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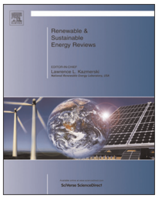

A review of optimum sizing of hybrid PV–Wind renewable energy systems in oman

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ABSTRACT

Renewable energy hybrid power systems have been proven through their ability to address the limitations of single renewable energy system in terms of power efficiency, stability, and reliability while operating at minimum cost. In this regards many research and practical experiences have been done. The present paper reviews the different hybrid PV–Wind renewable energy hybrid systems used for electrical power generations. Different criteria of sizing the different system components of hybrid renewable energy power plant at the most preferable logistical environmental and economical considerations have been discussed. Also, the paper discussed some of the optimization approaches which are used to compare the energy production cost and performance of different hybrid system configurations using simulation techniques. Based on the fact that, potential of the wind and solar energy is not equal in Oman, this paper will discuss the optimum sizing process of two proposed hybrid PV–Wind plants in Oman.

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1. Introduction

Hybrid Renewable Energy Systems (HRES) are defined as an electric energy system which is made up of one renewable source and one or more sources. These sources could be conventional or renewable or mixed, that works in off-grid (standalone) or grid connected mode [1]. The main feature of hybrid renewable energy systems is to combine two or more renewable power generation and so they can address emissions, reliability, efficiency, and economical limitations of single renewable energy source [2].

HRES are becoming popular for standalone power generation in isolated area due to the improvement and efficiency increment in renewable energy technologies and power electronic converters [3]. Based on the availability of the natural local resources, there are some advantages of the hybrid system. Higher environmental protection, green house gas emission, especially CO_2 and reduction in other pollutants emissions is expected due to the lower consumption of fuel. The cost of solar and wind energy can be competitive with nuclear and the diversity and security of natural resources who are free, abundant, and inexhaustible [4]. Most of these appliances can be easily installed and they are rapidly deployed. Financially, the costs are predictable and not influenced by fuel price fluctuations [5–8]. However, because of the photovoltaic (PV)–Wind changeable nature and dependence on climatic changes and weather, a common drawback to PV and wind power generations is that both would have to be oversized to make their standalone systems reliable for the times when neither system is producing enough electric power to satisfy the load [9].

Many areas are concerned with the applications of the HRES. Researches [1,10] have focused on the performance analysis of demonstration systems and the development of efficient power converters, such as the maximum power point trackers and bi-directional inverters [11,12]. Other researches focused on the battery management units and the storages devices [6].

In the last decade, various HRES have been installed in different countries, resulting in the development of systems that can compete with conventional, fuel based remote area power supplies [13]. However, there are several combinations of hybrid energy system which mainly depend on the natural available resources, the wind or the solar energy practically represents one source of the hybrid renewable energy systems.

With the advance development of the hybrid PV–Wind systems for electrical power generation, the target to achieve reliable and efficient performance became complicated task. So that there is a need to select and configure the optimum sizing of all components in order to obtain the minimum capital investment while maintaining system reliability to satisfy the load [14,15]. This paper summarized three common used sizing methods for hybrid PV–Wind systems. Moreover, the paper will discuss some optimization techniques of the PV–Wind HRES. These techniques are used to compare the technical performance and cost of energy for different system configurations using simulation approaches.

The objectives of this study are to investigate the hybrid solar-wind systems in Oman and optimum design techniques used. This work will focus on the standalone (off-grid) PV–Wind HRES as both solar and wind has the highest potential in Oman compared to the other renewable energy sources [16,17]. Revision and discussion of the related studies in literature are presented. Two case studies will be discussed as a practical implementation of the right sizing and optimization of the Masirah and Al-Halaniyat Islands proposed HRES. Finally, discussion of the current hybrid systems in Oman and possibilities to install new systems is recommended.

2. PV–Wind HRES

In fact, the use of small isolated HRES is expected to grow enormously in the near future [18], both in developing and industrialized countries.

Solar and wind are naturally corresponding in terms of both resources being well suited to hybrid systems [19]. HRES combine PV–Wind systems to make the most of the area's seasonal solar and wind resources; solar relatively more available in summer months and during winter's sunlit days and with wind relatively more available in winter months and at night time [13].

These HRES provide a more consistent year-round output than either solar or wind-only systems and can be designed to achieve desired attributes at the lowest possible cost [20]. Most HRES have backup power through batteries or/and diesel engine generator. Moreover, Fig. 1 compares PV system capital costs of three common PV technologies. The cost of electricity of the three PV technologies has dropped from 15 to 20 times; and grid-connected PV systems currently sell for about 5–10$ per peak Watt (20–50 ¢/kWh), including support structures, power conditioning, and land. In contrast, the system efficiency of the three technologies has increased to about 10–13% [21].

