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Alternative Electrification in Rural Area of India

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ABSTARCT
Wind energy is one of the fastest developing renewable energy technologies. This is due to the vast resource of wind and also a green technology which does not emit any pollutants to the environment. Among the common renewable options for supplying electricity to remote locations is using wind turbines coupled to diesel generators with larger battery banks. Its dependency on diesel and thus sustainability could be improved by using hydrogen storage and fuel cells. To study the performance of the system, a typical rural electric load consisting of household electricity, small business facility, health post, school and water pump is modeled along with system components. The wind resource data for two locations Jamnagar and Dhwarka have been used. Simulation and optimization of the energy system are carried out in homer and numerous alternative implementable system designs have been proposed. The results show that the use of fuel cells enabled enhanced energy autonomy, higher renewable energy contribution and less CO_2 *emission with moderate increase in net present cost. Sensitivity study on diesel price, wind speed, average electric load has also been carried out.*

Key words: Energy; Fuel cells; Hydrogen; Renewable; Source

INTRODUCTION

India is currently looking for another alternative resource to generate electricity after so long dependent on coal and fuel. Coal and fuel is non-renewable resources as well as its prices rising in the global market due to decrement of its quantity and are only available in some countries. Malaysia has taken steps to exploring the resources of renewable energy as an alternative for generating electricity [1]. Among the resources of renewable energy (RE), the wind energy was the fastest growing energy technology in the world and considered as one or resource that meet the needs of modern societies in reducing the dependence on coal and diesel whilst at the same time delivering substantial reduction in greenhouse gas emission [3].

Hydrogen derived from renewable sources such as wind and solar is clean, self-sufficient and a permanent energy solution for sustainable development. A kilogram of hydrogen is roughly equivalent to a gallon of gasoline in energy content [4]. This makes hydrogen a technology of the future in reducing reliance on imported fuel and greenhouse gas emissions. Particularly in remote areas with plentiful renewable energy resources, but grid extension is not cost-effective and diesel cost is high because of transport, hydrogen energy systems are logical. In rural India where a majority of the population lives, access to electricity is very low. The people in these areas use small kerosene lamps that emit eye irritant smoke and very dim light. Lack of electricity hampered the development of various infrastructures such as basic health posts, schools, small business and telecommunication [4]. Hydropower is the major electricity source in India with installed capacity of 668.8MW in 2006 and a planned capacity of 4303.8MW in 2013. The electrification is 15% in 2009 as reported in by international energy agency and literature [5, 6]. This value is well below the sub-Sahara average of 29% in 2009. Further, it is argued the numbers mentioned are based on the population count near the grid and the real access is very much lower. The electrified rural areas account to 1% while the potentials of renewable energy resources are; wind 10, 000MW, solar, average insolation of 5.26kWh/m^2 across the country and geothermal 700MW. Several wind hydrogen energy system researches for remote area power supply and for hydrogen production usually combined with PV have been carried out [7, 8]. The researches all agree on the potentials and near term competitiveness of wind hydrogen systems. However, the capital costs of components are the major hurdles in the competitiveness of hydrogen based systems. Using an updated modeling tool Hydrogems, the research studied wind hydrogen energy system with 600KW wind turbine, 55KW hydrogen generator, 10KW fuel cell, 10Nm^3/h electrolyzer and flywheel and battery storage. The study used 2010 market survey cost data with electrolyzer cost of 2500$/KW and fuel cell capital cost of 3125$/KW. It was shown that the system, although not the cheapest, would reach much higher renewable fraction of 96% and operated in 100% stand alone mode for 50% of the time [9]. The important advantages of the system are the higher energy autonomy and more reliable power. In another study, the system could substitute diesel power plants and may be better than grid extension If strong wind resources are available.

