibility and economic viability for various energy supply options to feed the load demand of the proposed passenger service center, which is intended to be located on the Al-Nafud road 200 km from Hail city / Saudi Arabia. Therefore, the results obtained will provide an important step for practical implementation of RE resources in remote and desert areas not only in KSA but also in other countries having a similar climate.

A number of publications dealing with the utilization of RE resources in KSA is found in the literature. Mokheimer et al in [1] have investigated the utilization of hybrid wind / solar to feed reverse osmosis desalination system under constant load of 1 kW for 12 h/day and 24 h/day in Dhahran / Saudi Arabia. They found that that the cost of 1 kW load of 12 h/day is 3.693 $/m3 and that for the same load but 24 h/day is 3.812 $/m3. Shaahid [2] assessed the implementation of hybrid wind–PV–diesel power systems to meet the load demand of 620 MWh for commercial building in Dharan-Saudi Arabia. He found that the cost of generating 1 kWh is 0.154 $. In publication [3] Elhadidy et al have evaluated the feasibility of using hybrid wind/solar diesel energy system to supply 41531 kWh load demand in Dhran-KSA. They concluded that the hybrid wind/solar energy system can be considered to meet a considerable amount of the load demand in Dharan. The authors of the article [4] have studied the effect of sizing the components of a hybrid solar/wind/diesel energy system on its performance. Elhadidy M. [5] has evaluated the performance of a hybrid wind/solar/diesel energy system. Based on the technical and economic analysis, Al-Uglan et al in [6] assisted the implementation of solar energy to supply two types of air conditioning, under fixed cooling load during a day in Saudi Arabia. They concluded that the feasibility of both types is improved with the increase in the load demand. Rehman et al in [7] studied the utilization of a hybrid PV/diesel energy system to feed a load demand of a village in Saudi Arabia. There results show that the cost of energy (COE) of the hybrid diesel/PV system becomes less compared with that of diesel only system, if the diesel price becomes greater than 0.6 U$/l. The work presented in [8] investigated the optimum PV array configuration to feed a DC Helical water pump to provide the needed water volume; 22 m3/day. The investigation is carried out in Madinah - Saudi Arabia. The authors of the work presented in [9] have concluded that the cost of fossil fuel energy will be higher compared with that of solar energy, if the cost of the environmental and health damages caused by fossil fuel is considered in the assessment. Mansouri et al in publication [10] investigated the amount of carbon dioxide (CO2) emissions from renewable energy schemes compared with conventional fossil fuel energy system during the period 2010 to 2025. They found that saving in carbon dioxide (CO2) could reach 468 Mt CO2 by year 2025.

The implementation of renewable energy resources have been investigated in different parts of the world. The authors selected some of these publications. Sinha S. and Chandel have investigated in [11] the utilization of a hybrid PV/wind energy system in twelve locations in India. Their study shows that the best power generation system is achieved with less wind turbines and more PV generators. The work parented in [12] investigated the implementation of multi-generation energy system, instead of separate generation units, to supply multi-unit building.

HOMER Software

HOMER is a software package which is used to evaluate designs of both off-grid and grid-connected power systems for a variety of applications. Achieving optimum power system design, which is technically feasible and economically vital, is a very difficult task. This is because the designer has to make many decisions about the system configuration: the components which make sense to be included in the system design, how many and what size of each component, the technology option to be chosen and availability of energy resources. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate many possible system configurations.

The model inputs describing technology options, component costs, and resource availability have to be inserted to HOMER software package. HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, it compares the electric and thermal demand in the hour to the energy that the system can supply in that hour,

and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to operate the generators and whether to charge or discharge the batteries. It generates results that the user can view as a list of feasible configurations categorized by net present cost (NPC). The results are displayed in a wide variety of tables and graphs that help the designer to compare configurations and evaluate them based on their economic and technical features.

HOMER can also perform sensitivity analysis. To perform a sensitivity analysis, it is required to feed sensitivity values that describe a range of resource availability and component costs. HOMER simulates each system configuration over the range of specified values. The results obtained by sensitivity analysis enable the designer to identify the factors that have the greatest impact on the design and operation of a power system. Moreover, the results help to answer general questions about technology options to inform planning and policy decisions.

Input data

To perform HOMER software simulations it is required to input hourly load of a day in kW and environmental data including monthly average wind speed and monthly average solar irradiance. The expected load profile of the proposed project is estimated and the obtained results are shown in Fig. 1. Average monthly wind speed and average monthly solar irradiance data are imported to HOMER models from NASA meteorology and solar energy database, which has a record for 10 years period. Average monthly wind speed data and solar irradiance data of Al-Nafud location are shown in Fig. 2 and Fig. 3.

