Wind Resource Assessment Of Eastern Coastal Region Of Saudi Arabia

Elhadidy, M.A. and Shaahid, S.M.
Center for Engineering Research, Research Institute,
King Fahd University of Petroleum and Minerals,
Dhahran 31261, Saudi Arabia

ABSTRACT
In the present study, the hourly mean wind-speed data of the period 1986-1997 recorded at the solar radiation and meteorological station, Dhahran (Eastern coastal plain of Saudi Arabia), has been analyzed to present different characteristics of wind speed in considerable depth such as: yearly, monthly, diurnal variations of wind speed, etc. The long-term monthly average wind speeds for Dhahran range from 4.2 to 6.4 m/s. More importantly, the study deals with impact of hub height on wind energy generation. Attention has also been focussed on monthly average daily energy generation from different sizes of commercially available wind machines (150 kW, 250 kW, 600 kW) to identify the optimum wind machine size from energy production point of view.

It has been found that for a given 6 MW wind farm size, at 50 m hub height, array of 150 kW wind machines yields about 48 % more energy as compared to 600 kW wind machines. Literature shows that commercial/residential buildings in Saudi Arabia consume an estimated 10 - 40% of the total electric energy generated. So, concurrently, as a case-study, attempt has been made to investigate/examine the potential of utilizing hybrid (wind-diesel) power systems to meet the load requirements of hundred typical 2-bedroom residential buildings (with annual electrical energy demand of 3512 MWh).

The hybrid systems considered in the present case-study consist of different combinations of wind machines (of various capacities), supplemented with battery storage and diesel back-up. The deficit energy generated from the back-up diesel generator and the number of operational hours of the diesel system to meet a specific annual electrical energy demand of 3512 MWh have also been presented. The evaluation of hybrid system shows that with seven 150 kW WECS (wind energy conversion systems) and three days of battery storage, the diesel back-up system has to provide 17.5 % of the load demand. However, in absence of battery storage, about 37 % of the load needs to be provided by the diesel system

KEYWORDS: Wind machines, battery, hub-height, wind-diesel integration, residential loads

1. INTRODUCTION
Depleting oil and gas reserves, combined with growing concerns of global warming, have made it inevitable to seek energy from renewable energy sources such as wind. The utilization of energy from wind is becoming increasingly attractive and is being

widely used/disseminated for substitution of oil-produced energy, and eventually to minimize atmospheric degradation. Quantitative assessment of wind resource is an important driving element in successful establishment of a wind farm/park at a given location. More often than not, wind-energy resources are relatively better along coastlines.

In view of escalating/sky-rocketing cost of oil and uncertainty in supply of oil since the mid-1970s, utilisation of energy from renewables such as wind has gained considerable momentum and is being widely used for displacement of oil-produced energy, and eventually to minimize atmospheric degradation. Modern thinking considers wind as a permanent shield against ever increasing power prices. Literature indicates that wind energy (being free, non-depletable, site-dependent, environment-friendly, promising, non-polluting) is being vigorously pursued by a number of developed and developing countries with average wind speeds in the range of 5 m/s – 10 m/s, in an effort to reduce their dependence on fossil-based non-renewable fuels (Nfaoui et al., 1998), (Rizk et al., 2001), (Nayar et a., 1991), (Bellarmine and Joe, 1996), (Lori, 1992), (Randall and Paul, 1992), (Daoo et al., 1998), (Amr et al., 1990). Cumulative global wind energy installed capacity reached 47,000 MW at the end of 2004 [an increase of 20% as compared to the global installed capacity of 2003 (which was 39, 294 MW)]. By 2020, wind is expected to share 10% of global electricity supply. The price of generating energy using wind machines has dropped dramatically over the last decade and currently it is in the range of 3 to 5 cents per kWh depending upon wind-speed/wind-farm-size at a given project site. The cost of generating electric energy from other energy sources is in the range of 4.8 to 14.5 cents per kWh (Coal: 4.8-5.5 cents/kWh, Gas: 3.9-4.4 cents/kWh, Hydro: 5.1-11.3 cents/kW, Nuclear: 11.1-14.5 cents/kWh, etc.). The technology of the wind machines has improved considerably over the last five years. WECS in the range of 3.2 MW are commercially available. The rate of increase in installed capacity during the last ten years is in the range of 30 percent per annum (www.awea.org, 2005). Typical wind power applications/targets include lighting, electical appliances, military installations, communication/gas stations, electricity for remote settlements, water pumping for irrigation or desalination, and cathodic protection of pipe lines, etc.