The wind capital cost of class 4 and 6 wind turbines is shown in Fig. 2. The cost of both systems has dropped by 180 $ per kW in the last two decades [21].

However, both Figs. 1 and 2 shows promised figures for the real investments of the solar and wind HRES, the optimum design of hybrid system becomes complicated through uncertain renewable energy supplies uncertain load demand, non-linear characteristics of the resources with the increased complexity, the need for practical sizing and optimum configuration becomes an important issue [22].

Industries and researchers face some challenges in the developments of the hybrid PV–Wind energy systems. The following may be considered, poor efficiency of the solar PV sources as the efficiency cannot reach more than 17.5%, high manufacturing cost which leads to longer payback time [16–17].

Beside all of the technical considerations there are other factors which must be included such as the local infrastructure, social aspects, financial investment, and the whole system durability. Furthermore, references [1,10] have presented some steps which must be taken into account before installing PV–Wind HRES. They include selecting the most suitable location for installation, acquiring data on the local natural potential of available wind energy and solar energy and determining the annual energy. Then the right sizing of the whole system can be set as it will be discussed in the following sections.

3. Sizing tehcniques of PV–Wind HRES

Before setting up or installation of a new HRES, it is essential sizing using intuitive method of the individual components to obtain the initial capital investment cost and feasibility study [18]. Unit sizing is basically a method of determining the right practical sizing of the HRES components by minimizing the system cost [14] while maintaining system reliability. The correct sizing is to determine the wind generator capacity (size and number of wind turbines), the number of PV panels and number and capacity of battery banks needed for the standalone system. Note that it is important to maintain optimum resource management in a hybrid generation system in order to avoid wrong sizing. Over sizing the system components will increase the system cost whereas under sizing can lead to failure of power supply to fulfill the load requirements [14]. The literature has presented three techniques of sizing.

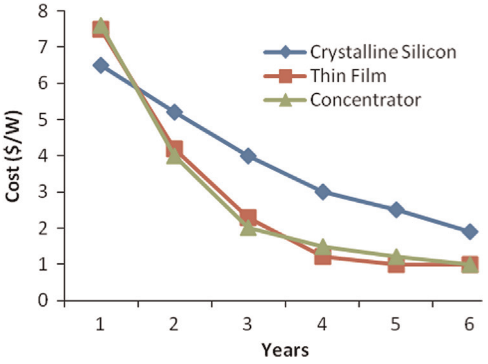

Fig. 1. Capital cost for PV system with different technologies.

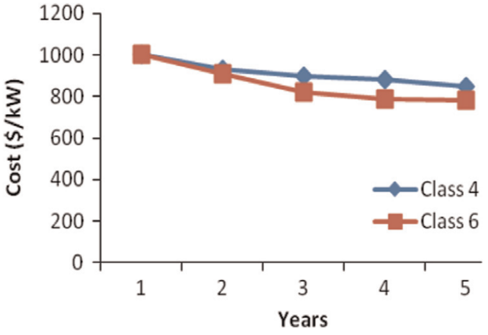

Fig. 2. Capital cost of wind system with different classes.

3.1. *The annual monthly average sizing technique*

The PV panels and wind generators size are determined from the average annual monthly values of energies statement. This calculation is based on the average annual monthly data of solar radiation and wind speed.

3.2. *The most unfavorable month technique*

The PV and wind generators are being calculated in the most unfavorable month. Generally the month most unfavorable in wind is favorable in irradiation. Here the system must be dimensioned in two most unfavorable months (unfavorable irradiation and wind months). When the system functioned in these months it's automatically functioned in the other months.

3.3. *Loss of power supply probability (LPSP) technique*

The LPSP is the probability that an insufficient power supply results when the HRES is not able to satisfy the load demand [23,24]. This technique consists in determining the optimal number of the batteries and the PV modules according to the optimization principle knowing: the reliability, which is based on the concept of the probability of loss of energy [25,26], and on the cost of the system. This technique presents the advantage that the introducing of the wind generator permits to minimize the cost of the PV standalone system, by minimizing the size of the PV generator and storage number of batteries [27]. Two methods can be used for the application of the LPSP in designing an off-grid hybrid PV–Wind HRES. The first one is based on chronological simulations. The second approach uses probabilistic techniques to incorporate the fluctuating nature of the resource and the load, thus eliminating the need for time-series data.

