A HYBRID POWER SYSTEM USING WIND AND DIESEL GENERATOR: A CASE STUDY AT MASIRAH ISLAND IN OMAN

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ABSTRACT

This paper presents the cost reduction of electricity generation using a hybrid system on an Island network in the Sultanate of Oman. A case study has been carried out for Masirah Island having an installed capacity of about 9 MW of diesel generators. Load characteristics of the island are considered to determine the necessary demand to be met by the hybrid system. A wind turbine model is developed to determine the potential of mechanical power available for wind generators at Masirah Island based on its daily wind speed profile. The cost of wind and diesel power generation is determined by considering three factors viz. capital cost, running cost and maintenance cost. Ten 900-kW wind turbine units are considered for wind power generation. The case study shows that overall cost of electricity generation by the proposed hybrid system is considerably less compared to the cost of diesel generation alone. The paper also addresses the benefits of the wind-diesel hybrid system in terms of the reduction in carbon emission, and outlines other benefits of the proposed scheme relating to providing power to isolated communities as verified by Masirah Island.

INTRODUCTION

Masirah is Oman's largest island. It is located some 15 km from the coast of Al Wusta in central Oman. There are steady Khareef winds blowing from the Southwest along the coast of Oman. Masirah Island is therefore abundant in renewable resources, such as wind power and solar photovoltaic.

Inspection of the electrification world map shows that rural areas or isolated areas are in great need of affordable and reliable electricity to achieve development. Likewise, an overview through the most important literature on rural electrification indicates that renewable energies (RES) are one of the most suitable and environmentally friendly solutions to provide electricity within isolated areas.

At present, the national electricity supply in Oman is heavily subsidised by the state. It is reported that a unit of electric power is sold to the public at a fifth of the generation and transmission cost. In this paper, a hybrid generation system is proposed to reduce the real cost of power generation.

Many academic studies have been carried out assessing the potential of using wind power in the Middle East. In 1996, Al-Ismaily *et al* [1] carried out a study of wind energy potential in Oman and concluded that Masirah Island has significant potential as a rich site of wind power. Other wind characteristic studies for Oman carried out by Sulaiman *et al* [2] and Dorvlo *et al* [3] confirmed Masirah Island as having significant potential for wind power exploitation. However, in a similar study carried out more recently in 2005, Rehman *et al* [4] concluded that it was not economical to use wind power as a hybrid to diesel generators unless the cost of diesel fuel was more than US$ 0.1 per litre or the annual average wind speed was more than 6 ms^{-1}.

HYBRID ELECTRIC POWER SYSTEM

A. Definition

A combination of different but complementary energy generation systems based on renewable energies or mixed (RES- with a backup of diesel genset), is known as a hybrid power system (“hybrid system”). Hybrid systems aim to capture the best features of each energy resource and can provide “grid-quality” electricity, with a power range between 1 kilowatt (kW) and several hundred kilowatts.

B. Masirah Island Power System

At present, all electric power demand at Masirah Island is met by ten diesel powered generators located at a central power station. The individual generator power ratings range from between 265 and 3,136 kW. With a total installed power capacity of more than 8,200 kW.

The power system for Masirah Island consists of 54% residential load demands, 40% commercial and governmental usage and 6% industrial loads. The electric power is used increasingly to meet air-conditioning load in the summer months.

C. Necessity of designing a hybrid system for Masirah Island

In order to provide a cost-competitive and environmentally friendly electricity service to Masirah Island, a hybrid energy system planning scheme is proposed in this paper. The proposed wind-diesel hybrid generation system aims to:

- Gain an immediate access to reliable electricity at any time.
- Avoid long waits for grid extension and permit the connection when/if this becomes available.
- Reduce negative impact of possible oil price fluctuations.
- Improve health care and education in Masirah Island.
- Respond positively to climate change and fuel poverty.

- Allow for a more effective use of local natural resources.

In Middle East countries, oil and gas are the main sources of energy. However, diesel-based power systems will, sooner or later, grow to be a barrier for Masirah Island due to the operating costs (elevated fuel and transport prices), the high needs of maintenance, acoustic and environmental pollution issues and the geographical difficulties to deliver the fuel to remote areas. Retrofitting hybrid power systems to the existing diesel based plants will significantly minimise delivery and transport problems and will drastically reduce maintenance and emissions, providing an effective solution to address the social, economic and environmental development needs of Masirah Island and Oman in general.

