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Case Study of a Hybrid (Wind and Solar) Power Plant

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Abstrak

The paper highlights the urgency of utilizing and promoting use of non conventional sources, particularly the wind and solar energy, so as to control the environmental pollution, such as ozone layer depletion, deforestation, loss of biodiversity, global warming etc. As a case study, the various performance factors of a 10 kW hybrid (wind and solar) power plant, which is having 60:40 power generation share of wind power to solar power were analysed. The study shows that there is mismatch between the designed and actual plant load factor (PLF), as well as the power generation share of the wind and solar power plant. It was also found that the plant utilization factor (PUF) was poor and that there is very less scope for installation of solar tracking system. Based on the detailed analysis of obtained results, certain recommendations were made for streamlining and optimizing the power generation capacity, and also for better utilization of generated power.

Kata kunci: *hybrid power, energy conservation, global warming, plant load factor, plant utilization factor.*

Abstract

The paper highlights the urgency of utilizing and promoting use of non conventional sources, particularly the wind and solar energy, so as to control the environmental pollution, such as ozone layer depletion, deforestation, loss of biodiversity, global warming etc. As a case study, the various performance factors of a 10 kW hybrid (wind and solar) power plant, which is having 60:40 power generation share of wind power to solar power were analysed. The study shows that there is mismatch between the designed and actual plant load factor (PLF), as well as the power generation share of the wind and solar power plant. It was also found that the plant utilization factor (PUF) was poor and that there is very less scope for installation of solar tracking system. Based on the detailed analysis of obtained results, certain recommendations were made for streamlining and optimizing the power generation capacity, and also for better utilization of generated power.

Keywords: *hybrid power, energy conservation, global warming, plant load factor, plant utilization factor.*

1. Introduction

Electrical power is very important for economical growth of a country. It is an important input (basic requirement) for all the industries. The standard of living, development, prosperity and strength of any nation are directly related to its per capita electrical power consumption. The requirement of electrical power has increased manifolds, but the power generation capacity has not been able to cope up with the increased demand. This is mainly for various reasons, like fast depletion of conventional (non renewable) natural resources, their uncontrolled use, neglecting use of non conventional (renewable) energy resources so far, wastage of power due to the lack of awareness for energy conservation etc. The world is facing the problems, like environmental pollution, release of green house gases (GHG's), ozone layer depletion, acid rains, global warming, loss of bio diversity and many more [1]. It is imperative now to cut down on the use of conventional energy resources and to concentrate on harnessing the potential of non conventional energy sources which are green, renewable and available in ample quantity. The hybrid power plant utilizing wind and solar power as the source of energy could be one of the solutions for tackling this acute power shortage problem and for the environment conservation [2] - [7].

With the above objectives in mind, a 10 kW capacity wind and solar hybrid power plant was identified and studied as a model to analyse its performance.

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2. Hybrid Power Plant Details

The hybrid power plant selected for the study has been installed in June 2009 at Mapusa-Goa in India. The installation cost of this hybrid power plant estimated to approximately Rs.30 lacs.The installed power generation capacity of the plant is 10 kW and the capacity ratio of wind to solar power units is 60:40. This plant is designed to develop 30 kWh/day which meant that wind power plant should generate 18 kWh/day and solar power plant should generate 12 kWh/day. Thus, the annual generation should be up to 10950 kWh. The specifications of the hybrid power plant [8] are as given below.

2.1 Wind Power Plant Details

Number of wind mills- 2, rated power (each aero generator)- 3200 watts @ 12.5 m/sec, number of blades- 2, rotor diameter- 15 feet, weight- 70 kg, start-up wind speed- 3.4 m/sec, voltage configuration- 48 volt, number of wind controller- 2, wind controller input power (each)- 3.5 kVA, input voltage- 48 to 60 volt 3 phase AC, output voltage- 48 to 62 volt DC.