4. Optimization techniques of PV–Wind HRES

Optimization techniques for PV–Wind HRES in general, are used to provide the best system sizing with minimum cost. Many techniques are used for this purpose, but the most popular models are revised in this chapter, namely Graphic Construction, Probabilistic, Iterative and Artificial Intelligence optimization techniques.

Optimization techniques of the PV–Wind HRES are used to set up the optimum configuration of renewable energy configuration. Simulation techniques are used to compare the performance and cost of energy for different system configurations. Several software tools [28] are available for designing of hybrid systems, such as homer, hybrid2, hoga and hybrids [29]. Depending on the availability of the metrological data, two approaches are followed to achieve the correct optimum sizing. The conventional techniques are based on the energy balance and reliability of supply and they make use of the metrological weather data. If the weather data are not available, the system must be optimized using different methods as will be discussed in this section.

4.1. *Graphic construction technique*

This technique can configure the optimum combination of PV array and battery for a standalone hybrid PV–Wind system based on using long-term data of solar radiation and wind speed recorded for every hour of the day for very long years [2]. Other applications used the monthly-average Markvart [7]. For given load and a desired LPSP, the optimum sizing of the HRES PV–Wind can be achieved by assuming that the total cost of the system is linearly related to both the number of PV modules and the number of batteries. The minimum cost will be at the point of tangency of the curve that represents the relationship between the number of PV modules and the number of batteries.

4.2. *Probabilistic technique*

The effect of variation of the solar radiation and wind speed are the main factors in the system design of this technique. Authors of Ref. [29] has proposed a sizing method treating storage energy variation as a random walk. The probability density for daily increment or decrement of storage level was approximated by a two-event or three- event probability distribution. This method was extended to account for the effect of correlation between day to day radiation values.

Other applications presented the probabilistic technique based on the convolution technique. The fluctuating nature of the resources and the load is incorporated, thus eliminating the need for time-series data for the assessment [30].

4.3. *Iterative technique*

Ref. [31] proposed a Hybrid PV–Wind System Optimization (HSWSO) model, which utilizes the iterative optimization technique following the LPSP model and Levelised Cost of Energy model for power reliability and system cost, respectively. Three sizing parameters are considered, i.e. the capacity of PV system, rated power of wind system, and capacity of the battery bank. For the desired LPSP value, the optimum configuration can be identified finally by iteratively searching all the possible sets of configurations to achieve the lowest Levelised Cost of Energy.

Similarly, in Ref. [32] an iterative optimization method was presented to select the wind turbine size and PV module number using an iterative procedure to make the difference between the generated and demanded power (DP) as close to zero as possible over a period of time. From this iterative procedure, several possible combinations of PV–Wind generation capacities were obtained. The total annual cost for each configuration is then calculated and the combination with the lowest cost is selected to represent the optimum mixture.

4.4. *Artificial intelligence technique*

There are different artificial intelligence techniques which are widely used to optimize a HRES in order to maximize its economic benefits [32], such as Genetic Algorithms, Artificial Neural Networks and Fuzzy Logic. Genetic Algorithms are also widely used in the design of large power distribution systems because of their ability to handle complex problems with linear or non-linear cost functions. Ref. [33] proposed one optimum sizing method based on Genetic Algorithms by using the Typical Meteorological yearly data, while desired LPSP with minimum Annualized Cost of System is maintained. Two optimization variables that are not commonly seen, PV array slope angle and turbine installation height have been considered. Such algorithms are applicable for the conventional optimization methods such as dynamic programming and gradient techniques. Ref. [34] has compared between all optimization techniques and listed all advantages and disadvantages.

Comparing between the mentioned models has been made, which they are the most prevalent models, hence Graphic Construction, Probabilistic, Iterative and Artificial Intelligence has been compared in term of accuracy, time consumption and complexity. In Table 1, accuracy of optimization techniques categorized as (high, low, fair) and for time consumption as (fast, long, fair). Besides the category of complexity as (high, low, fair).

Iterative and artificial intelligence techniques have a better result than other techniques because of low average of RMS error value. From the other side graphic construction and probabilistic techniques are simple with the acceptable accuracy. Furthermore, Iterative and artificial intelligence are more complex than the other two techniques. Finally, selecting the optimization technique depend on adopted criteria, available information, and simplicity and accuracy of the technique.