SYSTEM DESIGN

To determine the most appropriate technological solution for hybrid systems a feasibility study based on gathering field data for the specific site and on a life cycle cost analysis is required. Technical, economic, financial, and socio-cultural considerations must all be included in the decision process to ensure the appropriate choice of technologies and operational and ownership scheme. Location, resource evaluation and load analysis are among the basic criteria to be considered to design an optimal power supply solution.

Once the most appropriate system configuration has been chosen, a carefully and responsible selection of components should be carried out considering a range of factors such as: quality (reliability), yield, regular maintenance requirements, after sales service availability, cost of servicing, warranty, spare parts availability and price.

It is not realistic to consider all the above factors to illustrate the design a hybrid energy system in this paper. The focus here will be cost reduction and environmental improvement. To design a hybrid energy system at Masirah Island, it is necessary to know the exact nature of energy consumption and wind power generation in a given period, e.g., daily or annually.

A. Wind Power Generation Model

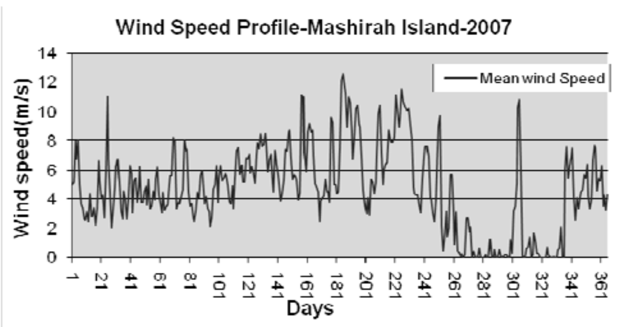

Fig. 1 Daily wind speed profile for Masirah Island

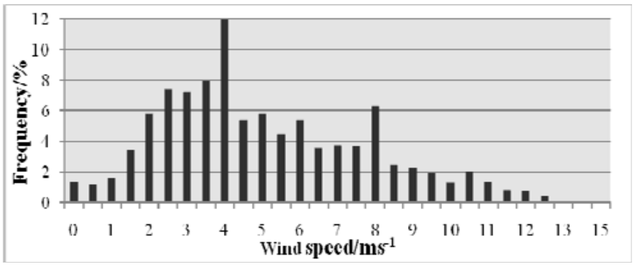

Fig. 2 Annual wind speed distribution at the Masirah Island

Figure 1 shows the wind speed profile for Mashirah Island in 2007 and Figure 2 shows the wind speed distribution based on three years of historic data.

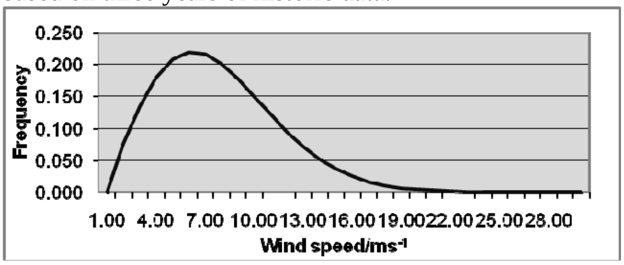

Fig. 3 Weibull distribution of wind speed

A random variable v can be expressed with a Weibull distribution (shown in figure 3) by utilising the probability density function (pdf) as given by Stevens and Smulders [5] and shown below (1),

$$f(v,c,k)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}},\quad v>0,c>0,k>0 \qquad (1)$$

Where c is a scale parameter with the same units as the random variable and k is a shape parameter.

The electric power output of a wind turbine is primarily a function of wind speed [6] and as shown below (2),

$$P_w(v)=\begin{cases}0 & 0\le v<v_i\\ P_r\dfrac{v^k-v_i^{\,k}}{v_r^{\,k}-v_i^{\,k}} & v_i\le v<v_r\\ P_r & v_r\le v<v_0\\ 0 & v_0<v\end{cases} \qquad (2)$$

Where v_i is the cut-in wind speed, v_r is the rated wind speed, v_o is the cut-out wind speed and P_r is the rated electrical power (illustrated in Figure 4).