Stand-alone WECS (inspite of remarkable technological advancements/milestones) do not produce usable energy for considerable portion of the time during the year. This is primarily due to relatively high cut-in wind speeds (speed at which WECS starts producing usable energy) which range from 3.5 to 4.5 m/s. In order to overcome this downtime/offset, use of hybrid (wind-diesel) systems have been recommended in the literature. Stand-alone diesel generator sets, while being relatively inexpensive to purchase, are generally expensive to operate and maintain especially at low load levels (Nayar et al., 1993). In general, the variations of wind energy generation do not match the time distribution of the load demand on a continuous basis. Therefore power generation systems dictate the association/incorporation of short-term battery storage facility to smoothen/shrink the time-distribution-mismatch between the load and wind energy generation and to account for maintenance/outages of the systems (Traca et al., 1983), (Seeling, 1997). Wind-driven power systems are expandable (in view of modular concept), additional capacity may be added as the need arises. The cost of wind power system is ≈ 1100$/kW and that of battery is ≈ 170$/kWh (Bergey,

1993)**.** The prospects of derivation of power from hybrid wind/diesel/battery sources of

energy are proving to be promising world-wide (Nayar et al., 1993), (McGowan and Manwell, 1998), (Cramer, 1994), (Beyer and Langer, 1996), (Bhatti et al., 1997). The hybrid based power generation is becoming a viable, cost-effective approach for remotely located communities (that need an independent source of electrical energy) where it is uneconomical to extend/stretch the conventional utility grid.

The Kingdom of Saudi Arabia's total electricity generation has increased sharply *(from 1141 MW in 1975 to 30,000 MW in 2003; also the peak demand is expected to be 59000 MW in 2020)* during the last two decades (Ministry of Industry & Electricity, 1997), (Omar, 2002)**.** In particular, Dhahran's peak electricity demand has escalated substantially from 7317 MW in year 1995 to 8332 MW in year 2001 (Saudi Electricity Co., 2000), (Abdurrahman, 2002). The above significant increases can be attributed to rapid growth in residential, commercial, and industrial sectors**.** The number of consumers grew from 300,000 in early seventies to approximately 3.5 million in 2000. The installed generating capacity of the power plants in the Kingdom reached more than 26,000 MW in 2001 (Saudi Electriicty Co., 2001)**.** Since, Saudi Arabia is blessed with reasonable wind regime, an appreciable fraction of its energy needs may be harnessed from wind energy**.** Moreover, use of alternative sources of energy reduces CO_2 emmision which is the principal cause of global warming. Literature indicates that addition of 1.5 MW WECS, capable of producing about 4 million kWh of energy/year, would eliminate 5.6 million tons of CO_2 (Hansen, 1998), (www.win.enron.com). Also investments in mobilization of wind power can stimulate the local economy by making use of available local resources (Bellarmine, 1996).

The research on viability of renewable energy systems at Dhahran in particular and at Saudi Arabia in general has been the subject matter of several earlier studies (Elhadidy and Shaahid, 2000), (Elhadidy and Shaahid, 1998), (http://www.un.int/saudiarabia/solar1). Wind resource assessment is an important driving consideration in successful establishment of a wind farm at a given location. In the present study, hourly mean wind-speed data for the period 1986-1997 recorded at the solar radiation and meteorological station, Dhahran (26° 32' N, 50° 13' E), Saudi Arabia, has been analyzed to address the yearly/monthly/diurnal variations of mean wind speed, frequency distribution of wind speed (i.e. availability of wind in different wind speed bins), etc**.** More importantly, the study deals with the effect of hub height on wind energy production. Attention has also been focussed on monthly average daily energy generation from different sizes of commercial wind machines (150 kW, 250 kW, 600 kW) to identify optimum wind machine size from energy production point of view (for a given wind farm size, for a given hub height). Literature shows that commercial/residential buildings in Saudi Arabia consume an estimated 10-40% of the total electric energy generated. In this perspective, attempt has been made to investigate/examine the potential of utilizing of hybrid wind-diesel power systems to meet the load requirements of hundred typical 2-bedroom houses. As a case-study and as a representation of residential buildings, the measured annual average electric energy consumption (based on 5 years of data) of hundred *typical* centrally air-conditioned family houses (floor area of each house = 169.98 Sq.m), located in Dhahran, has been considered as predefined yearly load profile (3512 MWh) in the present study. The hybrid systems considered in the analysis consists of

different combinations of wind machines (of various capacities), supplemented with battery storage system and diesel back-up units**.** The deficit energy generated from the   back-up diesel generator and the number of operational hours of the diesel system to match the above electrical energy demand of 3512 MWh have also been addressed. The diesel back-up system is operated at times when the power generated from wind energy conversion systems (WECS) fails to satisfy the load and when the battery storage is depleted.