2.2 Solar Power Plant Details

Solar PV cell panels (combined power generation capacity)-3.6 kW_p, V_{oc} of each module- 19 volt, type of cell- mono/poly crystalline silicon, efficiency of cell-13% +, power of each module- 75 W_p, number of modules- 48 nos, number of solar controller- 1, solar controller input power- 4 kW_p, input voltage- 48 to 80 volt DC, output voltage- 48 to 68 volt DC.

2.3 Inverter Details

Output power- 5 kVA, efficiency- 80 to 90%, duty- continuous, wave form- sine wave, protection- I/P under voltage, I/P over voltage, O/P short-circuit, output- single phase, 50 Hz.

2.4 Battery Details

Capacity - 1200Ah, voltage - 48 volt, type - tubular, lead acid flooded electrolyte, positive plate - tubular, negative plate - pasted flat, voltage of each cell - 2 volt nominal.

2.5 Load Details

The load connected to this plant is isolated and variable. It comprises of six tube lights (40 W each), four fans (60 W each) and four halogen flood lights (500 W each), which are used as and when required.

3. Research Method

In the present study, the actual plant performance parameters, like total power generation capacity, individual power generation capacity shared by the wind and solar power generation units, plant load factors (PLF), power utilization factor (PUF) etc., were calculated from the recorded performance data. The obtained results were analysed and compared with the corresponding plant design parameters using both tabular as well as graphical representation, so as to check for their conformity. Apart from this the other vital aspects of a power plant such as payback/rate of returns, technical and commercial viability and benefits from clean development mechanism (CDM) were also given due consideration. Finally few suggestions were made for improvement of plant performance.

The power generation and performance data of this power plant was recorded over the period of 195 days i.e. from June 2009 to January 2010. Additional readings were also recorded, as and when required, for the analysis purpose. The various desired performance parameters were calculated and tabulated, which is given in Table 1. The sample calculations for the various parameters are given below.

Sample calculations:

1) Power generation per day by wind power = Total generation for a given period/ No. of days of the period =15.8 kWh /4days = 3.95 kWh/day
2) PLF of wind power = (Per day generation / 18) x 100 = (3.95 kWh/18) x 100 = 21.94%.
3) Power generation per day by solar power = Total generation for the period/ No. of days of the period = 36.6 kWh/4 days = 9.15 kWh.
4) PLF of solar power = (Per day generation / 12) x 100 = (9.15 kWh/12) x 100 = 76.25%

5) Power generation per day by hybrid power =Total generation for the period/ No. of days of the period = 52.4 kWh/ 4 days = 13.1 kWh
6) PLF of hybrid power = (Per day generation / 30) x 100= (13.1 kWh / 30) x 100 = 43.67%
7) Total projected generation by hybrid power plant for the period = Number of days of the period x 30 kWh/day = 195 days x 30 kWh =5,850 kWh
8) PUF of the hybrid plant = (Per day energy consumption / Per day energy generated by the plant) x 100 = (1.25 / 17.15) x 100 =7.2886%
9) Percentage of the generation share of wind power = (Per day generation by wind mills / Per day energy generated by hybrid power plant) x 100 = (3.95 / 13.10) x 100 = 30.153%
10) Percentage of the generation share of solar power=(Per day generation by solar panels / Per day energy generated by hybrid power plant) x 100 = (9.15 / 13.10) x 100 = 69.8473%

4. Results and Analysis

As given in Table 1, the total electrical energy generation by both the wind mills (aero generators) over the period under study is 1248.6 kWh, whereas that by the Solar Photo voltaic (SPV) cells is 2233.4 kWh. The total energy generation by hybrid plant during this period is 3482 kWh. The per day energy generation by the hybrid plant varies over a wide range from 8.96 kWh to 32 kWh. Similarly, the consumption of energy generated by this plant varies from 0 to 14.8 kWh/day. This variation pattern shows that the energy generation and consumption is not regular and fixed. The system operates at an average PLF of 63.14%, which is not so good. Also it is largely under loaded with average plant utilization factor of 32.19%. Because of this low PUF, the inverter batteries would remain in fully charged condition (or float charging mode), forcing reduction and restriction of the daily power generation by wind power plant on account of locking or slowing down of the wind mills (aero generators) due to inbuilt auto braking feature. Also, most of the times the stored power has to be compulsorily wasted through the diverter load in order to prevent the battery overcharging. The comparison of energy generation by the hybrid plant and its utilization over the period under study is represented graphically in Figure 1.