5. Discussion of solar-wind energies in Oman

Authors of Ref. [17] have discussed and addressed all renewable energy resources in Oman, solar and wind energy present the highest potential for applicability in the country. The following sections overview these energies and their potential applications.

5.1. *Solar energy*

In Oman, solar energy is the main renewable energy resource which is currently utilized in Oman for some local small applications. Oman is one of the highest solar energy densities in the world, the received solar radiation ranging from 5500–6000 Wh/m^2 a day in July to 2500–3000 Wh/m^2 a day in January [17].

Table 1
Technical details of the load and different sources at Masirah Island.

Modeling technique	Accuracy	Time consumption	Complexity	References
Graphic construction technique	Low	Fast	Low	[2,7]
Probabilistic technique	Fair	Fast	Low	[29,30]
Iterative technique	High	Long	High	[31,32]
Artificial intelligence technique	High	Long	High	[32–34]

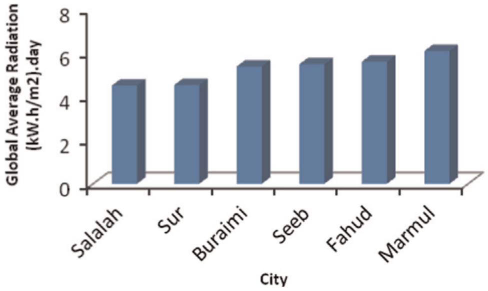

Fig. 3. Global average radiation in Oman for 1987–1992.

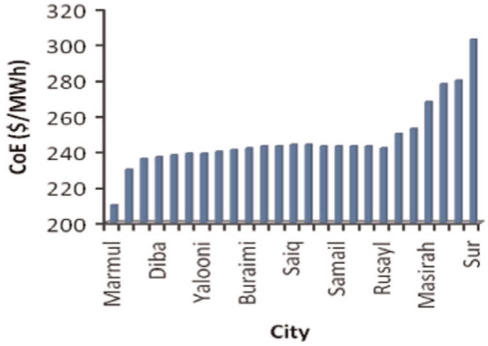

Fig. 4. The CoE for 25 locations in Oman.

A solar energy evaluation study [35] covered several years in order to estimate the long term average solar energy resources. The average global isolation data which is the sum of direct and diffuse radiation from 1987 to 1992 for six locations in Oman is depicted in Fig. 3.

As shown in Fig. 3, the solar isolation varies from 4.5 to 6.1 kWh/m^2 per day which corresponding to 1640–2200 kWh/m^2 per year. Salalah and Sur have a significant lower insolation compared with other stations; this is due to the summer rain period in Salalah and the frequent period with fog in Sur. Relatively high solar energy density is available in all region of Oman. The total solar energy resources in Oman are enormous and can cover all energy demands as well as could provide export [17].

The consumption of energy is higher during the summer time due to the need for air conditioning. During the winter time the surplus production can be exported to Europe where the need for energy is highest [17]. For real solar PV energy investment in Oman, the following points must be considered [8]

1. The solar PV technology is suitable for grid power plants electricity generation in northern and southern parts of Oman.
2. The solar PV technology is also suitable for electricity generation in off-grid power plants in rural desert areas where the solar energy can reduce diesel fuel use. The efficiency of PV cells is influenced by high air temperature and dust contamination.
3. It was found that highly suitable land for PV applications in Oman can provide more than 600 times the current electric energy demand if Thinfilm PV technology is used [8].

Authors of Ref. [36] has investigated the economical prospect of the solar PV in Oman for a 25 location assuming a 5 MW plant as shown in Fig. 4.

The research results revealed the following:

1. The renewable energy produced each year from 5 MW PV power plant vary between 9000 MWh at Marmul and

6200 MWh at Sur while the mean value is 7700 MWh of all the 25 locations.
2. The capacity factor of PV plant varies between 20% and 14% and the cost of electricity CoE varies between 210 and 304 $/MWh for the best location to the least attractive location.
3. The study has also found that the PV energy at the best location is competitive with diesel generation without including the externality costs of diesel.
4. An average of about 6000 t and 5000 t of green house gases GHG emissions can be avoided for each implementation of PV station that is currently using diesel and natural gas, respectively.

Theoretically, it is possible to power Oman by utilizing about 280 km^2 of desert from solar collectors, corresponding to 0.1% of the area of the country [36].

5.2. Wind energy

Wind energy has become a major source of energy today; it is clean, free, and inexhaustible source of energy. In 2012, wind power capacity increased by 19% bringing the world total to almost 283 GW [37].