The feasibility analysis is also required to input the technical specifications and cost of each system element. For example, the initial cost (IC), the replacement cost (RC), and operation & maintenance cost per year (O&M/Y) of the chosen wind turbine (WT) are 50000 $US, 50000 $US and 500 $US, respectively. The WT maximum output power is 10kW. The power curve of the wind turbine is shown in Fig. 4. In addition, a capacity shortage fraction (CSF) constraint is needed to carry out HOMER simulations. The CSF indicates the percentage of the power system fails to feed a specified load. It is recommended to use CSF of 2% for off-grid renewable energy configurations [13, 14]. The life span of the proposed project is assumed 25 years.

Results and Discussion

This section presents the results obtained by HOMER software, National Renewable Energy Laboratory - US, for five energy scenarios. These are diesel alone, hybrid wind/PV/diesel, hybrid wind/PV, wind alone and PV alone systems. A great number of computer simulations for different combinations of each system components are carried out to achieve the optimum configuration for each energy scenario.

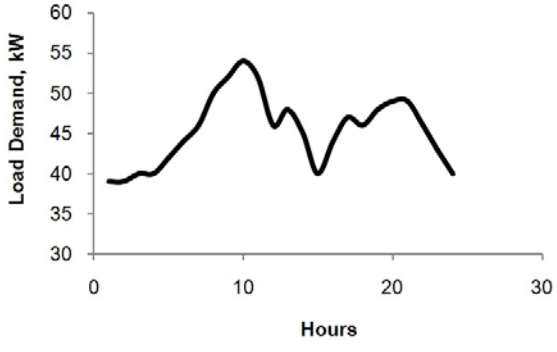

Fig.1. Expected daily load profile of the proposed project

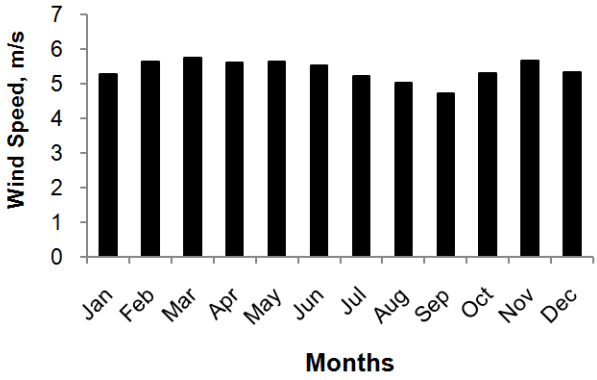

Fig. 2. Average monthly wind speed in Al-Nafud location.

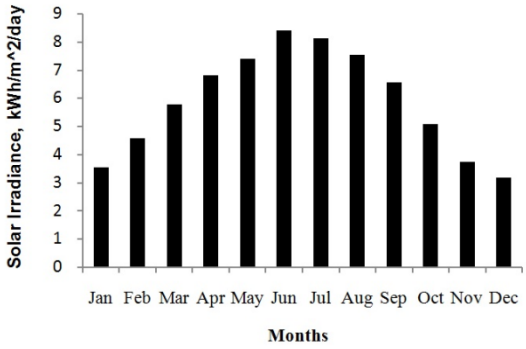

Fig.3. Average monthly solar irradiance in Al-Nafud location

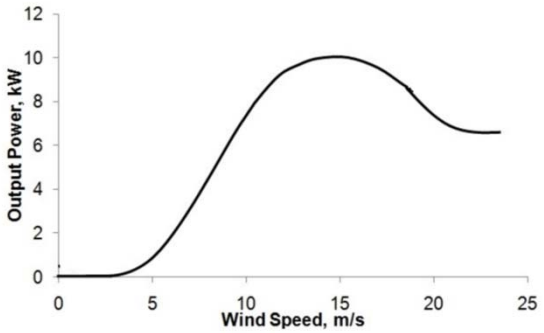

Fig. 4. The power curve of the chosen wind turbine

The utilization of stand-alone diesel scheme to supply the load demand of the proposed station is investigated and intensive HOMER simulations for different diesel fuel prices are carried out. The NPC of this scheme for diesel price of 0.07 $US/l is 468,435.8 $US. The effect of diesel price on NPC of this scheme is shown in Fig. 5. As can be observed, the increase in the diesel price resulted in linear increase in net present cost.

