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Stand-Alone Hybrid Wind-Diesel Power Systems for Commercial Loads of Turaif-Saudi Arabia - Techno-Economics of Hot Desert Regions for Sustainable Clean Future

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Abstract**: *Hybrid wind-diesel technology is disseminated world-wide to minimize depletion of fossil-fuels and carbon emissions. Appreciable amount (10-40%) of energy generated is consumed by commercial/residential buildings of Kingdom of Saudi Arabia (K.S.A.). This investigation aims at techno-economic assessment of hybrid wind-diesel systems (HWDS) to satisfy electrical demand (620,000 kWh per year) of a representative commercial building at Turaif (Northern Province, K.S.A.) by analysis of wind speed data. As per the study, the monthly average wind speed of Turaif lies in the range 3.4 - 4.4 meters per second. The configurations simulated include various mixes of 100 kW wind machines (WTG) and diesel systems. The techno-economic evaluation is carried out by using NREL's (HOMER Energy's) HOMER software.***

The results point out that the wind fraction (with zero % load rejection) is 20% for a hybrid configuration composed of one 100 kW WTG together and 175 kW diesel generator. The energy generation cost (COE) from this system is 0.123 $/kWh. Also, 20% wind fraction, results in reducing carbon emissions by 91 tons/year. The diesel operation time is less with higher penetration of wind. Also, emphasis is on effect of wind fraction on energy produced, COE, operational time of diesel sets, un-met load, excess energy, fuel savings, carbon emissions, cost of HWDS, etc.

Keywords:* *Hybrid systems, wind-diesel technology, Commercial electrical demands, emissions, HOMER.

I. INTRODUCTION

Presently, we are witnessing a new evolving non-stable era in the global energy scenery. This poses serious challenges and opportunities for countries, industries, professionals and academics. The energy we use everyday leads to air pollution and carbon emissions. The threat of global warming and change in climatic conditions due to carbon emissions by use of fossil fuels paves avenue for exploring environmentally benign ways of generating energy. More importantly, to cater to Dec. 1997's Kyoto's requirement on carbon emissions, many countries are opting wind energy to cut-down carbon emissions. The quest for energy security and sustainable development (to meet growing needs/challenges) revolves on the ability to exploit/tap energy from non-depleting and environment friendly non-depleting sources (like wind).

Wind energy is a nature-friendly solution to displace energy generated from fossil fuels. As per literature, many nations with average wind speeds varying from 4 to 10 meters/second are deploying wind power systems to minimize dependency on fossil fuels [1-4]. World's wind installed capacity is 487,000 MW as of December 2016. The cost of energy generation from WTG is about 5 to 6 cents per kWh. The installed capacity of WTG is increasing at the rate of 25 - 30 percent per annum [5].

Stand-alone WECS are incompetent on economic front. Atmospheric pollution is mainly due to operation of stand-alone diesel systems [6]. However, coupling of WECS with diesel systems decreases pollution, may lower the COE ($/kWh), and yields reliable diesel system together with cost-effective wind energy. Considerable research is being conducted world-wide on renewable/wind energy systems [7-13]. As per literature, wind-diesel technology is disseminated globally (eventually to avoid atmospheric degradation and to protect our planet).

The electrical power consumption of the K.S.A. is rising fast. By 2023, the demand is forecasted to be 60000 MW. The air- conditioning systems consume about 70 percent of the power generated [14]. In view of reasonable wind potential of K.S.A., a portion of the requirements can be covered by alternative wind which cuts carbon emissions. According to literature, deployment of 1.5 Mega Watt WTG (which produces annually around four million kilo Watt Hour energy), will displace 5.6 million tons of emissions [15].

Some earlier studies have focused on viability of renewable power at K.S.A. [16]. This study aims at viability of HWDS to cover energy demand (620,000 kWh per year) of a commercial building at Turaif (*31°41' N, 38°40' E*, Northern Province, K.S.A.) by analysis of 1970-1982 data. At 10 m height, the average wind speed lies in the range 3.4 - 4.4 m/s. Wind speed is being used to examine the possibility of using HWDS technology. Simulation of hybrid systems includes various mixes of 100 kW WTG and diesel systems by using HOMER which is a sophisticated tool used for designing alternative/sustainable power systems [17].