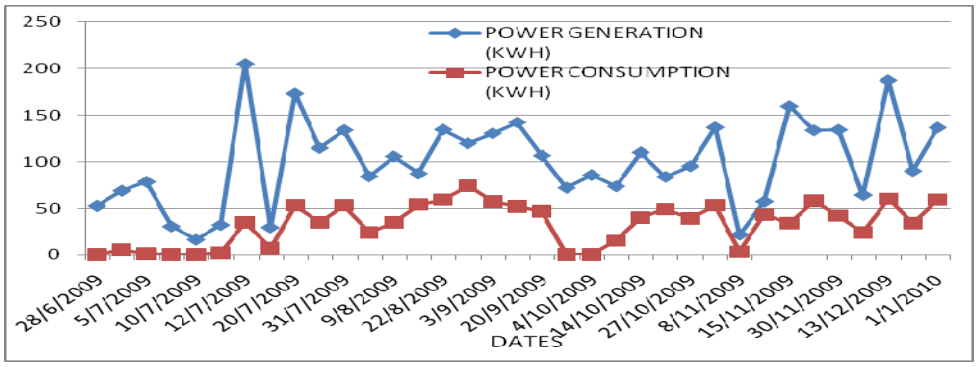

Figure 1. Total generation by the hybrid power plant and consumption of this power

The uderutilization of the generated power is clearly indicated in the graph above. If 100% energy generation and utilization of the plant was ensured by connecting a suitable load, then around 5850 kWh of energy would have been generated for the period under consideration (@ 30 kWh/day x 195 days). That meant an additional generation of 2368 kWh as compared to the present energy generation of 3482 kWh. Further, the utilization of this additionally generated energy would have totally saved around Rs. 20,475/- over this period of time (in 195 days) (considering energy charges @ Rs. 3.50/- per kWh) and Rs. 38,325/- annually for projected 10,950 kWh generated(considering @ 30 kWh/day x 365 days) [9].

Table 2 gives the month wise energy generation and utilization pattern of the hybrid power plant. The maximum energy generation is 747.2 kWh in July month and minimum is 447.7 kWh in October month. The energy consumption is maximum in August month i.e. 299 kWh and minimum in July month i.e. 138 kWh.

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Table 1. Analysed data sheet of hybrid power plant from June 2009 to January 2010