It is a fact that, especially in complex terrain, wind energy content may vary significantly from one region to another. Therefore, wind data taken over many years are utilised to calculate wind climatology [10-15]. The WindPRO and Wind Atlas Analysis and Application Program (WAsP) software were widely used by researchers for analyze the wind turbine and energy production and validate as the best software in this research field [16]. WindPRO and WAsP are softwares for predicting wind climates, wind resources and power productions from wind turbines and wind farms. The predictions are based on wind data measured at stations in the same region. The software function includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles [17]. The main aim of this study is about the wind energy potential at Jamnagar and Dhwarka. The wind speed and energy analysis was conducted by using the WindPRO and WAsP softwares. The advanced computational methods have been developed to gain the data to use in estimation of wind energy potential and micrositing. An accurate prediction of the wind speed at a given site is essential for the determination of regional wind energy resources. Because of aerodynamic reasons, the power output of a wind turbine is proportional to the third power of the wind speed.

MATERIA L AND METHODS

An earlier study shows there is west - east and south-north increase of wind speed in the country. The most recent study, on four major towns in India, Bhuj, Jamnagar, Dhwarka and Wapi, identified the resource in Jamnagar and Dhwarka as wind class 2. Since strong wind conditions are required for effective use with hydrogen technologies, these two towns are selected for further study. The wind profiles are shown in Fig. 1 and Fig. 2.

