UACEE International Journal of Advancements in Electronics and Electrical Engineering
Volume 1: Issue 1

Economic & feasibility analysis of off-grid hybrid PV–Wind–diesel–battery systems for rural electrification in Rajasthan, India

A way towards clear future

Rajesh Kumar, R. A. Gupta
Department of Electrical Engineering
Malaviya National Institute of Technology
Jaipur 302017-INDIA
rkumar.ee@gmail.com, ragmnit@gmail.com

Ajay Kumar Bansal
Department of Electrical Engineering
Poornima Institute of Engineering & Technology
Jaipur 302015- INDIA
ajaykb007@gmail.com

Abstract— **The green sources of energy are being encouraged to reduce the environmental pollution, combat the global warming of the planet and burning of depleting fossil fuels. Moreover, solar photovoltaic (PV) – wind – diesel hybrid system technology promises lots of opportunities in remote areas which are far from the utility grid and are driven by diesel generators. The Rajasthan in India being endowed with high intensity of solar radiation and large wind power is a prospective candidate for deployment of hybrid systems. Rajasthan has a large number of remote scattered villages. The aim of this study is to analyze weather data of Rajasthan, India, to assess the techno-economic feasibility of hybrid PV-wind–diesel–battery power systems to meet the load requirements of a typical remote village with annual electrical energy demand of 15,943 MWh. The monthly average daily global solar radiation ranges from 3.5 to 7.8 kWh/m2. NREL's HOMER software has been used to perform the techno-economic evaluation. The cost of generating energy (COE, Rs/kWh) from the above hybrid system has been found to be 5 Rs/kWh (presuming diesel fuel price of 43 Rs/l). The study exhibits that the operating hours of diesel generators decrease with increase in PV and wind turbine capacity. The investigation also examines the effect of PV/battery penetration on COE, operational hours of diesel generators etc. The decrease in carbon emissions by using the above hybrid system is about 35% as compared to the diesel-only scenario.**

Keywords— **Solar radiation, Wind Speed, PV, Battery, Rural electrification, Diesel generators, Carbon emissions, optimization.**

I. INTRODUCTION

Presently, about two billion people worldwide living in small remote villages, which are far from the utility grid, not have asses to electricity grid. Due to the continuously increasing diminution of fossil fuels and the associated environmental problems, all countries in the world take effort to the development of renewable energy power generation technology in recent years [1, 2]. The use of renewable energy system has become an imperative alternative as power provider in rural electrification program, when the price of oil is reaching its highest level. However the assessment of the correct type of renewable energy system needs to be done so that the system can be optimized [3-6].

In many cases, utility grid extension is impractical owing to dispersed population or rugged terrain, thus standalone power systems are likely to be the most viable options. Various combinations of renewable energy sources (such as wind, solar etc.) and diesel generators with rechargeable batteries are currently being researched and are marketed as cost-effective and ecologically sound solutions in a long run. In this context, one of the options to provide electricity to remote locations is by utilization of indigenous solar energy, wind energy together with existing diesel generators [7,8]. Such systems are referred to as remote hybrid power systems. Also, hybrid system shields the increasing oil price-risk and minimizes unprecedented environmental damage due to burning of finite/fixed/depleting fossil fuels [9]. Additionally, to comply with December 1997s Kyoto's protocol on climate change (due to carbon emissions), about 160 nations have reached a first ever agreement (to turn to renewable/wind/PV power) to limit carbon emission which is the principal cause of global warming [10-14].

Since last two decades, India's electricity sector has grown remarkably. The installed generating capacity of the power plants reached more than 180,000 MW in 2011 [15]. Population growth and industrialization are increasing the demand (7-10% per annum) for electricity, which is expected to reach about 350,000 MW by 2020. The needs in the India's transmission and distribution expansion are equally daunting. Although currently India has about 10,000,000 Km of transmission networks, the creation of a unified national grid will require more than 1,000,000 km of additional lines. The India's area is large, with large number of settlements (far from electric grids) scattered all over the area [16]. The supply of electricity to these remote villages through diesel generators alone or by connecting into the nearest grid can be an expensive option in a long run. In the light of these problems, attention is being focused on the feasibility of utilizing of hybrid wind–PV–diesel–battery power systems for providing electricity to remote villages [17-19].

Rajasthan is endowed with high solar radiation level and high wind speed, a fraction of its energy needs may be tapped. Although, solar energy is enormous, but PV driven power system is still an expensive option. PV cells have the advantage of minimum maintenance and easy expansion to meet growing energy needs. The price of generating energy using wind machines dropped dramatically over the last decade. The technology of the wind machines has improved remarkably over the last five years. Wind energy conversion systems (WECS) from the range of 3.2 MW are commercially available. Stand alone WECS (in spite of remarkable technological advancements/milestones) do not produce usable energy for considerable portions of the time during the year. This is basically due to the relatively high cut-in wind speeds (speed at which the WECS starts producing usable energy), which range from 25 to 45 m/s. In order to overcome this downtime/offset, the use of hybrid (Wind–PV-Diesel) systems has been recommended in the literature.