Dates		No. of days	Wind Energy Data			Solar energy Data			Total Energy Generated (KWH)	Per Day Energy Generated (KWH)	Average plant PLF	% generation Share Wind Energy	% generation Share Solar Energy	Total Energy Consump-tion (KWH)	Per Day Energy Consump-tion (KWH)	Average % Power Utilization Factor
From	To		Total Units generated (KWH)	Per Day (KWH)	PLF	Total Units generated (KWH)	Per Day (KWH)	PLF								
28/6/09	1/7/09	4	15.8	3.95	21.94	36.6	9.15	76.29	52.4	13.10	43.67	30.153	69.8473	0	0.00	0.0000
1/7/09	5/7/09	4	51.7	12.93	71.81	16.9	4.23	35.21	68.6	17.15	57.17	75.394	24.6647	5	1.25	7.2886
5/7/09	9/7/09	4	52.6	13.15	73.06	25.6	6.40	53.33	78.2	19.55	65.17	67.263	32.7366	1	0.25	1.2788
9/7/09	10/7/09	1	24.1	24.10	133.89	6.3	6.30	52.50	30.4	30.40	101.33	79.276	20.7237	0	0.00	0.0000
10/7/09	11/7/09	1	12.5	12.50	69.44	3.5	3.50	29.17	16.	16.00	53.33	78.125	21.875	0	0.00	0.0000
11/7/09	12/7/09	1	29.8	29.80	165.56	2.2	2.20	18.33	32.0	32.00	106.67	93.125	6.8750	2	2.00	6..2500
12/7/09	19/7/09	7	177.6	25.37	140.95	27.3	3.90	32.50	204.9	29.27	97.57	86.672	13.3235	35	5.00	17.0815
19/7/09	20/7/09	1	20.6	20.60	114.44	8.7	8.70	72.50	29.3	29.30	97.67	70.307	29.6928	7	7.00	23.8908
20/7/09	27/7/09	7	128.0	18.29	101.59	45.1	6.44	53.69	173.1	24.73	82.43	73.963	26.0427	53	7.57	30.6181
27/7/09	31/7/09	4	74.8	18.70	103.89	39.9	9.98	83.13	114.7	28.68	95.58	65.214	34.8038	35	8.75	30.5144
31/7/09	6/8/09	6	71.6	11.93	66.30	62.2	10.37	86.39	133.8	22.30	74.33	53.498	46.5022	53	8.83	39.6114
6/8/09	9/8/09	3	48.7	16.23	90.19	35.5	11.83	98.61	84.2	28.07	93.56	57.827	42.1496	24	8.00	28.5036
9/8/09	16/8/09	7	42.0	6.00	33.33	63.6	9.09	75.71	105.6	15.09	50.29	39.773	60.2557	35	5.00	33.1439
16/8/09	22/8/09	6	20.5	3.42	18.98	66.6	11.10	92.50	87.1	14.52	48.39	23.559	76.4638	54	9.00	61.9977
22/8/09	29/8/09	7	49.2	7.03	39.05	85.1	12.16	101.31	134.3	19.19	63.95	36.642	63.3805	59	8.43	43.9315
29/8/09	3/9/09	5	51.7	10.34	57.44	67.9	13.58	113.17	119.6	23.92	79.73	43.227	56.7726	74	14.80	61.8729