2. METEOROLOGICAL/SITE-SPECIFIC INFORMATION

Climatic conditions dictate the availibility and magnitude of wind energy at a site**.** Dhahran is located just north of the Tropic of Cancer on the eastern coastal plain of Saudi Arabia and is nearly 10 km inland from the Arabian Gulf Coast. Although it is in the vicinity of the coast, Dhahran is situated in very much a desert environment**.** Two distinct seasons are noticed in this region : a very hot season (May to October) and a cold season (Nov. to April)**.** Monthly mean temperatures reach close to 37°C for hot months and in cooler months the mean temperatures drop by about 20°C as compared to the hot months**.** The relative humidity exhibits a large diurnal cycle on the order of 60% round the year. Typical annual precipitation totals are around 80 mm. The winds blow from 270° to 360° direction range (north to north-westerly winds) for most of the time during the year (Shaahid and Elhadidy, 1994).

3. INSTRUMENTATION

The solar radiation and meteorological station of the Center for Engineering Research of the Research Institute is located at Dhahran on the roof of Research Institute's building from where the view of the horizon is unobstructed. Currently, fourteen solar radiation and six meteorological sensors are being monitored using an IBM PC based Data Acquisition System (DAS). List of the parameters measured at the station are reported in (Elhadidy and Shaahid, 1994). The instruments meet the requirements for class 1 sensors according to the classifications of the World Meteorological Organization (Guide to meteorological instrument, 1971). The data is collected every minute and integrated over each hour using DAS. The hourly values are transferred, on monthly basis, to the university mainframe computer for further processing. The wind speed measurements are made using Texas cup anemometer. The station is continuously supervised (to clean the sensors, to minimize loss of data due to instrumental problems, to ascertain accuracy, etc). The sensors are regularly calibrated against reference sensors maintained at the station. More description of the station and the DAS have been provided in (Shaahid and Elhadidy, 1994).

4. WIND DATA AND OPERATIONAL   STRATEGY   OF WIND-DIESEL SYSTEM

Figure 1 shows yearly variation of wind speed. The variation is almost following a cycle, which repeats itself every 10 or 11 years**.** This clearly supports the need for long-term wind speed for design purposes. The long-term monthly average wind speeds for Dhahran (for the period 1986-1997) are presented in Figure 2**.** Wind speeds are generally higher in summer months (May to Aug.) as compared to other months. This indicates that a WECS would produce appreciably more energy during summer months as compared to the other months. The seasonal behavior/trend of wind speed matches the higher electrical load requirements during summer period in