The research on feasibility of renewable energy systems in India, has been the subject matter of several earlier studies. The objective of this study is to analyze solar radiation data and wind speed data (of the period 2010) of Jaipur, Rajasthan (latitude: 26°92 N, longitude: 75°82 E and altitude: 431 m above sea level), to assess the technical and economic feasibility of hybrid PV–diesel–battery power systems to meet the load requirements of a typical remote village like Barwada, Sunderpura, Pando, Balesar, Kheda etc. with the annual electrical energy demand of 1566 kWh/day. The hybrid systems simulated consist of different combinations of wind-PV panels/sizes supplemented with battery storage and diesel generators. The study investigates the feasibility of utilizing wind/PV energy to meet the load requirements of the remote village in conjunction with the diesel generators. Specifically, the merit of hybrid wind–PV–diesel– battery system has been evaluated with regards to its size, operational requirements, cost, etc. The National Renewable Energy Laboratory's (NREL) HOMER software has been used to perform the techno-economic feasibility of hybrid wind–PV– diesel–battery power systems. HOMER is a tool or a computer model that facilitates the design of stand-alone electric power systems. The villages have about 500 homes and 5000 inhabitants. The investigation demonstrates the impact of wind-PV penetration and battery storage in energy production, cost of energy, number of operational hours of diesel generators for a given hybrid configuration, etc. Emphasis has also been placed on un-met load, excess electricity generation, percentage fuel savings and reduction in carbon emissions (relative to diesel-only scenario) of different hybrid systems, cost of PV–diesel–battery systems, COE of different hybrid systems, etc.

II. THE DESCRIPTION OF HYBRID SYSTEMS

A typical hybrid generation system comprises of wind turbine generators (WTG), PV panels (PV), Diesel Generator (DG) and storage batteries (SB) as shown in Figure 1. In the hybrid generation system, they are integrated and complement each other in order to meet performance targets of generation systems and access to the most economic power generation.

Climatic conditions determine the availability of solar energy and wind energy at a given site. In other words, the availability of solar PV power is influenced by topography and weather conditions at a site. Jaipur is situated very much in a desert environment. Two distinct seasons are noticed in this region: a very hot season (May–October) and a cold season (November–April). Monthly mean temperatures reach close to 45o C for the hot months, and in the cooler months, the mean temperatures drop by about 100 C as compared to the hot months. The relative humidity is of the order of 40% round the year. The winds blow from east-northeast to west-southwest direction range for most of the time during the year.

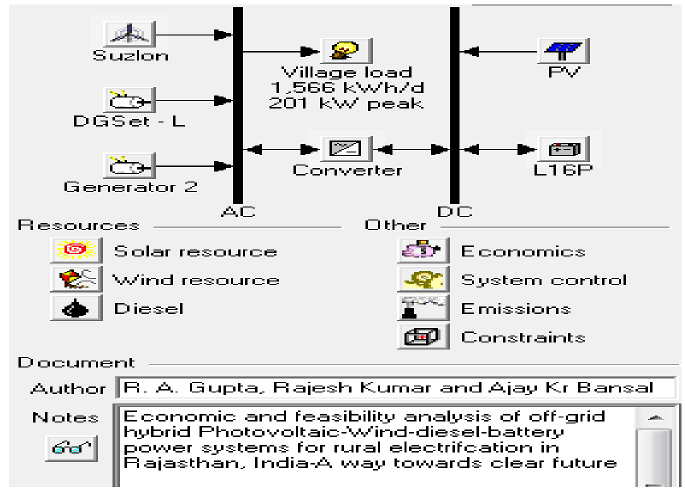


Figure 1. Schematic of hybrid WECS–PV–diesel–battery power system

III. SOLAR RADIATION DATA

Long-term monthly average daily (of the period 2010) global solar radiation data of Jaipur is plotted in Figure 2 and Figure 3. The irradiation level is high during the summer months (May– August) as compared to other months. The yearly average daily solar radiation is about 5.43 kWh/m2. The above long-term average data has been used for simulations in HOMER. The energy calculations are made by matching the solar radiation data with the characteristics of PV modules. The PV modules which are composed of several solar cells are integrated to form solar arrays. Despite advancements in the state-of-the-art, today's best PV systems can achieve an overall efficiency of about 12% .