3/9/09	12/9/09	9	31.4	3.49	19.38	98.8	10.98	91.48	130.2	14.47	48.22	24.124	75.8986	57	6.33	43.7788
12/9/09	20/9/09	8	32.9	4.11	22.85	109.2	13.65	113.75	142.1	17.76	59.21	23.139	76.8473	52	6.50	36.5939
20/9/09	27/9/09	8	21.7	2.71	15.07	84.4	10.60	88.33	106.5	13.31	44.38	20.357	79.6244	47	5.88	44.1315
27/9/09	4/10/09	8	24.9	3.11	17.29	46.8	5.85	48.75	71.7	8.96	29.88	34.700	65.2720	0	0.00	0.0000
4/10/09	9/10/09	5	20.0	4.00	22.22	65.6	13.12	109.33	85.6	17.12	57.07	23.364	76.6355	0	0.00	0.0000
9/10/09	14/10/09	5	7.3	1.46	8.11	66.0	13.20	110.00	73.3	14.66	48.87	9.9591	90.0409	15	3.00	20.4638
14/10/09	22/10/09	8	12.0	1.50	8.33	98.0	12.25	102.08	110	13.75	45.83	10.909	89.0909	40	5.00	36.3636
22/10/09	27/10/09	6	7.9	1.32	7.31	75.7	12.62	105.14	83.6	13.93	46.44	9.4737	90.5742	49	8.17	58.6124
27/10/09	01/11/09	5	10.2	2.04	11.33	85.0	17.00	141.67	95.2	19.04	63.47	10.714	89.2857	39	7.80	40.9664
01/11/09	8/11/09	7	24.9	3.56	19.76	111.8	15.97	133.10	136.7	19.53	65.10	18.230	81.7776	53	7.57	38.7710
8/11/09	10/11/09	2	10.0	5.00	27.78	11.5	5.75	47.92	21.5	10.75	35.83	46.512	53.4884	3	1.50	13.9535
10/11/09	15/11/09	5	49.0	9.80	54.44	8.0	1.60	13.33	57.0	11.40	38.00	85.965	14.0351	43	8.60	75.4386
15/11/09	22/11/09	7	16.5	2.36	13.10	143.0	20.43	170.24	159.5	22.79	75.95	10.357	89.6614	34	4.86	21.3166
22/11/09	30/11/09	8	15.5	1.94	10.76	118.0	14.75	122.92	133.5	16.69	55.63	11.625	88.3895	58	7.25	43.4457
30/11/09	09/12/09	9	15.0	1.67	9.26	119.0	13.22	110.19	134.0	14.89	49.63	11.216	88.7910	42	4.67	31.3433
09/12/09	13/12/09	4	9.0	2.25	12.50	55.0	13.75	114.58	64.0	16.00	53.33	14.063	85.9375	24	6.00	37.5000
13/12/09	25/12/09	7	42.0	6.00	33.33	145.0	20.71	172.62	187.0	26.71	89.05	22.460	77.5241	60	8.57	32.0856
25/12/09	1/1/10	7	12.0	1.71	9.52	78.0	11.14	92.86	90.0	12.86	42.86	13.300	86.6444	34	4.86	37.7777
1/1/10	10/1/10	9	15.2	1.69	9.38	121.2	13.47	112.22	136.4	15.16	50.52	11.151	88.8783	59	6.56	37.7778
	Total	195	1248.6									39.580	60.4100	1146		29.4300