Saudi Arabia. Long-term monthly average wind speeds for Dhahran range from 4.2 to 6.4 m/s. The overall average wind speed is about 5.2 m/s. The data also shows that there is considerable variation of monthly average wind speed from one month to another month. These variations show that the monthly energy output/yield from WECS would be subjected to considerable differences. Figure 3 exhibits diurnal variation of wind speed. The diurnal variation provides information on the availability of the wind during entire day. The diurnal variation shows relatively higher winds between 0900 and 1800 hours while lower values during the rest of the day. This type of diurnal pattern of wind speed matches with the general electricity load requirement and hence may be useful to capture more power of the wind during day time. Regarding frequency distribution of wind speed (i.e. availability of wind in different wind speed bins), previous studies at Dhahran show that wind speeds are less than 4 m/s for 35% of time (Elhadidy and Shaahid, 1999). The cut-in speed of most of the commercial wind machines (CWMs) is about 4 m/s. This implies that stand-alone WECS installed at Dhahran will not produce energy for about 35% of the time during the year. In-order to overcome this downtime, a diesel back-up or a large energy storage system may be needed to meet the required load.
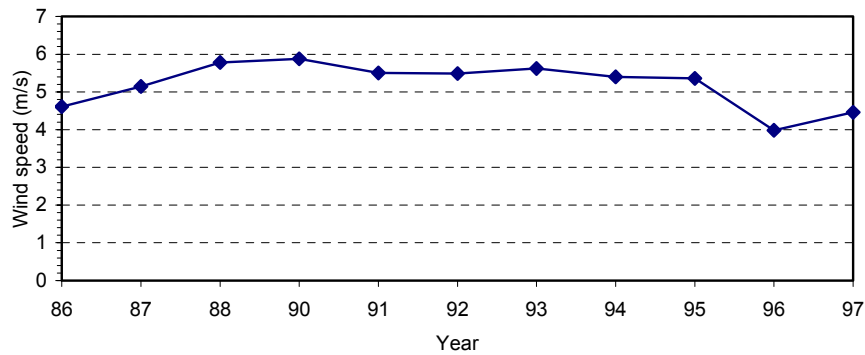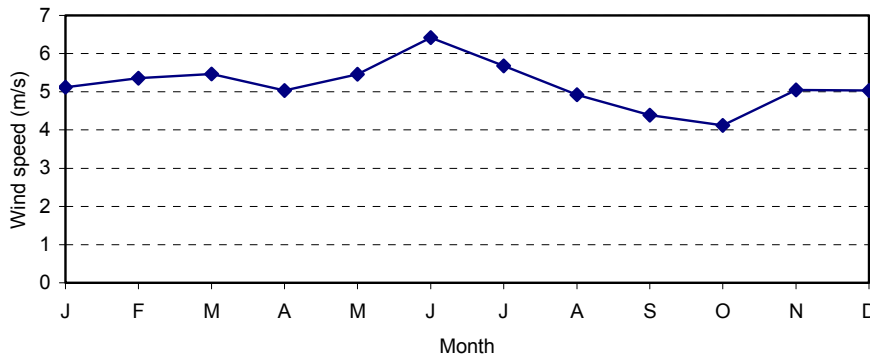

Figure 1. Yearly average wind speed at Dhahran

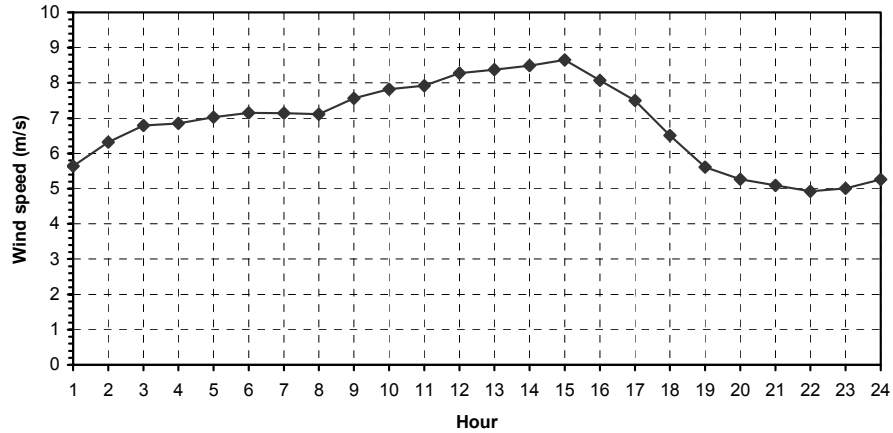**Figure 2. Monthly average wind speed at Dhahran (average of period of 1986-1997)**

Figure 3. Diurnal variation of wind speed at Dhahran (1993)

Wind energy calculations are made by matching the power-wind speed characteristics of CWMs with the long term hourly wind speed data. The characteristics/technical-data of some NORDEX-CWMs are furnished in Table 1. Despite, maturity in the state-of-the-art/technical-know-how, today's best wind machines can achieve an overall efficiency of about 35 percent (Elhadidy and Shaahid, 1998). Earlier study on wind energy (Elhadidy and Shaahid, 1999) suggests that in order to avoid undersizing or oversizing of WECS or diesel systems, the data of the years 1987-1995 can be safely used for design purposes. In this regard, the year 1992 has been considered as a representative year for present analysis .

Table 1. Power-wind characteristics of some commercial wind machines

Wind machine model	Rated Power (Kw) Rp	Rated Speed (m/s) Vs	Cut-in Speed (m/s) Vci	Cut-out Speed (m/s) Vco	Rotor Diameter (m)	Hub height (m)
Nordex N27/150	150	16.0	3-4	25	27	30, 40, 50
Nordex N29/250	250	15.5	3-4	26	29.7	30, 40, 50
Nordex N43/600	600	13.0	3-4	25	43	40, 50, 60
Nordex N54/1000	1000	14.0	3-4	25	54	50, 60, 70
Nordex N60/1300	1300	15.0	3.5	25	60	50, 60, 70

Rp   is the maximum power obtained from the WECS.
Vci   is the speed at which WECS starts producing energy.
Vs   is the speed at which generated power reaches Rp.
Vco is the speed at which WECS no longer produces power.