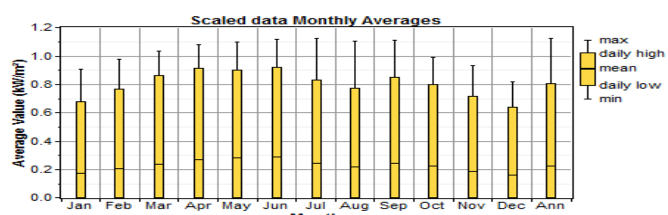


Figure 2. Minimum, Maximum and Average Solar radiation in a month

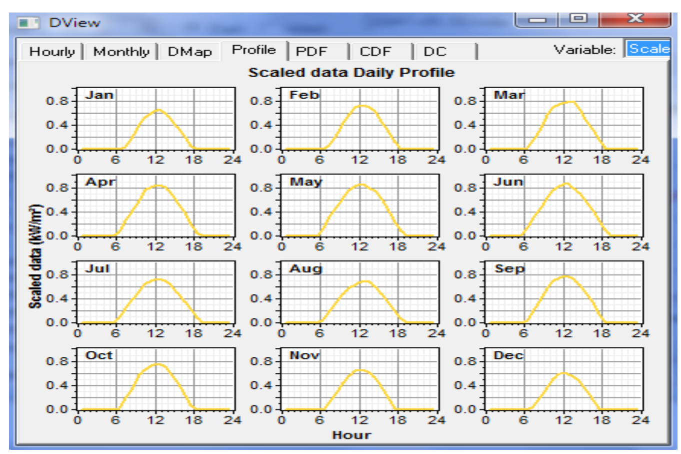


Figure 3. Typical Monthly curve of daily global solar radiation

The solar radiation varies not only during different seasons but also at different times of the day. Therefore, for applications where energy is required for a 24-h period, the need cannot be met through a PV system alone. In this connection, integration of PV installations with a wind turbine or battery storage or diesel system or with all, can meet the required load distribution on a 24-h basis.

IV. WIND DATA

The long term monthly average wind speeds for Jaipur (for the period 2010) are presented in Figure 4 and Figure 5. Wind speeds are generally higher in the summer months (May–August) as compared to other months. This indicates that a WECS would produce appreciably more energy during the summer months as compared to the other months. The monthly behavior/pattern of wind speed matches the higher electrical load requirements during the summer period in Rajasthan. The overall average wind speed is 5.43 m/s.

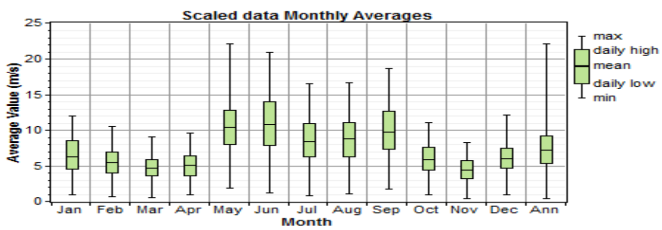


Figure 4. Minimum, Maximum and Average Wind speed during a year

Notably, data also show that there is considerable variation of the monthly average wind speed from one month to another. These variations show that the monthly energy output from a WECS would be subject to considerable differences. Despite the maturity in the state-of-the-art, today's best wind machines can only achieve an overall efficiency of about 35%.

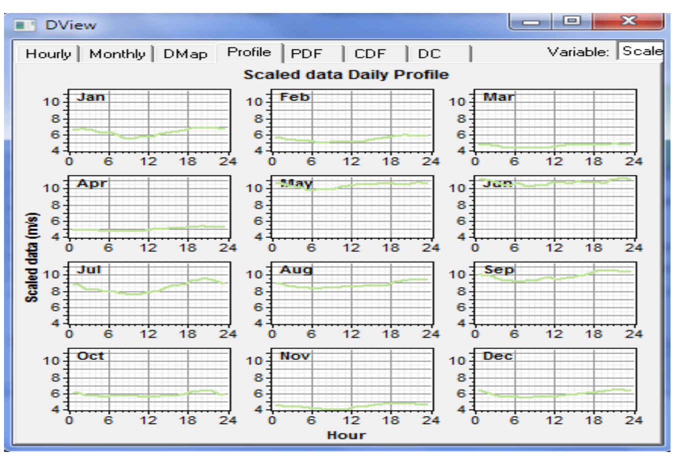


Figure 5. Monthly average daily global wind Speed

V. OPERATIONAL STRATEGY OF HYBRID SYSTEM

The architecture of hybrid WECS–PV–diesel–battery system is shown in Figure 1. The dispatch/operation strategy of the hybrid Wind–PV–Diesel–battery system in the present case study (in the simulation) is as follows: in normal operation, WECS+PV feed the load. The excess energy (the energy above the average hourly demand; if any) from WECS+PV is stored in the battery until full capacity of the storage system is reached. The main purpose of introducing battery storage is to import/export energy depending upon the situation. In the event, that the output from WECS+PV exceeds the load demand and the battery's state of charge is a maximum, then the excess energy is fed to some dump load or goes un-used (due to lack of demand). A diesel system is brought online at times when WECS+PV fail to satisfy the load and when the battery storage is depleted.