The readings used for the analysis purpose are logged via an automatic data logger. However, some of the additional data, which was required for the analysis of plant performance, was recorded manually, which is given in Table 3.

Table 2. Month wise power generation and its consumption for the period from June to December 2009

Month	Generation (KWH)			Consumption (KWH)	Utilization factor (%)
	Wind	Solar	Hybrid		
July	571.7	175.5	747.2	138	18.46
August	283.7	380.9	664.6	299	44.98
September	110.9	339.6	450.5	156	34.62
October	57.4	390.3	447.7	143	31.94
November	115.9	392.3	508.2	191	37.58
December	78.0	397.0	475.0	160	33.68

Table 3. Performance data of hybrid power plant on a day from 7.30 a.m to 7.30 p.m

Time	Wind velocity (m/s)	Aero generator voltage (V)	Aero generator current (A)	Power generated by aero generator (KVA)	Actual lux incident on the SPV panels	SPV Voltage (V)	SPV Current (A)	Actual power generation by SPV cells (KVA)	Projected lux on panels when perpendicular to sun rays	Projected power generation (KVA) by SPV
7.30	0.7	50.1	0.8	0.040	9100	49.6	2.8	0.138	16550	0.2509780
8.00	1.4	50.3	0.9	0.045	31300	49.8	7.2	0.359	81600	0.9359233
8.30	1.1	51.6	1.0	0.051	55500	51.3	14.0	0.718	126800	1.6404036
9.00	1.3	52.1	1.0	0.052	80000	51.7	21.6	1.106	122100	1.6880325
9.30	1.1	52.4	0.9	0.047	102800	52.1	28.2	1.469	127500	1.8219601
10.00	3.0	52.9	1.0	0.047	110600	52.4	34.4	1.802	128200	2.0887559
10.30	2.1	53.2	0.9	0.047	106000	52.8	38.5	2.032	130400	2.4997434
11.00	3.0	53.2	0.8	0.031	123400	52.9	37.4	1.985	145100	2.3340640
11.30	0.8	53.5	0.6	0.032	140400	53.3	43.0	2.274	147000	2.3808974
12.00	2.7	54.2	1.2	0.065	153500	53.8	42.6	2.270	155600	2.3010554
12.30	1.4	54.8	1.0	0.054	154800	54.5	42.0	2.272	155800	2.2866770
13.00	2.5	56.3	0.8	0.045	155600	55.6	41.4	2.399	156400	2.4113342
13.30	1.6	57.9	1.6	0.098	154900	58.0	34.4	1.970	155200	1.9738154
14.00	2.0	55.9	1.0	0.098	132500	54.8	11.8	0.640	132800	0.6414491
14.30	2.6	57.0	7.2	0.403	140700	57.1	14.9	0.930	140900	0.9313220
15.00	3.6	57.8	2.7	0.052	115100	57.2	9.2	0.450	115400	0.4511729
15.30	3.8	57.8	1.3	0.450	102900	57.3	10.2	0.550	108400	0.5793975
16.00	4.8	57.9	2.1	0.560	89200	57.4	11.8	0.670	114200	0.8577803
16.30	4.5	57.9	4.2	0.340	64400	57.4	11.3	0.630	105000	1.0271740
17.00	4.4	58.0	6.2	0.334	41100	57.5	10.2	0.512	84300	1.0501606
17.30	3.9	57.7	10.5	0.433	20500	56.9	6.1	0.350	39400	0.6726830
18.00	3.3	52.2	0.9	0.046	400	52.0	1.8	0.093	400	0.0930000
18.30	1.2	48.9	1.2	0.048	200	48.6	0.2	0.009	200	0.0090000
19.00	1.0	48.8	0.9	0.043	100	48.5	0.1	0.004	100	0.0040000
19.30	0.4	48.7	0.7	0.041	0	48.3	0.1	0.002	0	0.0000000
Average	**2.328**	**54.044**	**2.056**	**3.502**	**83400**	**53.632**	**19.008**	**1.025**	**99574**	**1.2372312**
				Total				**25.634**		**30.9307700**

The following observations have been made from the obtained results and performance analysis of the hybrid power plant:-

i) During the study period the wind power plant has generated 1248.6 kWh units at an average PLF of 46.67% (compared to 3510 kWh had it been operated at 100% PLF) and solar power plant has generated 2233 kWh at an average PLF of 87.85% (compared to 2340 kWh had it been operated close to 100% PLF). This indicates that the wind power plant has been operated near to half of its full capacity; where as solar power plant has been operated almost near to its full capacity. In total, the hybrid power plant has generated 3482 kWh at an average PLF of 63.14% (compared to generation of 5850 kWh had it been operated close to 100% PLF). The same has been indicated in Figure 2 below.

