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Life Cycle Cost Analysis of Small Wind Power Generation-A Case Study

By Smita G. Badgujar, Dr. Arun Kumar Dwivedi & Dr. Suresh Singh Kushwaha
SSVPS BSD College of Engineering, India

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This paper presents a feasibility study of a village for energy security through the wind energy. A wind energy generation system is proposed which will address the minimum energy needs including for household and street-lighting in a village. The life cycle cost analysis of a proposed wind energy generation system for a village is done. The unit cost of electricity is obtained for four phases in analysis period of 20 years, and it is found that the same tunes with the existing ones. A sensitivity analysis is also carried out for different rate of interest and different plant load factors.

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LIFE CYCLE COST ANALYSIS OF SMALL WIND POWER GENERATIONACASE STUDY

Strictly as per the compliance and regulations of

Life Cycle Cost Analysis of Small Wind Power Generation–A Case Study

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I. Introduction

The electricity demand continued to rise despite of the slow pace of the global economy as observed in last five years i.e. 2007-2012. The demand of electricity in India is expected to be three fold in year 030 than it was in year 2005. The shortage of electricity is common and it is an established fact that even today around 40% of the population has no access to modern electric services. The gap between the supply and demand is mismatching despite of major capacity additions over recent decades [GoI (2012)].

The technologies fulfilling the rural electric demand may be classified by three approaches. The first one is conventional approach i.e. the centralized thermal generation combined with rural grid extensions. The second approach is the small scale de-centralized distributed generation, whereas the third approach is the use of renewable energy with household or village level technology such as use of solar photovoltaic cells or small wind turbines with set of battery for energy storage. However, this approach is useful only for low consumption activities and is viable with minimal unit investment costs [GWEC (2012)].

According to a survey by NSSO (2001), the rural households spend around 10% of their monthly income on basic fuel and energy services, which are primarily used for cooking and heating activities. The rural household spending on energy as % of their monthly per capita expenditure group is shown in Figure – 1 [CEA (2007)]. However, the willingness to pay depends upon income, existing energy mix and costs thereof, availability of electricity, quality of supply and appliance ownership.

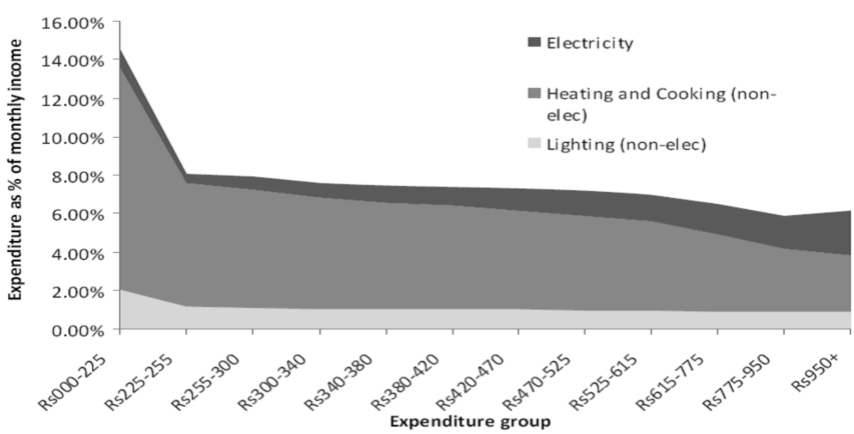


Figure 1 : Rural household spending on energy as % of monthly consumption, by monthly per capita expenditure group [NSSO (2001)] [Source : CEA(2007)]

Author α : Head, Department of Civil Engineering, Jaywantrao Sawant Polytechnic, Hadapsar, Pune-411 028, Maharashtra, India. E-mail : smita_daterao@sify.com
Author σ : Professor & Head, Department of Civil Engineering, SSVPS' BSD College of Engineering, Vidyanagari, Deopur, Dhule-424 005, Maharashtra, India. E-mail : akd321@gmail.com
Author ρ : Associate Professor, Department of Civil Engineering, Institute of Technology, Rajiv Gandhi Technological University, Gandhi Nagar, Bhopal- 462 036, Madhya Pradesh, India. E-mail : sskushwaha1963@gmail.com

II. Significance

The reliable electric services are significant as these are the key driver behind the economic development of country as well raises the basic stand level of the people. The rural India home around 65% of the country's population and around 25% of the world's poor. Rural electricity supply in India has been lagging in terms of service (measured by hours of supply). Only 31% of the rural households have access to electricity, and the supply suffers from frequent power cuts and high fluctuations in voltage and frequency. The demand-supply gap is currently 7.8% of average load and 13% of peak demand [GWEC (2012)].

The reliable and affordable supply of electricity is essential in rural India, because it helps in income generating activities and allows the utilization of modern appliances and agricultural equipments. The electrification also increases the likelihood that women will read and earn income. At the same time its use replaces the use of inefficient and polluting sources of energy such as kerosene.

The non conventional energy sources excluding the large hydro electric power generation, constitutes around 5% of the total installed electric power generation capacity. The significant potential of non-conventional energy sources is still untapped. The various feasibility studies have demonstrated the technical and economical suitability of renewable energy at rural area in India. These studies have concluded that a use renewable energy technology, especially at rural area offers the environmental as well the social sustainability [WB (2008)].