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More importantly, the study emphasizes on impact of wind fraction
on energy generation, COE, operational time of diesel sets, capacity shortage, generation of excess energy, fuel savings, carbon emissions, cost of HWDS, etc.

II. METHODOLOGY AND BACKGROUND INFORMATION, WIND DATA, OPERATION OF HYBRID WIND-DIESEL SYSTEM

The K.S.A. is a desert region with arid weather. The available wind regime dictates characterization of WTG. Wind speed data of the years 1970-1982 has been utilized in this study [18]. The presence of international oil pipeline in Turaif has led to its establishment. The population is about 92,000. Turaif has climate with hot summers and cold winters. Saudi Arabia produces and exports large quantities of petroleum products globally [19].

Fig. 1 shows the monthly average wind speeds. The magnitude of wind speed during summer (May to Aug) is more. In this regard, more power can be produced in summer period *(this is a positive feature because the demand is high in summer)*. The data exhibits considerable variation between different months. These wind speed variations lead variations in energy generation from WECS. At 10 m height, the average wind speed (monthly) lies in the range 3.4 - 4.4 m/s. The annual average wind speed is 3.9 m/s. Figure 2 depicts the wind speeds at various hub-heights (by using $1/7^{th}$ power law). The energy yield from wind is more at 30 m or more height. The increase in wind speed is 26% by increase of height from 10 m to 50 m. Figure 3 depicts the raw daily wind speed data. Figure 4 shows the cumulative frequency distribution (CFD) of wind speed (this assesses the potential of a given location). The technical details of 100 kW WECS (employed in the present analysis) are shown in Table I. The technical details of diesel systems are listed in Table II. Figure 5 shows the characteristics of the 100 kW WTG. The efficiency of present day WECS is approximately 35 percent [20-21].