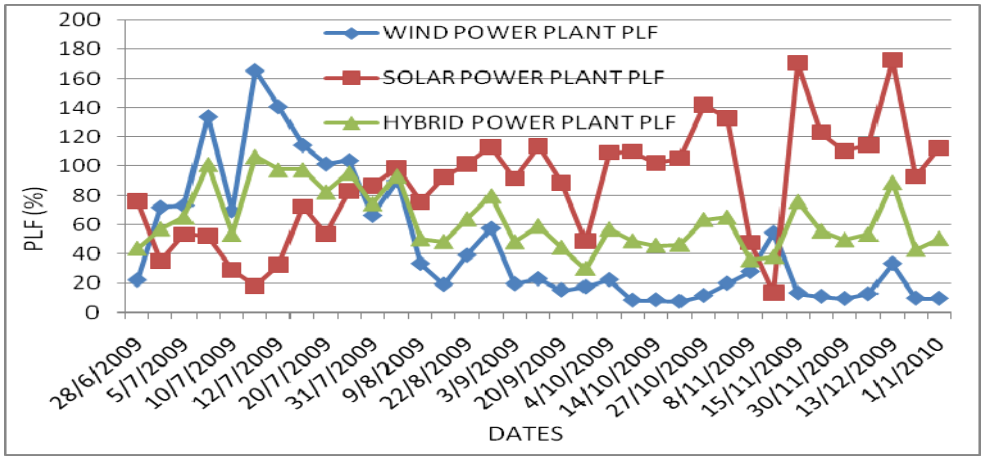

Figure 2. Comparison of actual PLF of wind, solar and hybrid power plant

ii) The average of actual generation share (over the period of this study) of wind power plant is 39.58% and that of solar power plant is 60.65% which is contrary to the designed share of 60:40. This may be due to lower wind density /velocity in this area than the wind velocity anticipated while designing. It may also be on account of automatic braking of the wind mills (aerogenerators), due to the batteries remaining in fully charged condition.

iii) Average plant utilization factor of the hybrid power plant is 32.91%. Due to this poor PUF the batteries do not discharge much and mostly remain fully charged. This forces the wind mills (on number of occasions) to rotate at a lower speed or get locked due to the auto braking feature provided to them which affects the performance and generation capacity of wind power plant [10].

iv) A close look at the data in Table 3, which is also represented graphically in Figure 3, reveals that if the period from 7.30 am to 7.30 pm of a given day is divided into two equal halves then the first half i.e. from 7.30 am to 1.30 pm becomes more significant from solar generation point of view. This is because the lux available during the first half is almost double than that available in the second half of the day.The energy generation by solar panels in the first half is almost four times more than that of second half.

Similarly, it is evident that the second half i.e. from 1.30 pm to 7.30 pm becomes more significant from the wind generation point of view. Because the wind velocity available during this period is almost one and half times more than that in the first half of the day.The energy generation by the wind mills in the second half is almost four and half times more than that of the first half.

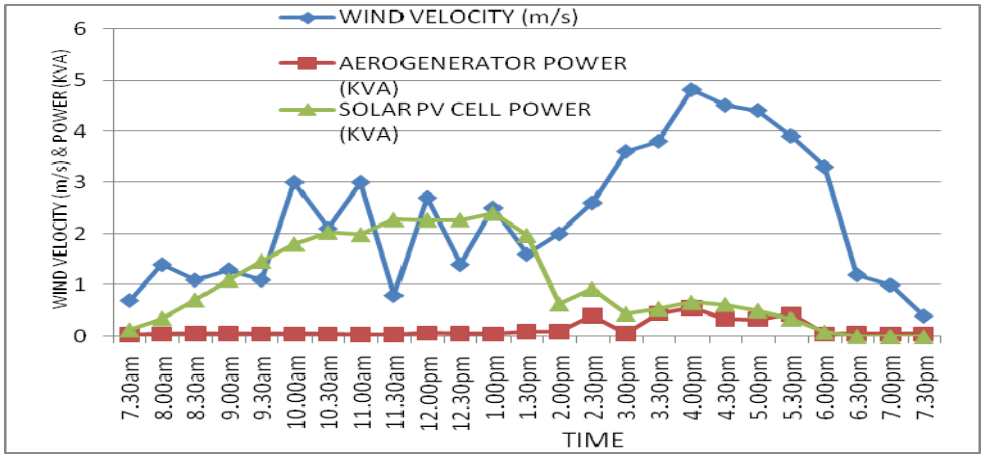

Figure 3. Wind velocity, solar and wind power generation in a day

v) It has been indicated in Table 3 and shown in Figure 4, that in case of this particular plant, the solar tracking would increase the quantity of lux incident on the SPV panels by 20%, thus increasing its generation capacity in accordance with the incident lux. However, since this SPV cell unit is designed to generate only 12 kWh per day, a 20% increase in the solar power generation capacity would increase the power generation by maximum of 2.4 kWh/day.This may additionally save only Rs.8.40 per day (@ Rs.3.50 per kWh) but this saving would be too small as compared to the cost of the proposed solar tracking system.