VI. RESULTS AND DISCUSSIONS

An important element of any power generating system is loading. Load has pronounced effect on system design. As a case study, the measured annual average electric energy consumption of a typical remote village with annual electrical energy demand of 1,566 KWh (minimum load = 14 kW, maximum load = 201 kW, average load = 65.2 kW) has been considered as yearly load in the present study. This load could also be a representation of many other remotely located settlements of the Rajasthan which are far from the utility grid.

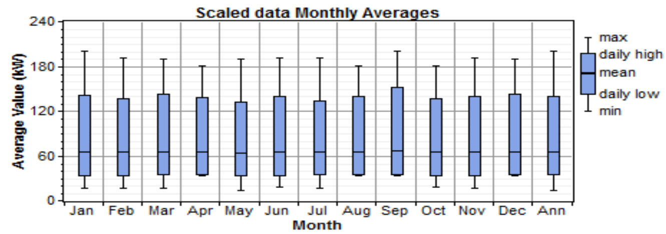


Figure 6. Minimum, Maximum and Average load during a year

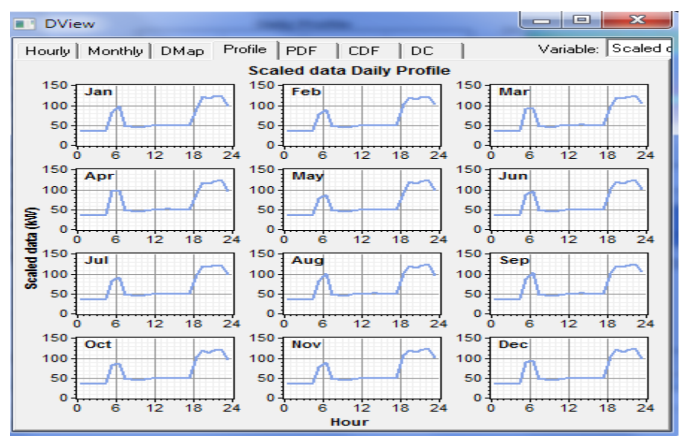


Figure 7. Monthly average daily load

The projected monthly average daily electrical energy consumption is shown in Figure 6. As depicted in Figure 6, the load seems to peak during May, June, September, December. The raw electrical load data for a complete year is presented in Figure 7. Currently, the load requirements of the village are met by a diesel system of 201 kW installed capacity.

The selection and sizing of components of hybrid power system has been done using NREL's HOMER (Hybrid Optimization Model for Electric Renewables) software. HOMER is general purpose hybrid system design software that facilitates design of electrical power systems for stand-alone applications. Input information to be provided to HOMER includes: electrical loads (load data), renewable resources (e.g. solar radiation data, wind resource data etc.), component technical details/costs, constraints, controls, type of dispatch strategy, etc. HOMER designs optimal power system to serve desired loads. HOMER is simplified optimization model, which performs hundreds or thousands of hourly simulations (to ensure best possible matching between supply and demand) in order to design the optimum system. It uses life cycle cost to rank order these systems. The software performs automatic sensitivity analyses to account for sensitivity of system design to key parameters, i.e. resource availability or component costs.

TABLE I. TECHNICAL DATA AND STUDY ASSUMPTION

Description	Data
PV	
Capital cost	200,000 Rs/kW
Lifetime	25 years
Operation and maintenance cost	1,000Rs/year /kW
Wind turbine	
Rated Power	300 KW AC
Capital cost	18,500,000 Rs
Lifetime	25 years
Operation and maintenance cost	370,000Rs/year
Cut-in speed (m/s) Vci	2- 3
Cut-out speed (m/s) Vco	25
Hub Height	30 m
Diesel generator units (Two units)	
Capital cost	20,000 Rs/kW
Rated power of each diesel unit 1	Variable (0-100 MW)
Minimum allowed power (min load ratio)	30% of rated power
Operation and maintenance cost	1 Rs/h/kW
Operating hours	16,000 h
Batteries	
Type of batteries	Tarjan L16P
Nominal voltage (V)	6V
Nominal capacity	360 Ah
Nominal energy capacity of each battery	2.16 kWh
Operation and maintenance cost	100 Rs/year
Dispatch/operating strategy	Multiple diesel load following
Converter	
Capital cost	50,000 Rs/kW
Operation and maintenance cost	100 Rs/year /kW
Lifetime	10 years
Spinning reserve	**10%**
Minimum Renewable fraction	**60%**
Annual Interest rate	**10%**
Project life time	**25 years**

The hybrid systems simulated in present investigation consist of different combinations of PV panels and WECS units supplemented with battery bank and diesel generators. The study explores a suitable mix of key parameters such as: PV array power (kWp), WECS power, battery storage, and diesel capacity to match pre-defined load (with 0% capacity shortage). HOMER allows use of two diesel units for simulation of hybrid systems. Diesel generators are generally sized to meet peak demand of power. The peak demand of village is about 210 kW. In this regard, two diesel generators each of maximum100 kW capacity (to cover peak load) have been considered for carrying out technical and economic analysis of hybrid systems. The operating/spinning reserve is surplus electrical generation capacity that is instantly available to serve additional loads. It provides reliable electricity supply even if the load was suddenly increased or the renewable power output was suddenly decreased.