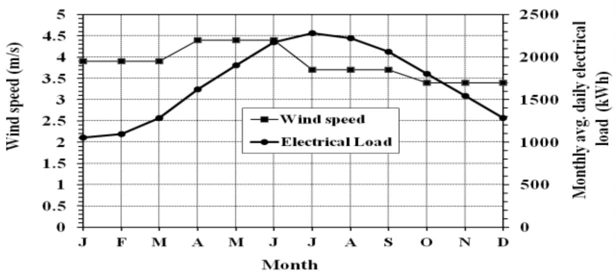


Fig. 1.Variation of wind speed and commercial load with months

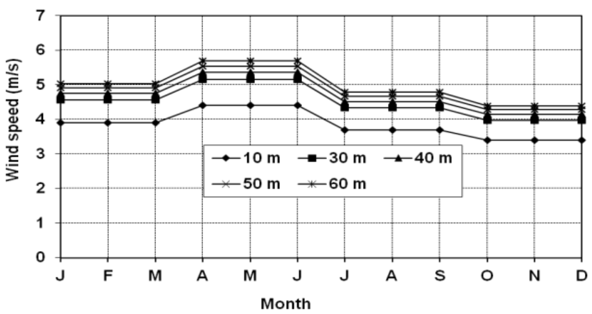


Fig. 2.Variation of wind speed with hub-heights

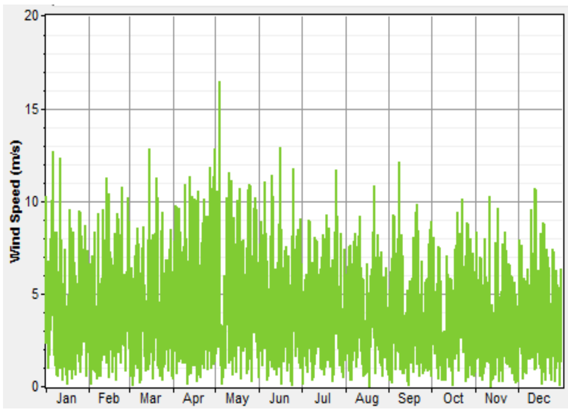


Fig. 3.Wind speed data (daily) for complete year

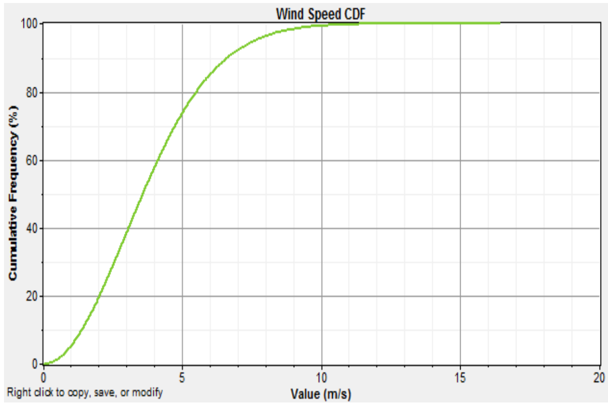


Fig. 4.Cumulatively distributed frequency of wind speed

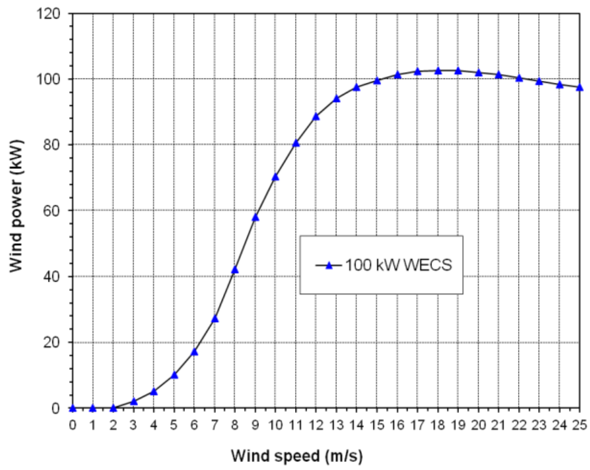


Fig. 5.Power characteristic of 100 kW WTG

Generally speaking, the cut-in wind speed (speed at which WECS generates power) of WECS varies from 3 to 4 m/s [16]. As per Figure 4, for 39 percent of time yearly, wind speeds (at 10 m height) are less than 3 meters per second. This means energy will not be generated for 39% of the time annually at Turaif. In this connection, to meet load with out interruption, WECSs are coupled with diesel systems.

The layout of HWDS is presented in Figure 6. The diesel system is operated whenever WTG fails to meet the load.

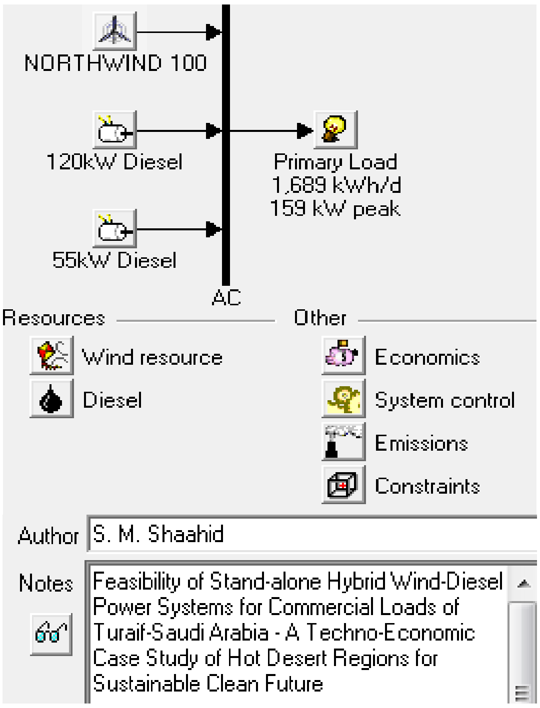


Fig. 6.Schematic of HWDS for commercial demands of Turaif

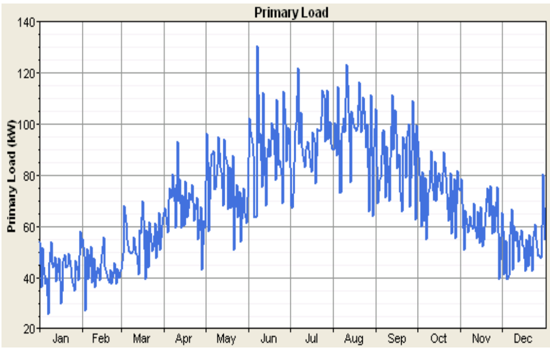


Fig. 7.Variation of commercial load (kW)