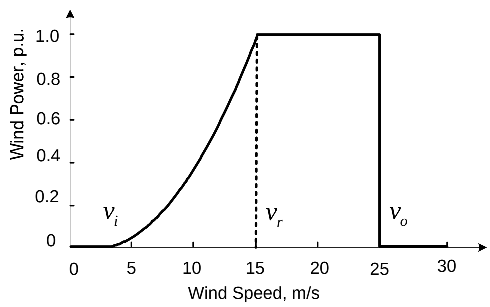

Fig. 4 Wind Turbine generator power curve

The average wind power output from a wind turbine is the power produced at each wind speed multiplied by the fraction of the time that wind speed is experienced, integrated over all possible wind speeds. The average power output of a turbine is a very important parameter for a wind energy system since it determines the total energy production and hence the total income. It is a much better indicator of economics than the rated power, which can easily be chosen at too large a value. The equation in integral form is as follows:

$$\overline{P}_w = \int_0^{\infty} P_w(v) f(v) dv \qquad (3)$$

The formula of average wind power output can be obtained by substituting (1) and (2) into (3), which gives (4),

$$\overline{P}_w = P_r \bullet [\frac{e^{-(\frac{v_i}{c})^k} - e^{-(\frac{v_r}{c})^k}}{(\frac{v_r}{c})^k - (\frac{v_i}{c})^k} - e^{-(\frac{v_o}{c})^k}] \qquad (4)$$

B. Load model

The electric load curve is essential for designing a power supply system based on hybrid energy resources in order to reduce the capital and operation costs – this is shown in Figure 5.

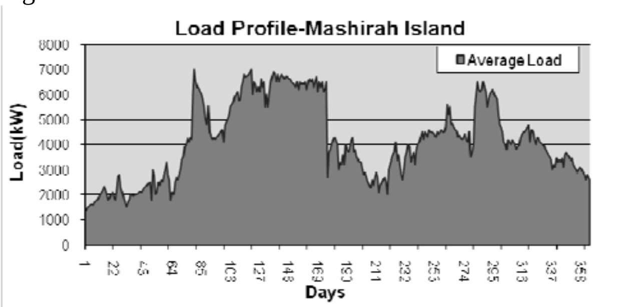

Fig. 5 Annual electric load demand

C. Hybrid System configuration

There are currently four types of diesel generators within the Masirah power system. . It is assumed that there are 10 Enercon-44 wind generators to be installed in Masirah Island (this provides the potential to provide the current peak demand solely from wind power). The technical data for the Enercon-44 unit is as follows [8],

Rated power: 900 kW
Rotor diameter: 44m
Hub height: 55m
Cut-in speed: 2 m/s
Cut-out speed: 28-34 m/s

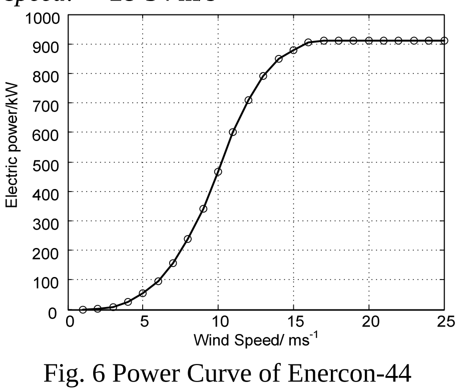

Fig. 6 Power Curve of Enercon-44

As discussed in the above context, the average wind power output from a wind turbine can be obtained by equation (4), provided that the parameters *k* and *c* are known. There are several methods which can be used to estimate the Weibull parameter *k* and *c*, depending on which wind statistics are available and what level of sophistication in data analysis one wishes to employ. Here the 'Least-squares Fit to Observed Distribution Method' has been employed to calculated the Weibull parameters, which are shown in table I,

Table I Weibull distribution parameters

shape parameter, *k*	scale parameter, *c*
1.931	5.428

Table II shows the costs for wind turbines and diesel generators [9],

Table II Annualised cost of generators

Generator	Initial Capital $	Annualised capital $/a	Annualised Replacement $/a	Annual O&M $/a	Annual Fuel $/a	Total Annualized $/a
E-44	6,468,750	506,030	119,545	5,625	0	631,200
265 kW Diesel	682,500	53,390	21,803	33,552	232,114	340,859
3136 kW Diesel	940,800	73,596	269,782	357,441	1,540,636	2,241,455
1000 kW Diesel	400,000	31,291	42,106	54,260	274,600	402,257

The annual fuel cost is calculated based on the International diesel price, which is circa 2.00 US$/Gallon on 1st Dec, 2008. Although Oman is rich in fossil fuel, the international fuel price is a better reflection of the real value of diesel.