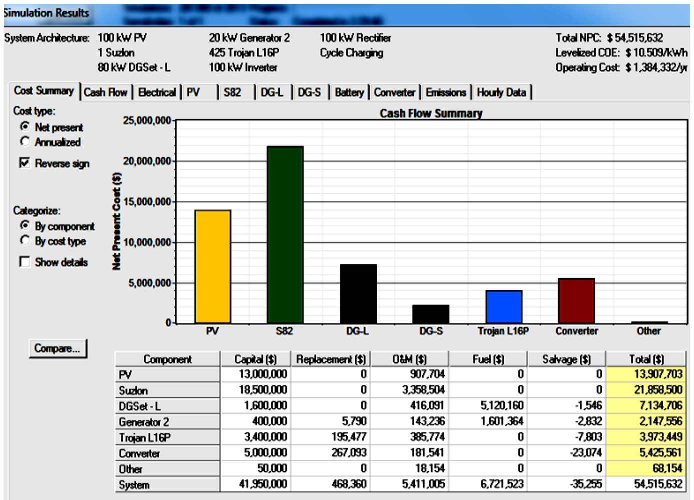
Several simulations for various scenarios have been made by considering different capacities. The PV capacity has been allowed to vary from 0 to 450 MW. The WECS units have been allowed to vary from 0 to 4 and both diesel generator capacities are allowed to vary from 0 to 100kW. The battery storage/bank sizes (units) considered is 0–200. The study assumptions made for making simulations on HOMER are tabulated in Table I.

As a starting point, simulations have been performed for WECS–PV–diesel systems with no-storage. The simulation results (for diesel price of 43 Rs/l) are presented in Figure 8. In Figure 8, first column shows presence of PV modules in hybrid system, the second shows the presence of WECS modules, third–fourth column indicate the presence of diesel units, fifth-sixth column indicates the presence of battery and converter respectively. Seventh column highlights size/capacity (kW) of PV considered in a given case, Eights shows WECs units, 15th column shows Net present Cost, 16th column shows cost of energy generation (COE, Rs/kWh), etc. It can be noticed from these results that, in general the PV penetration (renewable energy fraction, column 14) has varied from 0 to 50%.

For a given WECS capacity of 300 kW (together with 90 kW and 30 kW diesel system and 300 storage batteries), the details related to energy generated by hybrid systems, excess electricity, un-met loads (kWh), capacity shortage (kWh) and the cost breakdown of WECS–diesel power systems are presented in Figures 10 and 11. It can be seen from Figure 12 that with the above system configuration, un-met load is 0 kWh and excess energy of about 47.3% is generated. It should be mentioned over here, that this excess energy produced goes un-used due to lack of demand (sometimes provision is made to provide this excess energy to dump loads).

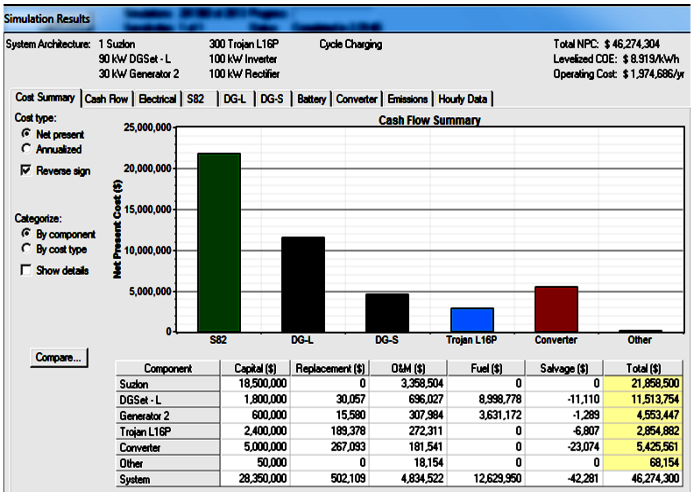
PV (kW)	S82	DG-L (kW)	DG-S (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG-L (hrs)	DG-S (hrs)
	1	90	30	300	100	$ 28,350,000	1,974,686	$ 46,274,304	8.919	0.92	32,359	852	1,131
100	1	80	20	425	100	$ 41,950,000	1,384,332	$ 54,515,632	10.509	0.96	17,221	573	789
100	1	100		500	100	$ 42,550,000	1,506,738	$ 56,226,716	10.837	0.96	19,224	878	
	2	100		350	100	$ 46,850,000	1,473,975	$ 60,229,324	11.611	0.98	13,495	605	
	2	100	50			$ 40,050,000	2,645,301	$ 64,061,504	12.348	0.96	38,767	1,040	2,359
150	1		50	850	200	$ 55,850,000	955,363	$ 64,521,868	12.442	0.99	4,871		389
100	2	100	50		100	$ 58,050,000	2,408,439	$ 79,911,488	15.403	0.97	31,000	941	1,668
250		90	50	850	100	$ 47,150,000	4,632,638	$ 89,200,632	17.192	0.67	89,261	1,320	3,669
200	2			750	200	$ 79,050,000	1,130,929	$ 89,315,480	17.226	1.00			
	4		40	850	100	$ 86,650,000	1,740,359	$ 102,447,2...	19.753	1.00	2,216		222