The mode of operation of the hybrid wind-diesel system in the present case-study (in the simulation) is as follows: in normal operation the WECS feeds the load demand. The excess energy (the energy above the average hourly demand; if any) from the WECS is stored in the battery until full capacity of the storage system is reached (i.e. until the battery gets fully charged). The main purpose of introducing battery storage is to import/export energy depending upon the situation. In the event, that the output from WECS exceeds the load demand and the battery's state of charge is maximum, then the excess energy is drained away or fed to some dump load. A diesel back-up

system is operated at times when WECS fail to satisfy the load *and* when the battery storage is depleted.

5. RESULTS AND DISCUSSION

5.1 Effect of hub height on wind energy production:

In-order to assess the effect of hub height, wind energy calculations have been made at 30, 40 and 50 above the ground level (*wind is faster, less turbulent and yields more energy at 30 m or more heights above the ground*) (www.eren.doe.gov), (Abdelrazzaq, 2002). These heights are equivalent to hub/tower heights of CWMs. The exercise of estimating wind-energy at different heights has been carried out by using $1/7^{th}$ wind power law. The $1/7^{th}$ power law is recognized as a handy tool to carry out vertical wind speed extrapolation to the desired hub height (Farrugia, 2002). Wind energy calculations are made by matching the power-wind speed characteristics of CWMs with the long term hourly wind speed data. Wind energy calculations have been made for different NORDEX wind machines of various rated capacities and the results are furnished in Table 2. The results exhibit that in passing from 30 m to 40 m height, the energy production increases by 7 %. Furthermore, in passing 30 m to 50 m height, the energy production increases by about 12 %.

5.2 Effect of wind machine size on energy production:

Attention has been focussed on the effect of size of wind machine on wind farm/park from energy production point of view (for a given wind farm size, for a given hub height). The monthly average daily energy calculations have been made for 6 MW (for eg.) wind farms consisting of 10, 24, and 40 machines of 600 kW, 250 kW, and 150 kW rated output (at a hub height of 50 m above the ground level) respectively and the results are summarized in Table 3. It has been found that for a given 6 MW wind farm size (at 50 m hub height) cluster of forty 150 kW wind machines yields about 39 % more energy as compared to twenty-four 250 kW wind machines. Furthermore, for the same 6 MW wind farm size (at 50 m hub height), cluster of forty 150 kW wind machines yields about 48 % more energy as compared to ten 600 kW wind machines. This analysis indicates that wind machines of smaller size produce more energy collectively in a given wind farm as compared to bigger size machines. This considerable increase in energy production could be attributed to an increase in the number of wind machines.

Table 2.0   Monthly average daily energy generated from commercial wind machines (for the year 1992, at different hub heights)

Rated power of the wind machine (kW)	Monthly average daily energy generated (kWh) at different hub heights		
	30 m	**40 m**	**50 m**
150	1441	1540	1621
250	1716	1845	1950
600	*	4110	4375

* In general, hub height of 600 kW wind machine varies from 40 m to 60 m.

Table 3.0   Monthly average daily wind energy (kWh) generated from 40, 24, and 10

wind turbines of rated capacities 150, 250, 600 kW respectively
(for the year 1992 at Dhahran, at a hub height of 50 m)

Month	Wind machines with different rated powers (kW)		
	Forty 150 kW (6 MW wind farm)	Twenty-four 250 kW (6 MW wind farm)	Ten 600 kW (6 MW wind farm)
January	75265	54045	51273
February.	71307	51364	48292
March	57624	41014	37680
April	53840	38729	35062
May	62074	44869	41802
June	93535	69669	67457
July	90200	66556	64944
August	53774	38218	34725
September	46199	33125	29648
October	44800	31433	27532
November	56224	40414	37189
December	73784	52376	49513
Annual Avg.	**64877**	**46821**	**43750**

5.3 Hybrid wind/diesel/battery system for residential loads (case-study):

An important governing element of any power generating system is load which is highly application-dependent. As a case study and as a representation of residential buildings, the measured annual average electrical energy consumption (based on 5 years of data) of hundred typical centrally air-conditioned family houses (floor area of each house = 169.98 Sq.m), in Dhahran, has been considered as predefined yearly load (3512 MWh) in the present study [Analysis of energy consumption in buildings, 1992]. This load could also be a representation of group of remotely located (off-grid) residential buildings which do no have access to the utility grid (even today, there are many communities living/dwelling in small pockets in remote locations of Saudi Arabia). The projected monthly average daily load profile is shown in Figure 4. As depicted in Fig. 4, the load seems to peak during June to Sept. The peak requirements of the load dictate/characterize the system size.