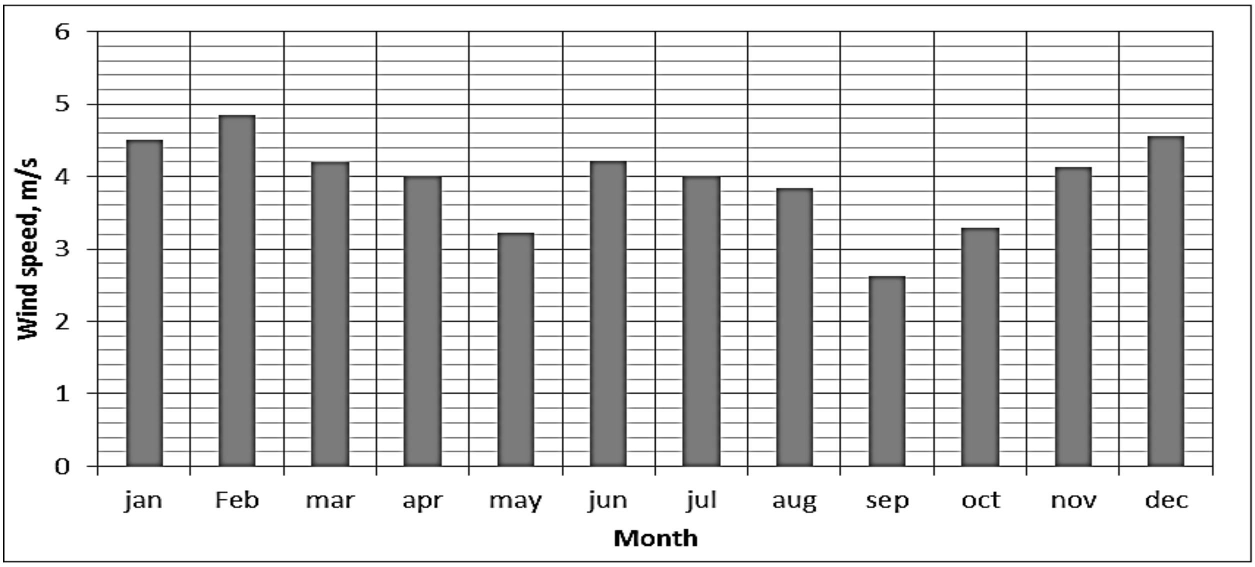

Fig.1: Wind speed profile of Dhwarka

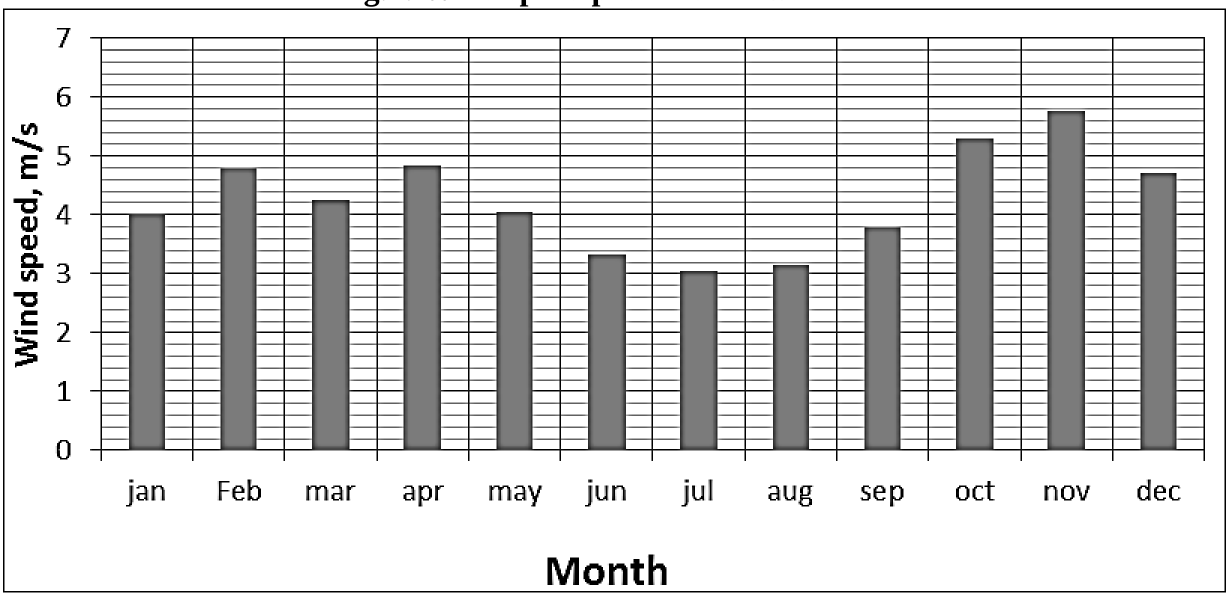

Fig.2: Wind speed profile of Jamnagar

Modeling rural electric load

To make good use of economy of scale in wind-hydrogen energy system, larger size of 500 families having school, clinic, grinding facility and water pumps is considered. The electrical loads are determined as discussed below.

Household load

The households have one 60W light bulb for the main house where most of the gathering takes place and a 5W light bulb for the bedroom. The use of LED light bulbs is not considered because of the current high cost [20]. Three hours of electricity at night, 18:00 to 21:00 is assumed sufficient because normally 21:00 is the last time to go to bed in India. The 5W Led light is assumed to stay in 1hr longer for bedroom considering time for sleep preparation.

Health post load

The RHC has a vaccine refrigerator which is compulsory for keeping vaccines for medication and two light bulbs for assumed 2 rooms. It is used to keep the vaccines in safe storage for 24hr/day at temperatures 2-8^{o}C. Communication VHF 3W radio has been included for the RHC.

Small business load

The grinding facility has one 12kW capacity grinder and a 1.1kW capacity small grinder for special crops.

School load

In quantifying the school load, two microscopes and light bulbs for night school has been assumed. For a family size of 5 per household with 2 adults and 3 children, the community will have at maximum 1000 children and 1500 adults. Assuming a better class size of 20-40 children, 40 classrooms are required for children assuming 100% primary education cover. For adult education in night school, a maximum of the 20 classrooms should have a light bulb. It is assumed that 40W light bulb is enough for each class room for 3hr in the evening. The total load calculated by homer is 267KWh/day and 63KW peak. A daily noise of 20% and hourly noise of 15% have been used to give a more realistic load distribution.