The assessment of the wind energy resources in Oman is based on the hourly wind speed data measured at twenty one stations in

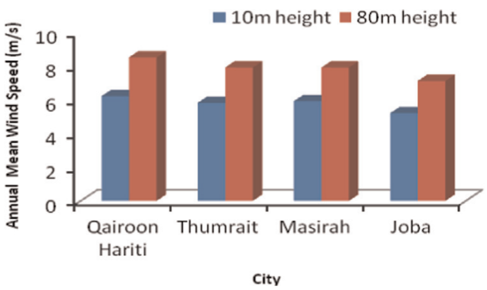

Fig. 5. Annual mean wind speed at 10 m and at 80 m above ground level at five meteorological stations.

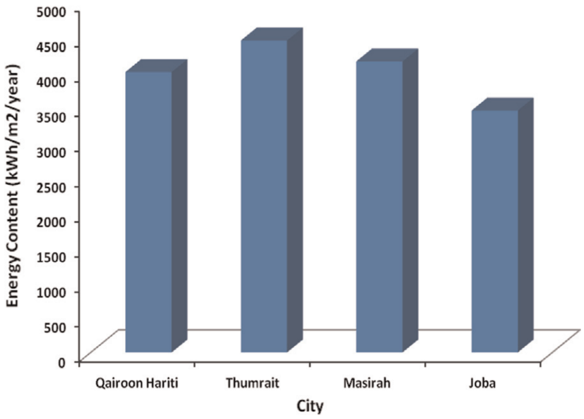

Fig. 6. Energy content in the wind at 80 m above ground level at five meteorological stations in Oman.

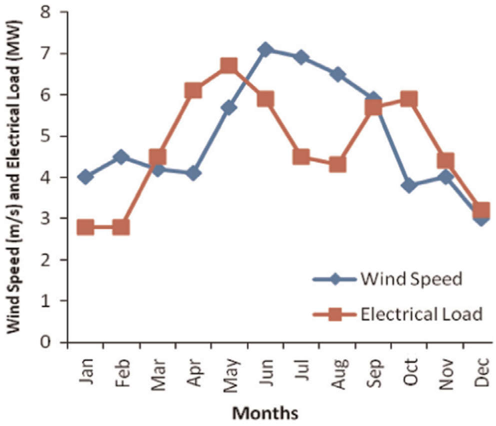

Fig. 8. Masirah monthly average wind speed in m/s and monthly load in MW (2008).

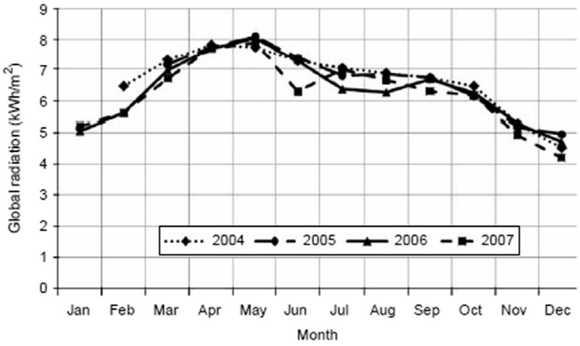

Fig. 9. Masirah monthly average solar radiation between 2004 and 2007.

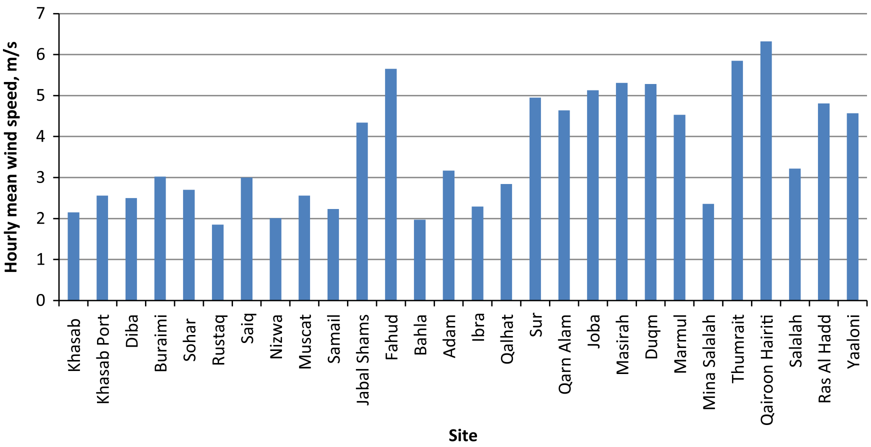

Fig. 7. Hourly measured mean wind speed at 10 m above ground level at 28 meteorological stations.