The hybrid systems simulated in the present study consist of different combinations of 150 kW WECS, supplemented with battery storage system and diesel back-up. The study explores a suitable mix of wind farm capacity and battery storage to match the pre-defined load while minimizing the operation of diesel-backup. In view of economic considerations and for optimum use of battery-storage/diesel, battery storage is assumed to be equivalent to three days of maximum monthly average daily demand (Elhadidy and Shaahid, 1999).

For given battery storage (equivalent to 3 days of maximum monthly average daily demand)**,** the variation of monthly average daily wind energy for different number of 150 kW machines, for the year 1992 is presented in Fig. 4. It is clear from Fig. 4, that a combination of three 150 kW, do not satisfy the load requirements for all the months of the year. This indicates that significant amount of energy needs to be supplied from the diesel generator to meet the load**.** Extensive use of the diesel system may result in frequent start/stop cycles (which promote wear) of the diesel generator**.** Moreover, focal point of the case-study is to minimize contribution of diesel. Therefore, in-order to minimize on the contribution of diesel, simulations have been made by increasing the number of wind machines. It is obvious from Figure 4 that, as penetration of WECS increases, operational months/time of diesel system decrease. For given seven 150 kW WECS and battery storage (equivalent to 3 days of maximum monthly average daily demand)**,** the load requirement is satisfied for about 8 to 9 months. For this scenario, invariably the diesel backup system has to be operated during August to October to match the load distribution**.**
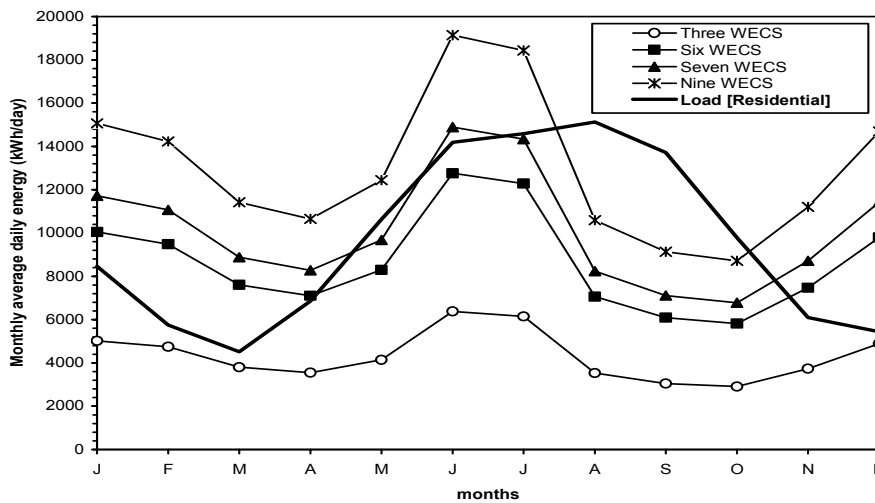

Figure 4. Comparison between energy generated by wind [WECS (150 kW)] systems using 1992 data with 3 days of battery storage at 30 m hub height (at Dhahran)

To gain more insight of the hybrid system, the impact of variation of rated wind farm capacity (for pre-defined battery storage of three days) on the ratio of diesel energy (De) generation to load (L) and on number of hours of operation of diesel system are shown in Figures 5 and 6**.** Examination of Fig. 5 yields some useful information**.** The diesel energy to be generated with three 150 kW WECS is considerably high**.** Expectedly, use of more wind machines (supplemented with battery storage) results in reduction of diesel energy to be generated for matching load**.** With six 150 kW WECS, about 23 % of the load requirement has to be provided from diesel system**.** However, with seven 150 kW WECS, the diesel system has to provide 18 % of the load demand (Fig. 5.), also the no. of hours of operation of the diesel system get reduced by about 74 % (Fig. 6)**.** Furthermore, decrease in diesel energy to be generated is not much (pronounced) for more than seven 150 kW WECS**.** However, it should be emphasized, that a trade-off has to be established/recognized between wind farm capacity and diesel energy generation**.** So, in-order to minimize the operation of