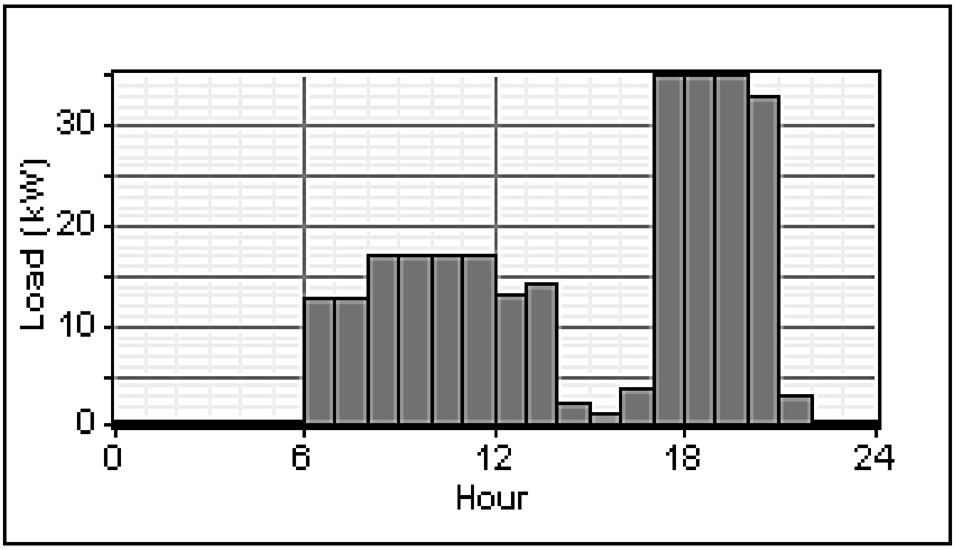

Fig. 3: Daily load profile of the model village

The Fig. shows the time distribution of the load. Grinding machines consist of the major daily load and light bulbs are the major evening loads. The refrigerator is working all day and after 06:00 the grinding business starts. The school load adds up to the load to reach a peak of 17KW. At night light bulbs and radio add to the load to reach a peak of 35KW power.

Deferrable load

To increase productivity during the dry seasons, water pumping is essential. Assume 10 electrical pumps with a rating of 150W each and a capacity of 10lit/min. Assuming 100lit/day for each family, a total of 50,000lit/day can be supplied for the households in 8hrs. Additional 5, 000lit/day safe drinking water is pumped for the school and the clinic. 12KWh/day energy is required for the households while 1.25 KWh/day is needed for the school and clinic adding up to a deferrable load of 13.25KWh/day. For a storage capacity of three days, the total energy required is 36KWh for the household and 3.75KWh for the school and clinic totaling 40KWh. The peak deferrable load (10 pumps of rating 0. 15KW) is 1.5KW. In the rainy seasons, June, July and August, and on January schools are closed. This reduces the total deferrable load by 0.6KWh/day. During these seasons, rain is assumed to supplement the water pumping. Assuming 3 of the pumps will be out of operation at these times, the load decreases to 8.4KWh/day. Totally the load in rainy seasons is

9KWh/day. Considering these variations, the yearly load profile is as shown below.

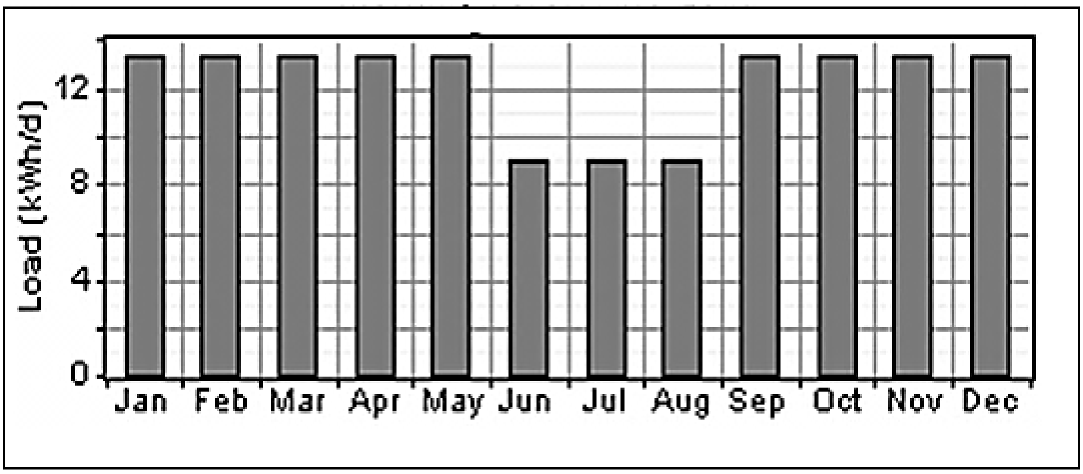

Fig. 4: Monthly deferrable load of the model village

Capital cost of equipment

The table below shows summary capital costs of equipment based on several publications between 2010.