Table 2
Technical details of the load and different sources at Masirah Island.

Item	Details	Remark
Site information (Masirah Island)	Area of about 649 km^2 population estimated to 12,000	Scattered in 12 villages
Average wind speed	4.99 m/s	1997–2008 at 10 m height
Solar average daily radiation	6.4 k Wh/m^2	from 2004 till 2007
Annual electrical energy demand	43,624,270 kWh	Year 2011 minimum load 550 kW maximum load 9530 kW

2005 under the responsibility of Directorate General of Civil Aviation and Meteorology (DGCAM) [35]. The wind data is measured at 10 m and estimated at 80 m above ground level to represent a hub height of a modern large wind turbine (capacity 2–3 MW). Five stations with the highest wind speeds were identified and the annual mean wind speed is shown in Fig. 5.

Further assessment was done to estimate the annual energy content at each of the five stations. The energy is specified as kWh per year through a vertical area of one m^2, kWh/year/m^2. The maximum expected energy is at Thumrat for an almost 4.5 kWh/m^2/year. The assessment results are shown in Fig. 6.

The main findings of the study are:

1. The high wind speeds are found along the coast from Masirah to Salalah. The highest wind speeds are in the Dhofar Mountain Chain north of Salalah. The low wind speed areas are in the north and western part of Oman.
2. The highest wind energy speeds are observed during the summer period. The summer period is also the period with the highest electricity demand in Oman.
3. The study reveals that at the present gas price of 1.5 $/MMBtu wind energy is not economical. The wind energy at Quiroon Hariti, the highest wind potential in Oman, becomes marginally economical at a gas price of 6 $/MMBtu [35].
4. This clearly shows that wind application for large wind farms is not presently economical. However, the wind energy remains a suitable option for hybrid applications.

Several studies were conducted on wind energy resource assessment in Oman [38], it was found that wind power can be considered as a promising renewable energy resource for power generation, especially on the coastal and southern parts of Oman (see Fig. 7). The global solar radiation in Oman is very high various in the range of 3.2–6.2 kWh/m^2/day with a high potential of solar energy the whole year on most of the land. Also, the ratio of sky clearness in Oman is about 342 days/year. The authors of Ref. [17] claimed that there are many places in Oman have a potential of solar energy and the highest solar radiation in Oman is found in Marmul, Fahud and Sohar. In other word, Oman has a very good solar energy potential and therefore, any PV system investment in this area expected to be worth. From the other hand, wind energy found to be high and continuous in many place specially the south part of Oman with average wind speed 4.5 m/s. Few places have both potential of solar and wind energy, which could be target for hybrid systems, as examples Marmul, Fahud, Thamrid and Masirah.

6. Hybrid PV–Wind energy systems in Oman

The authors of Ref. [13] have investigated different combinations of hybrid systems of diesel generator, wind turbine, PV array, and battery, for Masirah Island in Oman. The wind and the solar assessment for Masirah Island are presented in Figs. 8 and 9, respectively.

Table 3
Optimum sizing configuration for the proposed Masirah Island hybrid plant.

Proposed diesel generator details	10 Units capacity between 200 kW and 3300 kW	The actual diesel price for Masirah Island is 0.468 $/L
Number of the PV panels	1.6 MW PV, cost=3000 $/kW O and M cost=10$/year/kW	
Proposed Wind turbine	Rated power=250 kW @ Height= 31 m Rated wind speed =13 m/s	
Batteries	Type 6CS25P, Nominal voltage 6 V, Nominal capacity 1156 Ah Nominal energy capacity of each battery (VAh/1000) 6.94 kWh	
Converter: Cost=900$/kW, Efficiency=90%		
Level of RE penetration: 25%		

Figs. 5 and 8 shows that the average yearly wind speed is 4.99 m/s and the measured wind speed happens to be quite high when the electrical load requirement is also high. Moreover, wind speeds are generally higher during the months of April to September compared to other months. The average monthly solar radiation between 2004 and 2008 is shown Fig. 9.

Using the above metrological weather background and the technical details given Table 2, the optimum sizing of the system components was selected based on the monthly average sizing technique. The optimum sizing results are illustrated on Table 3.

Furthermore, a comparison of cost of energy of different hybrid PV–Wind-Battery-Diesel systems was developed as shown in Table 4.

It is shown here that using PV–Wind–Diesel HRES with a battery unit will produce the lowest CoE (0.182 $/kWh) compared to other hybrids. It can be noticed that the combination and the ratio of the types of energy depending greatly on the resources locally available in each geographical area.