diesel system, it is judicious to consider seven 150 kW WECS to meet the load requirements for considerable portion of the year.
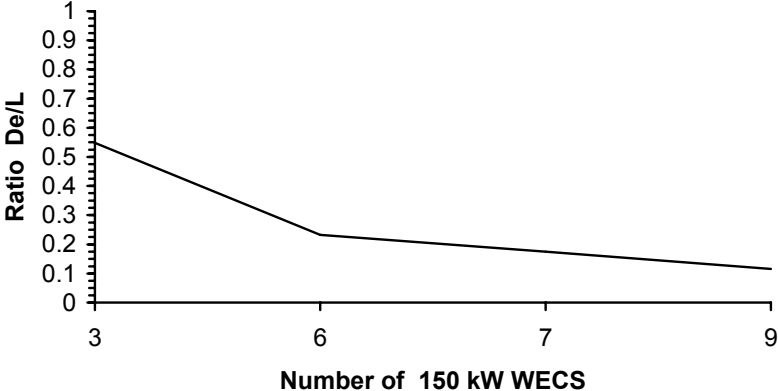

Figure 5. Variation of Ratio of Diesel energy [De] to Load [L] with different number of WECS (150 kW)
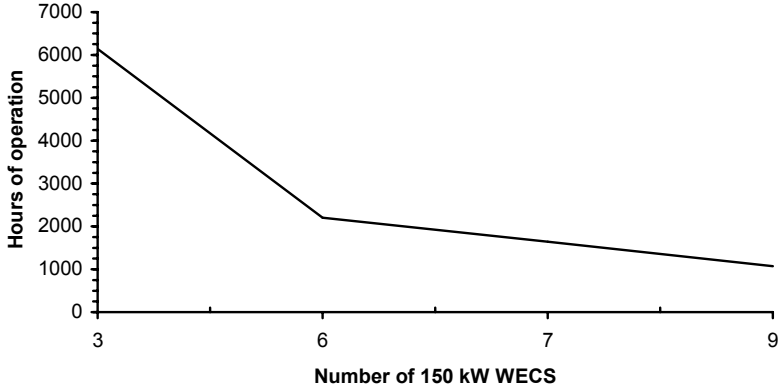

Figure 6. Variation of number of hours of operation of Diesel system area with different no. of WECS (150 kW)

As a final remark (to assess the significance of battery), and for a more realistic evaluation of the decrease in diesel energy generation, the hybrid system (seven 150 kW + three days of battery storage at the beginning of 1986 + diesel) has been simulated for the period 1986-1997. Similar simulation for the same time-frame has also been made *but without* any battery storage. The diesel energy generation for these scenarios has been plotted in Figure 7 which indicates that presence of battery makes all the difference. It is evident from Fig. 7, that the diesel energy generation is considerably less with inclusion of battery storage. It has been found that, on an average about 18 % of the yearly load has to be supplied from the diesel system with the presence of three days of battery storage. However, with elimination of battery storage, about 37 % of the yearly load needs to be provided by diesel system.
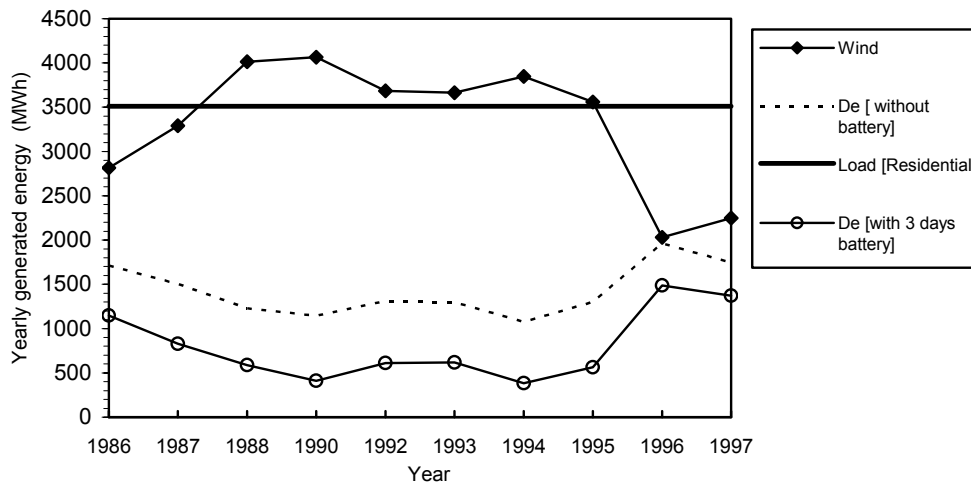
Figure 7. Yearly generation of Wind energy [seven 150 kW WECS] and Diesel energy (De) to meet a predefined Residential annual load of 3512 MWh