Figure 8. Optimization Results for components sizing



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	13,000,000	0	907,704	0	0	13,907,703
Suzlon	18,500,000	0	3,358,504	0	0	21,858,500
DGSet - L	1,600,000	0	416,091	5,120,160	-1,546	7,134,706
Generator 2	400,000	5,790	143,236	1,601,364	-2,832	2,147,556
Trojan L16P	3,400,000	195,477	385,774	0	-7,803	3,973,449
Converter	5,000,000	267,093	181,541	0	-23,074	5,425,561
Other	50,000	0	18,154	0	0	68,154
System	41,950,000	468,360	5,411,005	6,721,523	-35,255	54,515,632

Figure 9. Case flow for PV-WECS-DG-Battery System



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Suzlon	18,500,000	0	3,358,504	0	0	21,858,500
DGSet - L	1,800,000	30,057	696,027	8,998,778	-11,110	11,513,754
Generator 2	600,000	15,580	307,984	3,631,172	-1,289	4,553,447
Trojan L16P	2,400,000	189,378	272,311	0	-6,807	2,854,882
Converter	5,000,000	267,093	181,541	0	-23,074	5,425,561
Other	50,000	0	18,154	0	0	68,154
System	28,350,000	502,109	4,834,522	12,629,950	-42,281	46,274,300

Figure 10. Case flow for WECS-DG-Battery System (Optimum case)

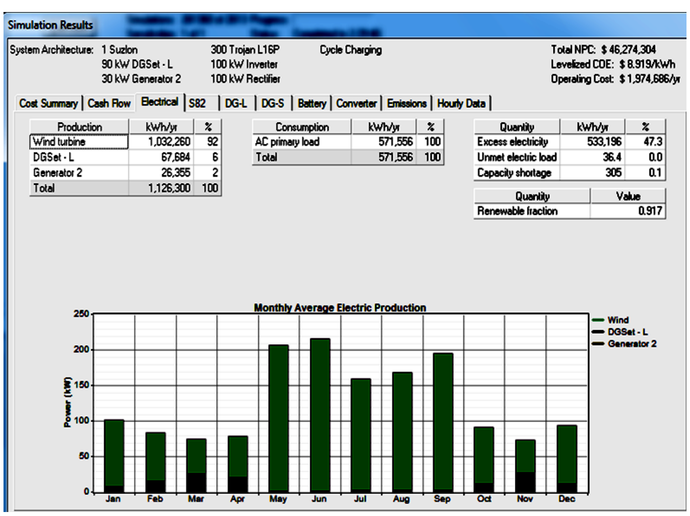


Figure 11. Electrical profile for WECS-DG-Battery System (Optimum case)

Figure 11 indicates that monthly average hybrid WECS–diesel generated power is high during summer months as compared to other months. This is a favorable characteristic because electricity demand is high during the summer months. HOMER hybrid model indicates that the total initial capital cost of the hybrid system (WECS-Diesel generator) is Rs. 28350000, while the net present cost (NPC) is Rs. 46274304 (Figure 10). It can be noticed from (Figure 10) that the initial capital cost of WECS system is about 65.25% of the total initial capital cost. This indicates that the initial cost of WECS systems in hybrid system is dominant.

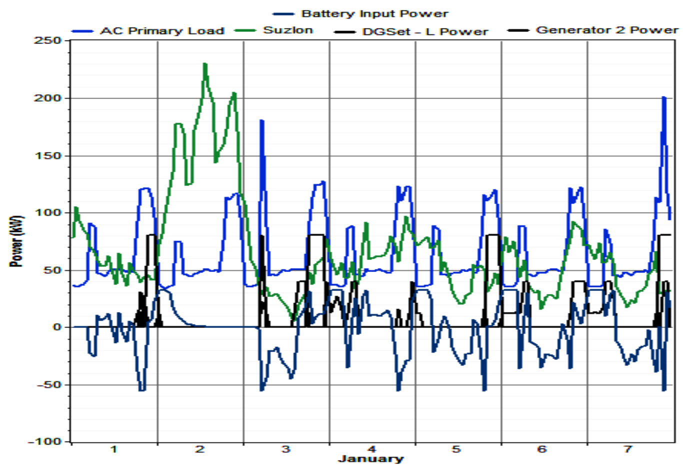


Figure 12. Hourly generation and load profile for WECS-DG-Battery System

In order to study the hourly behavior of power exchange in the hybrid power system, simulation results were conducted in a period from 1st to 7th January, 2011 in case of the optimal configuration obtained from the HOMER is shown in Figure 12. Figure 12 shows that the power supply from the renewable resources, the power demand, the input/output battery bank power etc. and can be easily verified. The Diesel Generator is used only when the renewable resources and the batteries are not able to satisfy the load demand. The hybrid system reduces the environment pollution to a large extend as given in Table II.