Authors of Ref. [13] used LPSP to size their HRES components. Homer software has been used to optimally design the system. Authors claims that Masirah Island have promising site to implement HRES, where they proposed different scenarios. Authors simulation results indicate that for a HRES composed of 2.25 MW wind generator, 1.6 MW PV array and existing 8.478 MW diesel with the presence of 28 minutes battery unit (equivalent to 28 min of average load) the CoE has been found to be 0.182 US$/kWh with the actual diesel price of 0.468 US$/L.

The second study is presented in for Al Hallaniyat Island in Oman [40]. The technical and economic viability of utilizing different configurations of hybrid system (PV–Wind–Diesel) was investigated using the weather data from 2004 to 2008. Al Hallaniyat's annual electrical energy demand for the year 2008 was 1,303,290 kWh with a minimum load of 50 kW and a maximum load of 320 kW. The average wind speed at 10 m height was 5.19 m/s and the yearly average daily value of solar radiation was 6.8 kWh/m^2 [40].

The wind assessment at Al Hallaniyat Island shows that wind speeds are generally higher during the months of from May to August when compared with other months. The wind duration

Table 4
A comparison of cost of energy for different systems.

CoE	Battery unit	PV–diesel hybrid system	Wind–diesel hybrid system	PV–Wind- diesel hybrid system
	Yes	**0.186 $/kWh** with 28minutes battery system	**0.189 $/kWh** with 28minutes battery system.	**0.182 $/kWh** with the presence of 28minutes battery unit
	No	**0.189 $/kWh** without batteries and the annual diesel consumption will increase by 1%	**0.187 $/kWh** with no battery system used	**0.185 $/kWh** if the battery unit is removed from the hybrid system

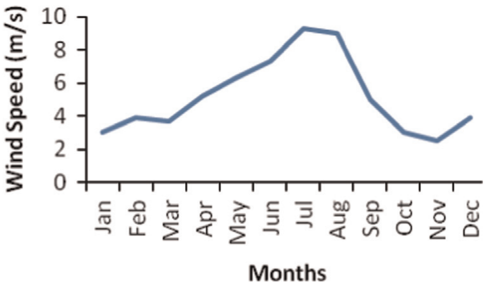

Fig. 10. Monthly average wind speed at Al Hallaniyat Island-Oman.

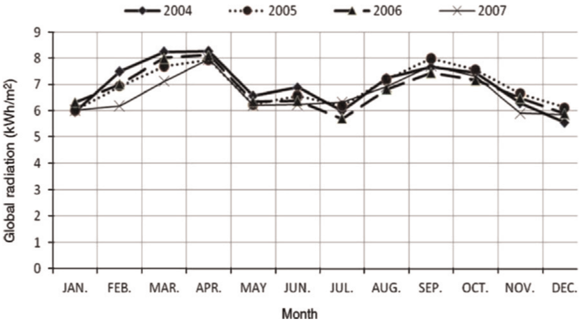

Fig. 11. Monthly average daily global radiation at a site near Al Hallaniyat Island-Oman.

Table 5
Technical details of the load and different sources at Al halaniyat Island.

Item	Details	Remark
Site information (Al Hallaniyat Island)	Area of about 56 km^2 population estimated to 150	Among five the Khuriya Muriya Islands
Average wind speed	5.19 m/s	At 10 m height
Average daily value of solar radiation	6.8 kWh/m^2	From 2004 till 2007
Annual electrical energy demand	1,303,290 kWh	Year 2008 minimum load of 50 kW and a maximum load of 320 kW

analysis indicated that the wind speeds are less than 4 m/s for about 40% of the time during the year, as shown in Fig. 10.

The monthly average solar radiation for the 2004–2007 is plotted in Fig. 11. The insolation level is high during the high electrical load season (March–May) when compared with other months. The yearly average daily value of solar radiation is 6.8 kWh/m^2.

The technical details of the site and the load are summarized in Table 5. Since both wind and PV are promising systems in this location, a hybrid system was considered in the analysis consisting of combinations PV–Wind–Diesel with and without batteries. Fig. 12 shows the proposed hybrid system which can be implemented Al Hallaniyat Island [40].

Using the above metrological weather background and the technical details given Table 5, the optimum sizing of the system components was selected based on the monthly average sizing technique. The optimum sizing results are illustrated on Table 6.