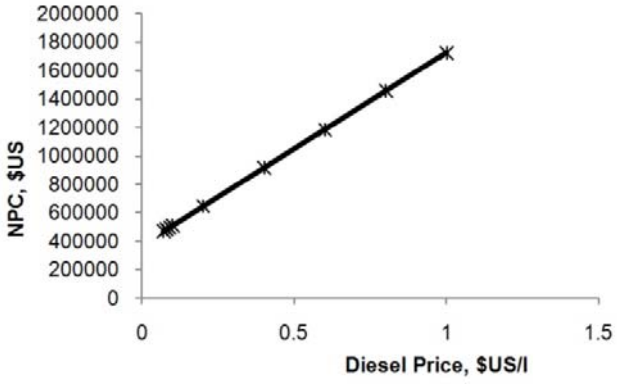

Fig. 5. The effect of diesel price on NPC of stand-alone diesel system

Figure 6 shows the obtained feasible configurations of the hybrid wind/PV/diesel scheme. HOMER categorized the feasible configurations based on net present cost (NPC). The optimum (lower NPC) configuration consists of 50 kW PV generator, 8 WT of 10 kW each, 30 kW diesel generator, 70 kWh lead acid battery and 40 kW converter. The NPC of this scheme is 595,262 $US. For the optimum configuration, the renewable energy resources contribute in 60% of the load demand and the remaining generated power is provided by the diesel generator. The effect of diesel price on NPC of stand-alone Wind/PV - diesel system is shown in Fig. 7 and the annualized emissions of the system are given in table 1.

The results presented in Fig. 7 and table 1 motivates the implementation of stand-alone (off-grid) wind/solar renewable energy schemes to supply the load demand of the proposed project. As can be noticed in Fig. 7, the inclusion of a diesel generator in a RE scheme causes the system NPC to increase as the diesel price increases. In addition, gas emissions have undesirable economic and environmental effects. If the rules of environmental restrictions are implemented the system NPC will increase. On the other hand, gas emissions will increase the environmental pollution level, which affects human beings, plants and animals.

The optimum (lower NPC) configuration for stand-alone (off-grid) wind/solar renewable energy scheme consists of 60 Generic 10kW wind turbines, 180 kWh lead acid batteries, 140 kW Generic flat plate-PV and 60 kW converter. The NPC of this scheme is 727969 $. As can be noticed, the NPC of this scheme is close to previous schemes. Compared with NPC per year of diesel only scheme, the NPC/Y of this system is greater by 10381$. This increase is due to the assumed diesel price (0.07$/l). It can be observed from Fig. 5, the NPC of stand-alone wind/PV becomes close to that of diesel only system if the diesel price reaches 0.3$/l.