6. CONCLUSION

The present study indicates that the long-term monthly average wind speeds for Dhahran range from 4.2 to 6.4 m/s. In view of this reasonable wind regime, appreciable fraction of this region's energy may be harnessed from wind energy. The analysis highlights that hub-height plays a role in energy generation. It has been found that in passing from 30 m to 50 m height, the energy production increases by 12 %. Emphasis has also been placed on the effect of wind machine size on wind farm/park, it has been noticed that for a given 6 MW wind farm size (at 50 m hub height) cluster of 150 kW wind machines yields about 48 % more energy as compared to 600 kW wind machines.

The case-study considered in the present investigation indicates that although Dhahran is a viable candidate for installation of WECS systems (to meet the energy needs of buildings), but large stand-alone WECS systems will be required to manage the peak load in the months Aug. to October**.** This offset in power can be taken care by integrating WECS with battery storage, and diesel back-up systems**.** The simulation study has discussed in considerable depth, the impact of variation of number of wind machines, and battery storage capacity on hybrid power generation. The case-study shows that a hybrid system configuration consisting of seven 150 kW WECS together with three days of battery storage is needed to satisfy the pre-defined residential load (3512 MWh) for significant portion of the year. For this scenario, the diesel back-up system has to provide 18 % of the load demand**.** With elimination of battery storage, about 37 % of the yearly load needs to be provided by diesel system.

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تقرير مصادر طاقة الرياح في منطقة الساحل الشرقي من المملكة العربية السعودية

الحديدي، م . أ و شاهد، س . م

مركز الأبحاث الهندسية، معهد الأبحاث ،جامعة الملك فهد للبترول والمعادن،
الظهران 31261، المملكة العربية السعودية.

ملخص

في هذا البحث تم تحليل نتائج سرعات الرياح المسجلة من عام 1986 حتى 1997 في محطة رصد إشعاع الشمس والأرصاد الجوية بالظهران (الساحل الشرقي من المملكة العربية السعودية)، للتعرف على خواص سرعات الرياح بعمق أكثر، مثل التغير السنوي، والشهري، واليومي. بلغ المتوسط الشهري، طويل الأمد، لسرعة الرياح في الظهران من 4.2 إلى 6.4 متر/ث. لقد اهتم البحث، بجدية أكثر، في دراسة تأثير ارتفاع توربين الرياح عن سطح الأرض في توليد الكهرباء. كما ركز البحث على حساب المتوسط الشهري للطاقة المتحصلة يومياً باستخدام توربينات رياح تجارية بقدرات متعددة (150 كيلووات، 210 كيلووات، 600 كيلووات) وذلك للتعرف على حجم التوربين الأمثل للاستخدام وفق طاقة الرياح المتوفرة.

لقد أوجد البحث أنه باستخدام حديقة توربينات بسعة إجمالية قدرها 6 ميجاوات، على ارتفاع 50 متر، لمنظومة مكونه من طواحين ذات سعة 150 كيلووات، تعطي 48% طاقة أكثر عند مقارنتها بطواحين ذات سعة 600 كيلووات. وتشير المراجع أن المنازل والمباني التجارية في السعودية تستهلك حوالي 10 إلى 48% من مجمل الكهرباء المولدة، لذلك سعى البحث على إختبار قدرة نظام هجين من طاقة الرياح ومكائن الديزل لتلبية احتياجات الحمل الكهربائي لمئة منزل سكني مكون من غرفتي نوم، و يستهلك سنوياً 3512 ميجاوات.ساعة.

والأنظمة الهجنية التي تم اعتبارها في هذه الدراسة تحتوي على مكونات متعددة من توربينات الرياح (ذات سعات متعددة) تساندها بطاريات خزن وماكينة ديزل، حيث تناول البحث دراسة العجز في تلبية الحاجة من الطاقة باستخدام مولدات الديزل لساعات تشغيلية من الطاقة السنوية بمقدار 3512 ميجاوات.ساعة. وبعد تقييم هذا النظام الهجين تبيّن أن استخدام 7 توربينات رياح، سعة كل واحد 150 كيلووات، مع بطاريات خزن لثلاثة أيام، فإن مولد الديزل سيساهم في تلبية 17.5% من الحمل المطلوب، أما في غياب البطاريات ، فإن مساهمة هذه المكائن حوالي 37%.