TABLE II. ENVIRONMENTAL POLLUTION

Pollutant	WECS-DG Emissions	Only DG Emissions	% Deduction
Carbon dioxide	86,350 kg/yr	606,114 kg/yr	85.75
Carbon monoxide	213 kg/yr	1,496 kg/yr	85.76
Unburned hydrocarbons	23.6 kg/yr	166 kg/yr	85.78
Particulate matter	16.1 kg/yr	113 kg/yr	85.75
Sulfur dioxide	173 kg/yr	1,217 kg/yr	85.78
Nitrogen oxides	1,902 kg/yr	13,350 kg/yr	85.75

As the global price of oil increase and the government of India have indicated that it can no longer provide the oil subsidy. It is important to note that if the true diesel price is used in the calculation the COE is going up by Rs. 0.1 per kWh for 1 Rs/litter increase in diesel price. The sensitivity result for diesel price is shown in Figures 13. If diesel price is raised to Rs 50 per liter the COE is increased by 3.6%.

Diesel ($/L)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG-L (hrs)	DG-S (hrs)
43.000	$ 28,350,000	1,974,686	$ 46,274,304	8.919	0.92	32,359	852	1,131
45.000	$ 28,350,000	2,039,403	$ 46,861,740	9.033	0.92	32,359	852	1,131
50.000	$ 28,350,000	2,201,196	$ 48,330,340	9.316	0.92	32,359	852	1,131
55.000	$ 28,350,000	2,362,989	$ 49,798,940	9.599	0.92	32,359	852	1,131

Figure 13. Tabulated Variation of COE with Diesel Price

It is also evident from Figure 14, that as penetration of PV increases, the operational hours of diesel generators decrease which eventually reduce emission of greenhouse gases. It can be noticed that for diesel-only situation, the operational hours of the two diesel units are 1878 and 5489, respectively. However, for hybrid PV–diesel system with 33% PV penetration, the operational hours of the two diesel units are 1272 and 3492, respectively. This clearly reflects that operational hours of the two 100 kW diesel generators of hybrid system decrease by 5%, 15%, and 45%, respectively as compared to diesel-only (0% renewable) situation. This indicates that with the introduction of PV machines, the load on the second diesel generators has decreased considerably.