Table 1 Summary of cost function of wind hydrogen subsystems

Item	Capital cost $/unit	Replacement cost $/unit	O&M cost	Life time	Unit
Wind turbine	1100	900	25$/KW	20yr	KW
Fuel cell	3000	2500	175$/yr	40,000hr	KW
Electrolyzer	2000	1500	25$/yr	20yr	KW
Hydrogen tank	1300	1200	15$/yr	20yr	Kg
Inverter	800	750	8$/yr	15yr	KW
Battery	833	555	15$/yr	12yr	1156Ah

This is the best possible approximation of actual costs of the project in India. However, because of the import of equipment, lack of local skill and many local factors, the installed project cost is expected to be higher. This could be studied in sensitivity studies.

RESULTS AND DISCUSSION

Calculation of monthly production of electricity Jamnagar

From the Fig. 5 it was observed that more than 50% of the power is produced from diesel generators for most of the months except October to December. In winter season, more than 80% of the power is produced by the diesel generator. The contribution of fuel cells is visible in all the months making them useful in improving availability of power. The table below shows the full report for the system.

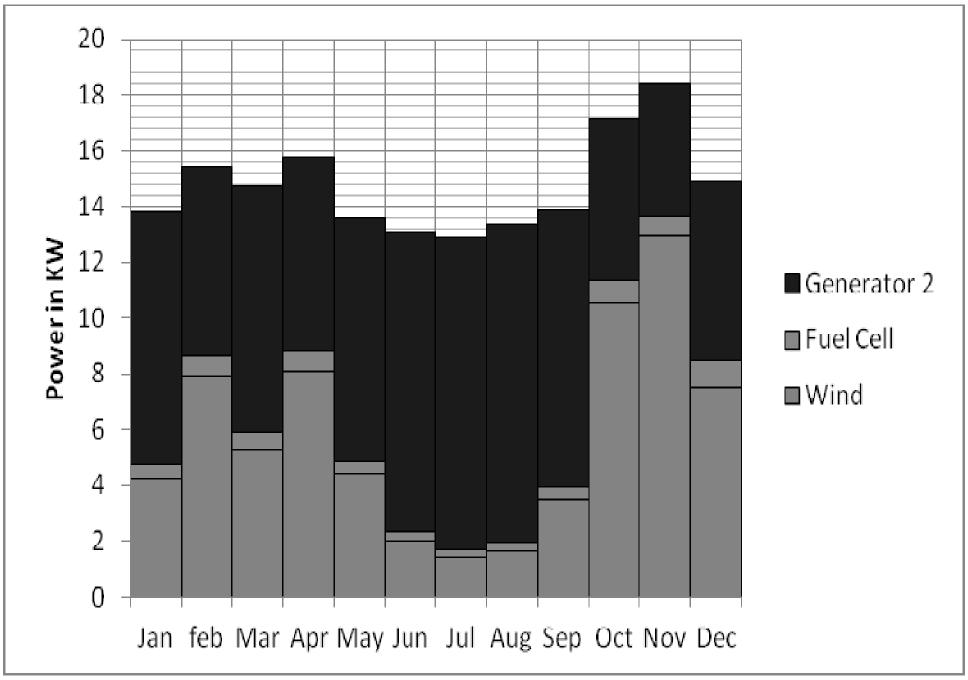

Fig. 1: Monthly average electric production from wind/fuel cell/diesel system in Jamnagar

Calculation of monthly production of electricity Dhwarka

From the Fig. 6 it was found that more than 50% of the power is produced from diesel generators most of the year unlike that of Dhwarka. Uniquely, the generator produces more than 80% of the power only on September. The contribution of fuel cells is visible in all the months contributing to better availability of power. The table below shows the full report for the system.