In addition, the impact of diesel generators on environmental, especially carbon dioxide emissions has been considered. Table III shows the emission data of a typical general diesel generator [10],

Table III Emission data for typical diesel generator

CO_2 lb/MWh	NO_x lb/MWh	SO_2 lb/MWh	CO lb/MWh	PM-10 lb/MWh
1300-1700	10-41	0.4-3	0.4-9	0.4-3

Figure 7 shows the proposed Wind-diesel Hybrid Energy System; in which energy storage is not included (energy storage would potentially provide additional benefits). It is assumed that the diesel generator can start immediately in case of low output of wind power.

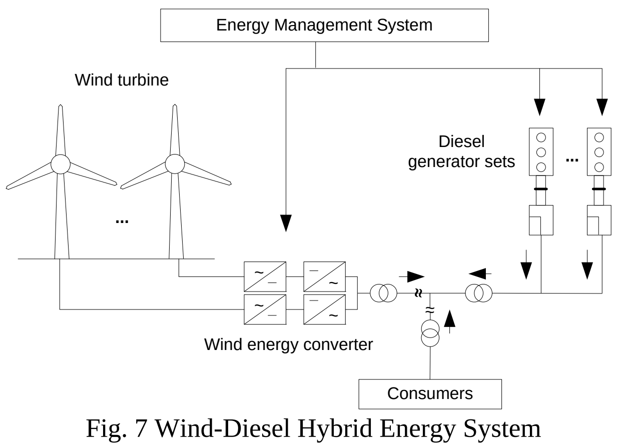

Fig. 7 Wind-Diesel Hybrid Energy System

RESULTS

A. Cost Reduction

The average wind power output P_w from E-44 wind generators can be obtained by substituting parameters v_i = 2.0 m/s, v_r = 15 m/s, v_o = 28 m/s, k = 1.931 and c = 5.428 into equation (4).

P_w = 112.722 kW, which means that 9.874×10^6 kWh of electricity in Masirah power system can be annually supplied by wind energy. The cost of energy production is found to be US$0.0639 from wind power generation, which is very competitive compared to that of diesel powered electricity generation (i.e. US$0.26) in Masirah Island. The cost of energy production of the proposed hybrid energy system will therefore be between US$0.0639 and US$0.26.

B. Environment Benefits

The environmental benefits are listed in Table IV,

Table IV Environmental impact reduction from wind-diesel hybrid system

CO_2 /t	NO_x /t	SO_2 /t	CO/t	PM-10/t
5822.4-7613.9	44.788-183.63	1.7915-13.436	1.7915-40.309	1.7915-13.436

For the purpose of encouraging reducing emissions of carbon dioxide to protect the environment, carbon tax is introduced in this paper. Peer-reviewed estimates of the social cost of carbon (SCC) for 2005 have an average value of US$43 per tonne of carbon (tC) (i.e., US$12 per tonne of carbon dioxide). In this paper, a tax of $100 per ton of CO_2 is assumed. A tax of $100 per ton of CO_2 translates to a saving of about 0.6 million US dollars for9.874×10^6 kWh of electricity generated by wind generators. The avoidance of paying carbon tax will further reduce the electricity tariff by $0.06/kWh.

CONCLUSIONS

The preliminary study of this paper implies a wind-diesel hybrid system is an economically viable alternative to a traditional diesel generation system. The cost of energy production from wind energy proved to be very competitive compared to that of the existing generation system.

At present, the electricity of Masirah Island is heavily subsidised by the state. The affordability of electricity in Masirah Island depends largely on the subsidy from the Government and the relatively low price of local diesel, which is much cheaper than the corresponding international fuel price.

By choosing renewable energy, developing countries can stabilise their CO_2 emissions while increasing consumption through economic growth. The introduction of carbon tax will put renewable energy such as wind and solar on a more competitive footing.

However, achieving sustainable economic and widespread use of hybrid systems will only be possible if local management schemes, effective policies, meaningful finance and international cooperation with industrialised countries are put in place.

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