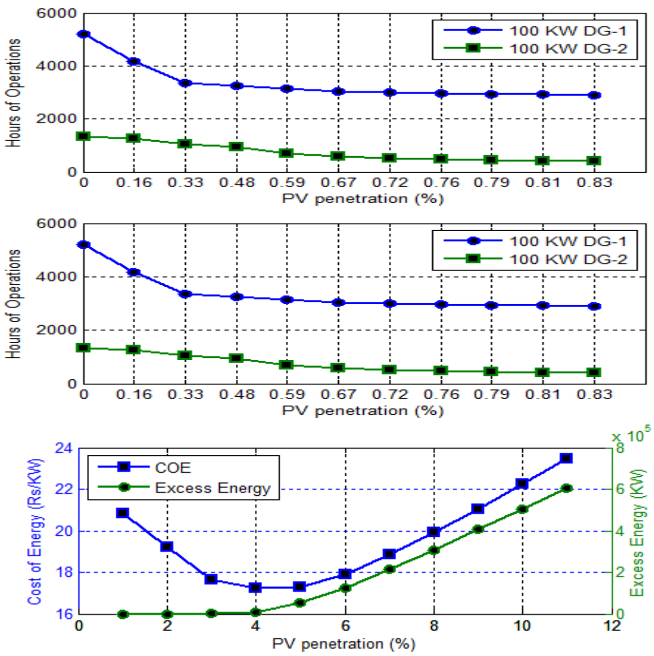


Figure 14. Effect of PV Penetration on Various Parameters

VII. CONCLUSIONS

Rajasthan is blessed with considerable monthly average daily global solar radiation intensity 5.43 kWh/m2 and monthly average daily wind speed 5 m/s, is a prospective candidate for deployment of WECS-PV power systems. The simulation results indicate that for a hybrid system composed of 100 kW PV system, 300 kW wind energy conversion system together with 90 kW and 30 kW diesel systems and a 300 battery units, the PV penetration is 27%. The cost of generating energy (COE) from hybrid system has been found to be 10.5 Rs/kWh (assuming diesel fuel price of 43Rs/l). The study exhibits that for given hybrid configuration, number of operational hours of diesel generators decreases with increase in WECS and PV capacity. The percentage fuel savings by using hybrid WECS–PV–diesel–battery system is 42% as compared to diesel-only situation. The percentage decrease in carbon emissions by using hybrid system has been found to be 24% as compared to the diesel-only scenario. More importantly, with use of hybrid system, about 519364 tons/year of carbon emissions can be avoided entering into the local atmosphere. The hybrid system configuration offers several advantages such as: diesel efficiency can be maximized; diesel maintenance can be minimized; and a reduction in the capacities of diesel and battery (while matching the peak loads) can occur. The present investigation shows that the potential of renewable energy option of wind and solar energy cannot be overlooked.

REFERENCES

[1] Ai Bin, Yang Hongxing, Shen Hui and Liao Xiaobo, “Computer aided design for PV/wind hybrid system,” Proceeding of 3td World Conference on Photovoltaic Energy Conversion, Vol. 3, pp. 2411-2414, May, 2003.

[2] Belfkira R, Hajji O, Nichita C and Barakat G, “Optimal sizing of stand-alone hybrid wind/PV system with battery storage,” 2007 European Conference on Power Electronics and Applications, pp.1-10, Sept, 2007.

[3] Belfkira R., Barakat G., Nichita C., “Sizing optimization of a stand-alone hybrid power supply unit: wind/PV system with battery storage”, International Review of Electrical Engineering (IREE) 2008, Vol 3 no 5.

[4] Bhuiyan M. M. H., Asgar M. A., “Sizing of a stand-alone photovoltaic power system at Dhaka”, Renewable Energy 2003, Vol 28, no 6.

[5] Borowy B.S., Salameh Z. M., “Methodology for optimally sizing the combination of a battery bank and PV array in a Wind/PV hybrid system”, IEEE Transactions on Energy Conversion 1996, Vol 11 no 2.

[6] Celik A. N., “Optimization and techno-economic analysis of autonomous photovoltaic-wind-hybrid energy systems in comparison to single photovoltaic and wind systems”, Energy Conv. and Manag. 2002, Vol 43 no 18.

[7] Chedid R and Rahman, S, “Unit sizing and control of hybrid wind-solar power systems,” IEEE Transactions on Energy Conversion, Vol. 12, no.1. pp.79-85, 1997.

[8] Chi-Jui Wu and Yung Sung, “Design of decentralized output feedback power system stabilizers using hybrid differential evolution,” IEEE Power Engineering Society General Meeting, pp.1404-1411, June, 2005.

[9] Daming xu, Longyun Kang, Liuchen Chang and Binggang Cao, “Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithms,” Canadian Conference on Electrical and Computer Engineering, pp.1722-1725, May, 2005.

[10] Dufo-Lopez R., Bernal-Agustin J. L., “Design and control strategies of PV-Diesel systems using genetic algorithms”, Solar Energy 2005, Vol 79, pp. 33-46.

[11] Elhadidy M. A., Shaahid S. M, “Parametric study of hybrid (wind+solar+diesel) power generating systems,” Renewable Energy, Vol.21, pp.129-139, 2000.

[12] Kellog W. D., Nehir M. H., Venkataramanan G., Gerez V.: Generation unit sizing and cost analysis for standalone wind, photovoltaic, and hybrid wind/PV systems. IEEE Trans. on Energy Conversion 1998, Vol 13 no 1.

[13] Koutroulis E., Kolokotsa D., Potirakis A., Kalaitzakis K., “Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms”, Solar Energy 2006, Vol 80 no 9.

[14] M.A. Habib, S.A.M. Said, M.A. E1-Hadidy, I. A1-Zaharna, “Optimization procedure of hybrid photovoltaic wind energy system,” Energy, vol. 24, no. 11, pp. 919-929, 1999.

[15] Markvar T.: Solar Electricity. 2nd Ed, J. Wiley & Sons, 2000.

[16] Sathyan A, Anthony K and AI-Hallaj S, ”Hybrid wind/PV/fuel cell generation system,” 2005 IEEE Conference on Vehicle Power and Propulsion, pp.1-6, Sept, 2005.

[17] Xu Daming, Kang Longyun, Cao Binggang, “Stand-alone hybrid wind/PV power system using the NSGA2,” Acta energiae solaris sinica, Vol.27, no.6, pp.593-598, 2006.

[18] Yang H., Lu L., Zhou W., “A novel optimization sizing model for hybrid solar-wind power generation system”, Solar Energy 2007, Vol 81, pp 76-84.

[19] Shaahid S. M., Elhadidy M. A., “Optimal sizing of battery storage for standalone hybrid (photovoltaic + diesel) power systems”, International Journal Sustain Energy, vol. 24, no. 3, pp.155–166, 2005.