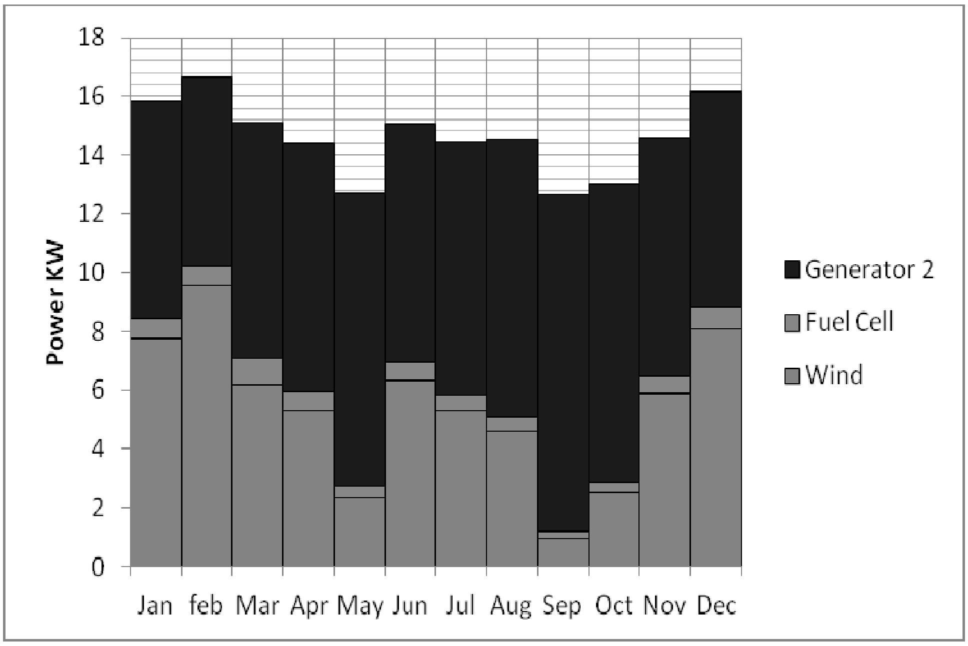

Fig. 2: Monthly average electric production from wind/fuel cell/diesel system in Dhwarka
Summarizes the fuel cell based systems performance in all locations.

About 43% of the annual demand can be met from renewable using wind/gen/battery system as shown in table 2.(Row 2) This system can be a very good candidate for implementation because of its high renewable proportion. This benefit could be enriched with integration of the hydrogen storage system.(Row 1) The net present cost increased by about 8% for the same operating cost over the system in row 1. It can be a good alternative if considerations are given to other related issues such as future price trend of components and unprecedented rise in diesel price. Compared to the least cost system where the contribution of the diesel generator is 83%, the annual CO_2 emission is around 74 ton. It excels both the100% fossil fuel (diesel/battery) system, which has CO_2 emissions of 108ton/yr and the least cost system (94ton/yr). For the model society around the vicinity of Dhwarka, using wind/gen/battery system shown in row 5, about 42% of the annual demand can be met from renewable This benefit could be enriched with integration of hydrogen storage system as shown in row 4 with only 5% increase in NPC for the same operating cost. This system could also be implemented if there is a motive to use the available wind resource. The least cost system shown in row 6 produces only 14% renewable fraction.

Table 2 summary of simulation results for the four cities

City	G20	FC (kW)	Gen2 (kW)	S6CS25P	Electrolyzer (kW)	Hydrogen tank (kg)	energy autonomy	Total NPC	COE ($/kWh)	Renewable fraction	Increase in NPC %
Jamnagar	3	2	30	10	12	25	3 days	$451,000	0.353	0.43	15
	3		35	60			12hr	$417,000	0.327	0.44	8
	1		35		15			$353,000	0.275	0.15	-
Dhwarka	3	2	35	5	12	25	3 days	$454,000	0.352	0.41	22
	3		35	60			22hr	$434,000	0.340	0.42	5
	1		35	15				$356,000	0.275	0.14	-