III. RESULTS AND DISCUSSIONS

This study places emphasis on commercial loads (620,000 kWh per year) [22]. Figure 7 shows electrical load data for different months of the year. The load is high during June to September. The sizing of system is highly dependent on peak demand (i.e. 159 kW, Fig. 6).

Simulation of hybrid systems includes various mixes of 100 kW WTG and diesel systems. The outcome of simulations is a possible combination of wind farm capacity (kW) and diesel capacity (kW) to satisfy requirement of 620,000 kWh.

The results of simulations (using HOMER software) are listed in Table III. The table clearly shows the impact of wind penetration on key parameters of HWDS. It can be noticed that increase in wind penetration decreases diesel fuel consumption and carbon emissions.

The techno-economic parameters of HWDS based on simulations are presented Figure 8. In this figure, ninth column shows COE. Figure 8 also shows that variation of wind fraction (column 10) varies from 0 to 71%. The hybrid systems installed worldwide have wind fraction of 11 to 25%. This figure also indicates that the COE from a HWDS (100 kW WTG and 175 kW diesel system) with 20% wind fraction is 0.123 $/kWh (without any shortage in capacity or without any rejection in load).

As can be seen in Figures 8, increase in wind fraction increases COE (which eventually reduces carbon emissions). For diesel-only scenario, the operational hours of the two diesel generators are 6801 and 2534. For a HWD with one 100 kW WTG and 175 kW diesel unit, the hours of operation of the above generators are 5898 and 3227. It is clear from the above; there is decrease in diesel operation time with presence of WECS.

For the above HWDS, the details about energy generation, excess energy, un-met load, and the cost of HWDS is depicted in Figure 9 and Figure 10. Fig 9 shows that the generated excess energy is 3%. Also, as per Figure 10, the initial capital cost of WTG is high.

It can be observed from Figure 8 that diesel-only system uses 15% more fuel as compared to hybrid system (20% wind fraction) with 100 kW wind machine and 175 kW diesel units. It can be mentioned that increase in wind fraction increases fuel savings. It has also been observed from simulations that with 20% wind penetration, 91 tons/year carbon emissions will not be injected in atmosphere.

IV. CONCLUSIONS

In view of reasonable wind speed (3.4 to 4.4 meter/sec), the study considers Turaif to have potential for installation of HWDS for electrical needs of commercial buildings. The study has emphasized on techno-economic evaluation of using stand-alone HWDS to serve the commercial energy demands (620,000 kWh per year). For a configuration composed of one 100 kW WTG and 175 kW diesel generators, the wind fraction (with zero % load rejection) has been found to be 20%. The energy generation cost from this system is 0.123 $/kWh.

It has been found that diesel-only system uses 15% more fuel as compared to hybrid system (20% wind fraction) with 100 kW wind machine and 175 kW diesel units. The results indicate that diesel operation time is more with lower penetration of wind. Additionally, with 20% wind penetration, 91 tons/year carbon emissions will not be injected in air. Additionally, the generation of excess energy for the above HWDS is very less (3%).