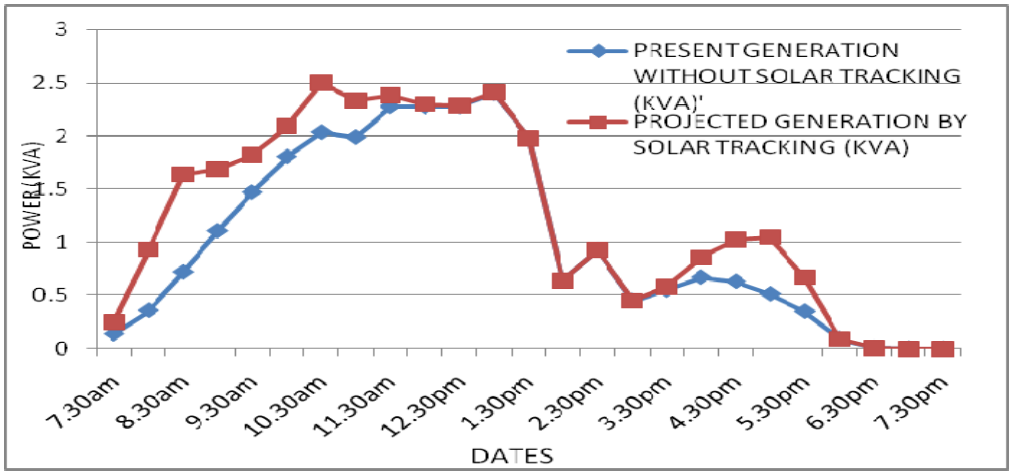

Figure 4. Comparison of actual and projected generation by SPV cells with solar tracking

5. Conclusion and Suggestions

From the above study, the conclusions were drawn and few suggestions were made for the improvement in the design and performance of the hybrid power plant:

i) The mismatch in the designed and actual energy generation share by wind and solar power units, is effectively reducing the generation capacity of the wind power plant and hence also of the hybrid power plant. Therefore, it is suggested that the actual wind and solar energy potential at this site should be reassessed properly and the design of hybrid power plant may be modified suitably.

ii) The installation and maintaining of a solar tracking system would not be economical for such a small capacity hybrid power plant hence the same need not be installed.

iii) For improving the present PUF from 32.91 % to near to 100 %, it is suggested to design and install a suitable load balancer circuit, working on the principle of sensing the battery bank voltage and automatically add or cut off the load connected to the output inverter of the hybrid power plant, depending on increase or decrease in the pre decided level of battery bank voltage [11].This would also prevent batteries from draining fully or remaining in idle charging mode. Also an intelligent real time data acquisition and instrumentation system may be installed for enabling monitoring, interfacing and programming of the plant operations and control [12].

iv) Hybrid power plants are green and clean unlike thermal or nuclear power plants. Earlier studies have shown that a hybrid power plant of 10 kW capacity, over its lifetime can prevent the release of considerable quantum of environmental pollutants, such as CO_2- 107.2 tonnes, H_2O– 17.66 tonnes, SO_2- 0.58 tonnes, O_2- 17.385 tonnes and N_2- 348.35 tonnes [13]. This certainly is an achievement towards the environment conservation and hence research in this field and installation of many such hybrid projects needs to be promoted on a much larger scale.

v) It is suggested to register this power plant combined with all other such power plants installed in the state of Goa, India, under the Kyoto Protocol's Clean Development Mechanism (CDM) so as to get additional revenues that accrue from the sale of certified emission reductions (Carbon Credits). This would result in improvement of project internal rate of returns (payback).

vi) The comparison of the installation cost of this power plant to the projected generation and saving in the electicity energy bills (as discussed earlier) [14], indicates that the payback period of such hybrid power plant would be very long, making it technically and commercially unviable option for energy generation. However, employment of better and efficient technology may largely improve the power plant reliability [15] along with its technical and commercial viability.

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