So far, the wind resource alone has been used. But the selected locations have also excellent solar resources [20]. This section deals with utilization of solar energy and its impacts on the energy system. The wind and solar profile of Jamnagar has been taken for illustration. The mean solar radiation in India is 5.2KWh/m^2. For the purpose of understanding the system performance, solar radiation has been varied from 5-7Kwh/m^2 and the wind speed is varied from 3-5m/s. The cost of PV cells is 6000$/KW. The figure below shows the results of the simulation. In location with wind speed above 4m/s the wind/FC/Gen system is the least cost option. This is mainly because of the current high capital cost of PV cells. The PV/FC/Gen system is preferable in locations with limited wind resource as could be the case of Dawa. The hybrid Wind/PV/FC /Gen system becomes the least cost option in locations with wind speeds between 3.0-3.8m/s. In conclusion, the use of solar or hybrid solar/wind comes to picture in locations with low to moderate wind conditions.

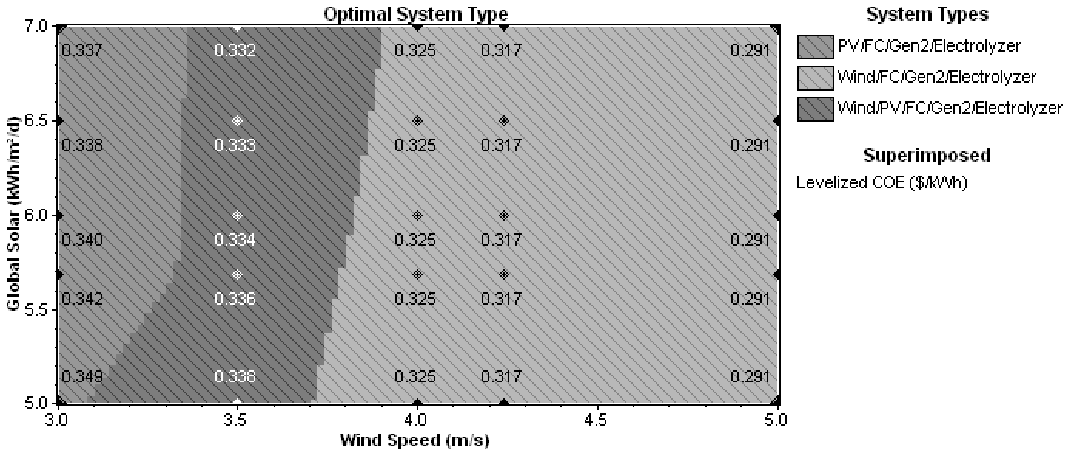

Fig. 7: Comparison of solar and wind with hydrogen storage

CONCLUSION

The performance of a wind hydrogen energy system in powering a model rural village of 500 families having a small business facility, school, health post and water pump has been presented. The wind resource potential of Jamnagar and Dhwarka has been used in the analysis. While battery based systems provide the least cost option, hydrogen storage systems enabled much higher energy autonomy at low to moderate cost increase. The stored hydrogen can sustain the average electric load for 3-8days as opposed to up to 1 day possible using large number of batteries. Also, hydrogen storage help is large scale renewable development where the size of battery becomes very high. In this case, the hydrogen storage enables cost effective and long term storage. Environmentally as well, hydrogen based systems have the least pollutant emissions compared to equivalent battery based systems. In conclusion, integration of hydrogen systems enhances the energy autonomy highly with low to moderate cost increase. The cost of electricity is found to be 30-40 cents/KWh for highly renewable hydrogen based systems. This is much higher than hydro power price (less than 5cents). However, considering the low access to electricity, its environmental advantages, its contribution to development of sustainable society and better life style, the future trend of fossil fuels and equipment costs, this cost should not be considered as high. Therefore, the use of fuel cells with wind turbines contributes to sustainable development by improving the renewable energy use, reducing emissions and reducing diesel dependency. If due emphasis is given for renewable development, the system must be a priority option.

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