Table- I Details of 100 kW wind energy system

Model/Type	Power rating in kilowatts	Speed at rated power (meters per sec)	Speed at start of power generation (meters per sec)	Speed at end of power generation (meters per sec)	Diameter of Rotor (meters)	Height of Hub in meters
NW100	100	15.0	3	25	21	37

Table- II: Details of diesel generators

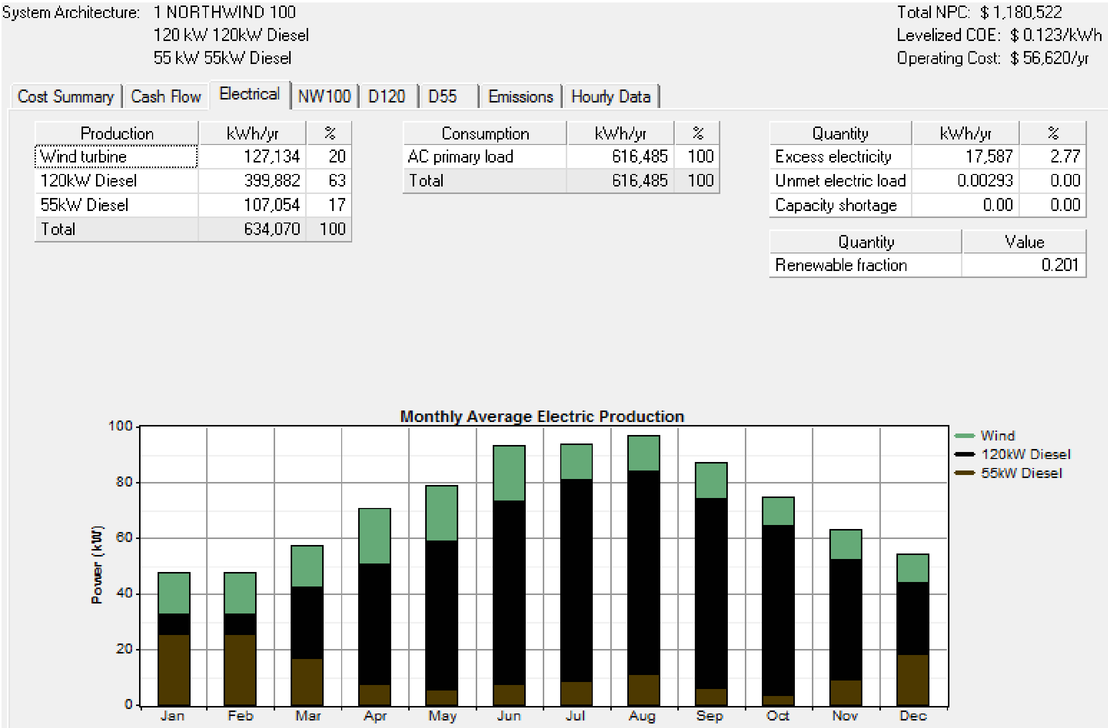
Items	**Data**
Unit 1's Rated Power (Rp)	120 kW
Lowest allowable power	30 % of Rp
Fuel consumption at no load	39.6 Liters per hour
Fuel consumption at full load	10.09 Liters per hour
Unit 2's Rated power (Rp)	55 kW
Lowest allowable power	30 % of Rp
Fuel consumption at no load	18.15 Liters per hour
Fuel consumption at full load	4.63 Liters per hour
Dispatch strategy:	Follows load
Spinning reserve:	10 % of electrical demand

Table- III Results of simulations of HWDS (using HOMER Software)

Wind-Diesel System Details	Wind penetration (%)	Diesel Fuel Consumption Liters/year	Carbon Emissions Tons/year	Cost of energy (COE) $/kWh
Zero Wind + 175 Diesel	0	228,024	616	0.087
One NW100 + 175 Diesel	20	194,269	525	0.123
Two NW100 + 175 Diesel	37	171,940	465	0.160
Three NW100 + 175 Diesel	49	155,806	421	0.198
Four NW100 + 175 Diesel	58	143,785	389	0.237
Five NW100 + 175 Diesel	65	133,998	362	0.277
Six NW100 + 175 Diesel	71	126,033	341	0.318