Author of Ref [40] used homer software to investigate the optimum scenarios to supply electrical demand in Al-Hallanyat Island. The author has claimed that there is potential site for deployment of a HRES, especially with the diesel fuel price $0.5081^{-1}. The simulation results showed that for a HRES composed of 70 kW PV, 60 kW wind, 324.8 kW diesel generators together with battery storage, with renewable energy penetration of 25%, the total CoE was found to be $0.222 kWh^{-1}. Also, it is found that removing the 30 min battery unit from the HRES will increase the CoE to $0.225 kWh^{-1}.

7. Conclusions

This study addresses the concepts of off-grid HRES for electrical power generation. HRES allows high improvement in the power reliability, with high accuracy and fast optimization techniques, high system efficiency, and reduce the system requirements for storages devices. The paper has also presented different sizing techniques for off-grid PV–Wind HRES. Accurate sizing of HRES can significantly help to determine the initial capital investment while maintaining system reliability at minimum cost. The optimization techniques of the PV–Wind HRES were also discussed. The optimization techniques compare the performance and energy production cost of different system configurations and that will help to set up the optimum configuration of HRES configuration using simulation techniques. It has been demonstrated that hybrid energy systems can significantly reduce the total life cycle cost of stand-alone power supplies in many situations, while at the same time providing a more reliable supply of electricity through the combination of energy sources. Nevertheless hybrid power systems may constitute the most economical solution in many applications. Two case studies have been discussed and compared. The first was for Masirah Island 12 MW hybrid PV–Wind solar plant and the other one was for Al Halaniyat Island where the CoE found to be 0.182 $/kWh and 0.222 $/kWh, respectively, which sound that HRES is promising in Oman. It is found that there is potential of solar-wind energy. However, Iterative and Artificial Intelligence optimization techniques used shows more accuracy and fast comparing with other optimization techniques.

It is highly recommended to apply similar scenarios in other places in Oman, which have high potential of solar and wind like Jabal Alakhdar and Thamrit.

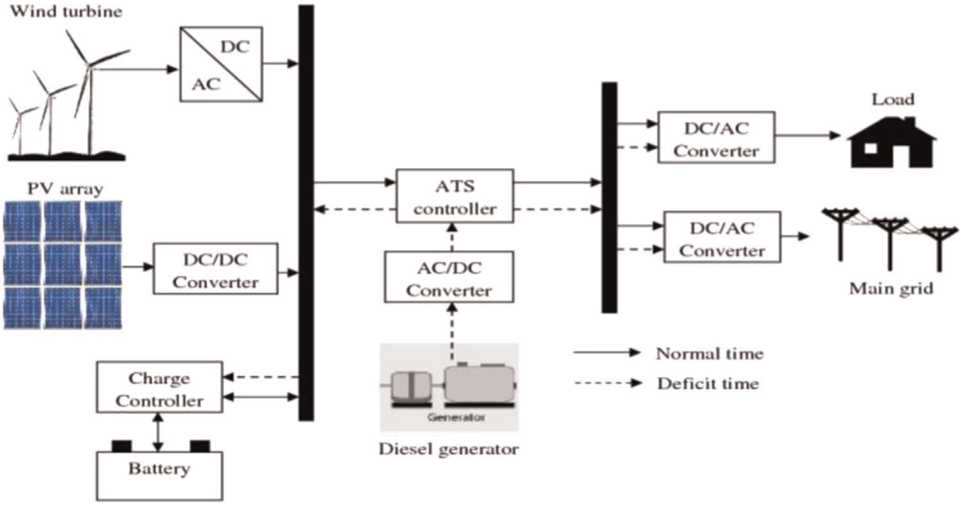

Fig. 12. Proposed hybrid PV–Wind–Diesel system for AL Halaniyat.

Table 6
Optimum sizing configuration for the proposed Masirah Island hybrid plant.

Proposed Diesel generator details	10 units Capacity 1080.8 kW	Diesel price: $0.508
Number of the PV panels	70 kW with 30 min storage capacity	A standard cost of $3000 kW^{-1} Lifetime 25 years O and M cost $10 per kW per year
Proposed Wind turbine	Rated power=60 kW @ 11.3 m/s Height= 10 m Rated speed =11.3 m/s	capital cost $60,000 Replacement cost $40,000 Lifetime 30 years
Batteries	Type US305HC, Nominal voltage 6 V, Nominal capacity 305 Ah Nominal energy capacity of Each battery (VAh/1000) 1.83 kWh	
Converter	Cost=900$/kW Efficiency=90%	
Level of RE penetration: From 10–25%		

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