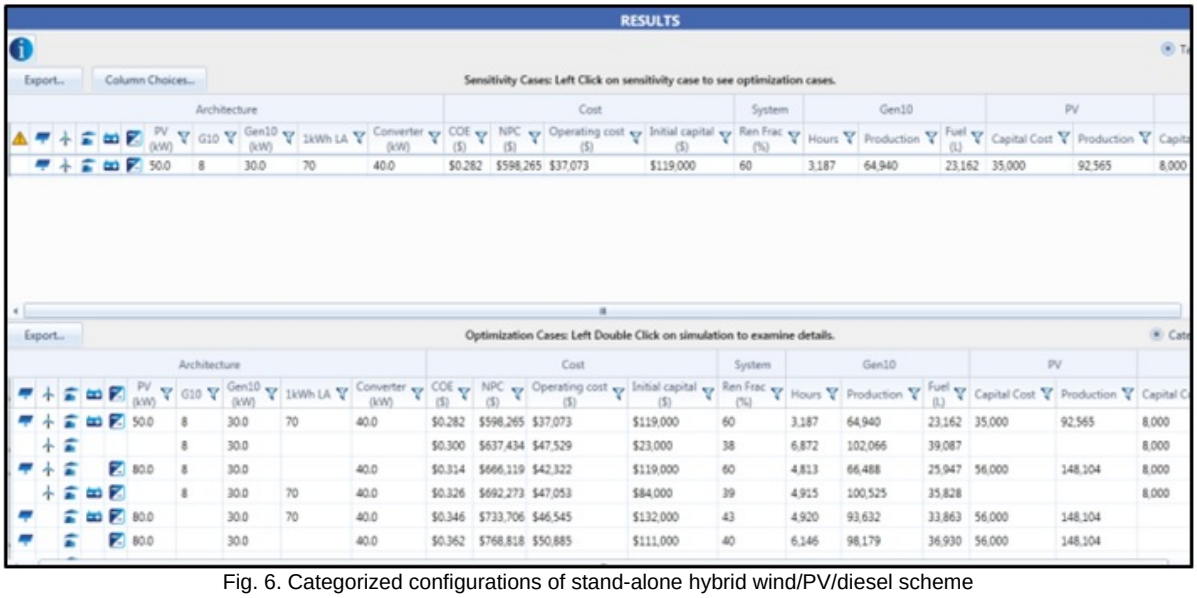

Fig. 6. Categorized configurations of stand-alone hybrid wind/PV/diesel scheme

Table 1. Annualized emissions of the optimum Hybrid wind/PV/diesel system

Quantity	Value	Unit
Carbon Dioxide	61022	Kg/yr
Carbon Monoxide	150.62	Kg/yr
Unburned Hydrocarbons	16.68	Kg/yr
Particulate Matter	11.36	Kg/yr
Sulfur Dioxide	122.54	Kg/yr
Nitrogen Oxides	1344	Kg/yr

The optimum (lower NPC) configuration of stand-alone wind scheme consists of 30 Generic 100kW wind turbines, 580 kWh lead acid batteries and 60 kW converter. The NPC of this scheme is 683,594 $. The effect of wind turbine hub height on NPC is investigated and the obtained NPC results as a function of wind turbine hub height are shown in Fig. 8. It can be observed that NPC decreases in a nonlinear manner with WT hub height. The NPC of this scheme is lower compared with that of Wind/PV system. Referring to the results presented in Fig. 5 and the NPC values of the previous schemes, it can be noticed that stand-alone wind scheme is most preferable scheme if the diesel price becomes 0.3 $/L. In fact, the diesel price in many countries having similar climate is higher than 0.3 $/L. Therefore, wind only supply option, or hybrid wid/PV scheme, are very promising schemes in different parts of the world.

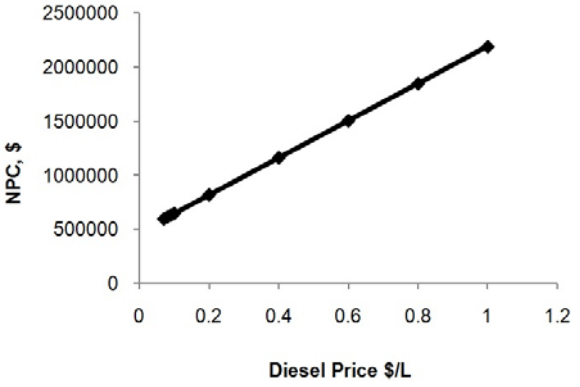

Fig. 7. The effect of diesel price on NPC of stand-alone Wind / PV - diesel system

The optimum (lower NPC) configuration of stand-alone PV Scheme consists of 190 kW PV generator, 800 strings lead acid batteries and 60 kW converter. The NPC of this system is 1,414,922 $. Due to the continuous

advancements in solar cell technology, it is expected that the cost of a PV generator will decrease and its efficiency will improve in the close future. Consequently, the NPC of a scheme includes a PV generator will decrease and as a result the implementation of a stand-alone hybrid wind/PV or stand-alone PV scheme will be a competitive supply option.

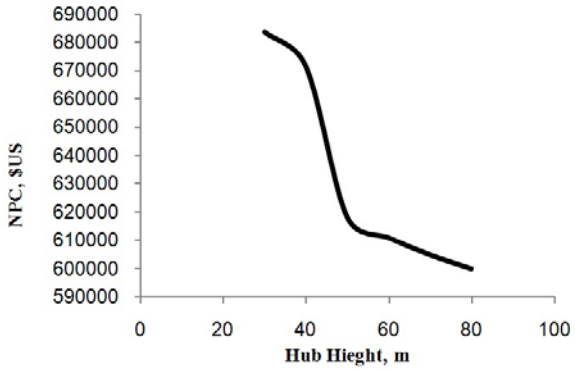

Fig. 8. the NPC of the optimized stand-alone wind scheme as a function of WT hub height

Conclusions

The present work is directed to investigate the utilization of five energy supply options to feed the load demand of the proposed center of passenger services to be built along Al-Nafud international road 200 km from Hail city-Saudi Arabia. All needed modeling, simulation and evaluation for each considered scenario are carried out using HOMER software. The configuration of the lowest NPC is considered as the optimum configuration. Based on the obtained results, stand-alone wind energy scheme is the most preferable supply option, if the diesel price reaches 0.3$ US/L. In addition, the implementation of such a RE supply option will eliminate the gas emissions and their economic and environmental effects.

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