NW100	D120 (kW)	D55 (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	D120 (hrs)	D55 (hrs)
	120	55	$ 46,000	50,704	$ 838,109	0.087	0.00	228,024	6,801	2,534
1	120	55	$ 296,000	56,620	$ 1,180,522	0.123	0.20	194,269	5,898	3,227
2	120	55	$ 546,000	63,505	$ 1,538,074	0.160	0.37	171,940	5,159	3,601
3	120	55	$ 796,000	71,064	$ 1,906,170	0.198	0.49	155,806	4,655	3,639
4	120	55	$ 1,046,000	79,263	$ 2,284,259	0.237	0.58	143,785	4,306	3,549
5	120	55	$ 1,296,000	87,882	$ 2,668,903	0.277	0.65	133,998	3,993	3,493
6	120	55	$ 1,546,000	96,849	$ 3,058,978	0.318	0.71	126,033	3,742	3,418

Fig. 8.Techno-Economic Parameters of HWDS



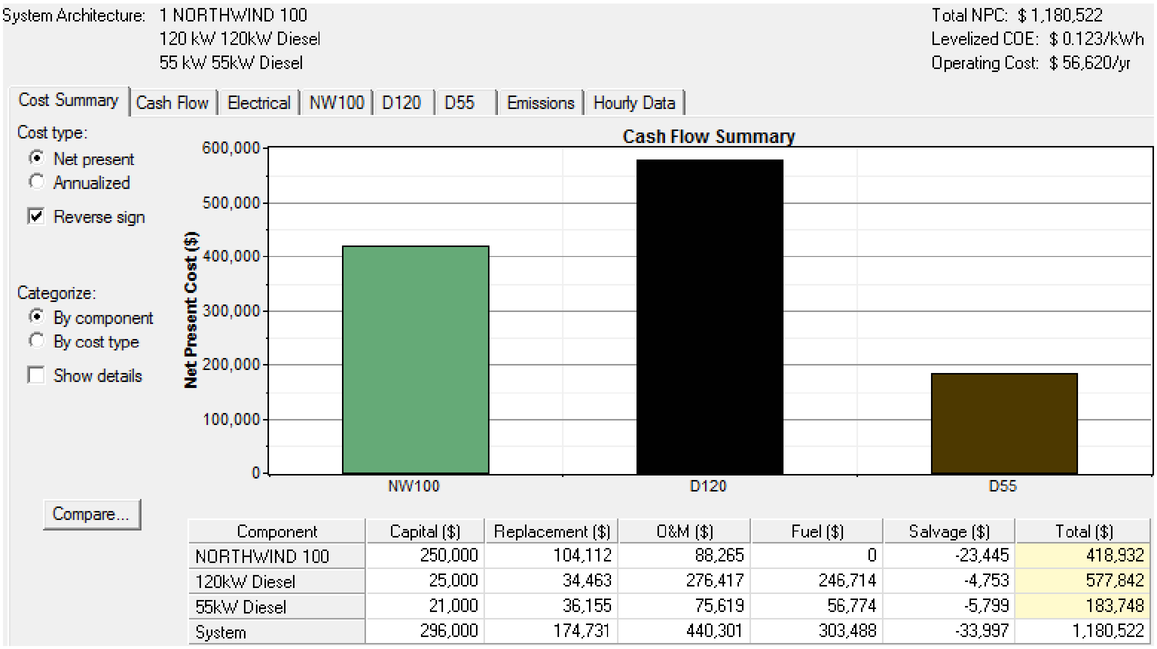
Production	kWh/yr	%
Wind turbine	127,134	20
120kW Diesel	399,882	63
55kW Diesel	107,054	17
Total	634,070	100

Consumption	kWh/yr	%
AC primary load	616,485	100
Total	616,485	100

Quantity	kWh/yr	%
Excess electricity	17,587	2.77
Unmet electric load	0.00293	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.201

Fig. 9.Hybrid power generation by HWDS



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
NORTHWIND 100	250,000	104,112	88,265	0	-23,445	418,932
120kW Diesel	25,000	34,463	276,417	246,714	-4,753	577,842
55kW Diesel	21,000	36,155	75,619	56,774	-5,799	183,748
System	296,000	174,731	440,301	303,488	-33,997	1,180,522

Fig. 10. Cost details of HWDS

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