III. Status of Wind Energy Conversion in India

Wind power is accepted as major complementary energy source for securing a sustainable and clean energy future for India. The total installed electrical power generation capacity in India is 207.80 GW as on start of financial year 2012-13. The share of the renewable energy is around 25 GW, out of which 67% is generated by the wind energy. As per an assessment by C-WET in 2011, the wind power potential in country is 102.78 GW at 80 m height above ground level and 49.13 GW at 50 m height above the ground level, both at 2% land availability. If the estimated wind power potential of 102.78 GW is fully developed, the wind electric power would fulfill 8% of the projected electrical demand in 2022 and 5% in 2032. The addition of wind power during the financial year 2011-12 is around 3.2 GW, which is highest addition in a year so far. The Government of India has fixed its target to add 15 GW of wind energy installations in 12th five year plan (2012~17). Currently, the 95% of the country's wind energy development is concentrated in five states i.e. Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Gujarat with their installed capacity 6987.6, 245.50, 1933.50, 2733.30 and 2966.30 MW respectively, as on start of financial year 2012-13. The two states i.e. Madhya Pradesh and Rajasthan have shown a considerable progress in spite of their poor potential. The total installed capacity in these two states is 376.40 and 2070.70 MW respectively.

The installation of wind mills in India has started in 21st century. The Figure -2 shows the year wise cumulative installation of wind mills in MW after year 2000 [Gomathinayagam (2012)].

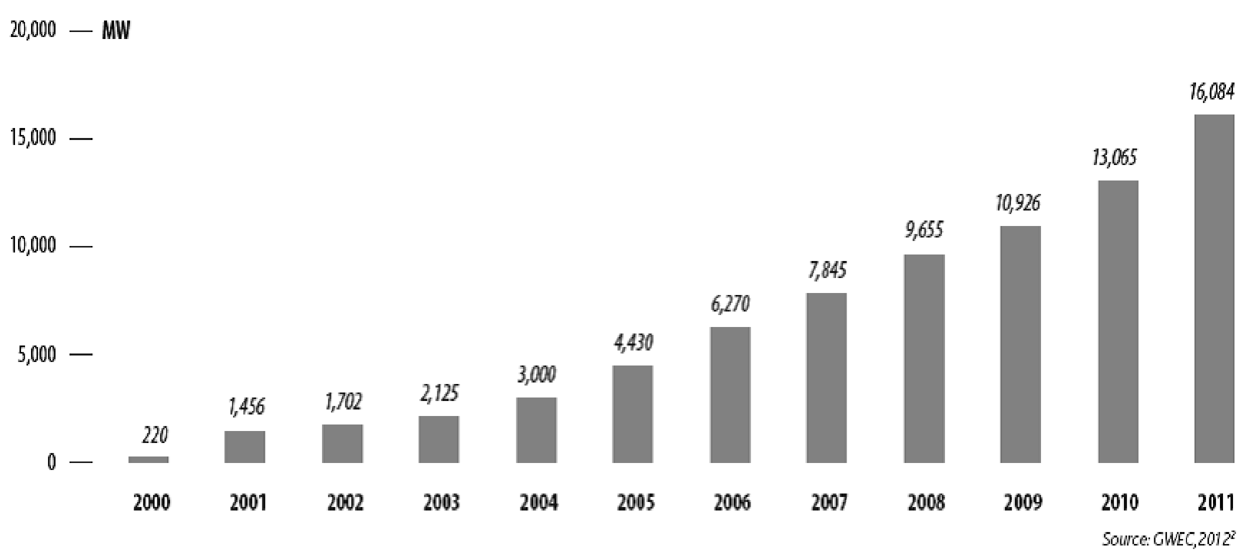


Figure 2 : India: Cumulative Wind Installation (MW)

IV. Principle of Generation of Electricity from Wind Power

Some of the important components of the small wind turbines are rotor, generator/alternator, gear box, nacelle, tail vane, control system, tower, batteries and charger, inverter, and rectifier. The rotor consists of blades and shafts. The wind moves over the blades and converts the kinetic energy from moving wind into rotary motion of rotor, the diameter of circle formed by which determine the quantum of energy extracted from wind and thus the power generated by the system. The generator produces electricity i.e. direct current (DC) from the rotation of the turbine rotor whereas an alternator converts the DC into alternating current (AC). The purpose of a gearbox is to match the rotor speed to that of the generator. The Nacelle is the removable casing to protect the generator/alternator and gearbox. A yaw system is required to align a wind turbine in the direction of the wind. There are many micro and mini systems use a simple tail vane that directs the rotor in the direction of wind. The control systems vary from simple switches, fuses and battery charge regulators to computerized systems for control of yaw systems and brakes. The sophistication of the control and protection system varies depending on the application of the wind turbine and the energy system it supports. The main function of the tower is to hold the turbine in the path of the wind and is an integral part of a wind energy system. It is designed to support adverse conditions of atmosphere. The additional equipments are needed to support the balance-of-system such as batteries with charger, inverter, and rectifier along with some protective equipment.

The ratio of actual output to installed capacity is the plant load factor (PLF) of the wind mill of that year. The wind may not be available at the wind farm site with required intensity throughout the year and hence the wind turbine may not be operational as would be a conventional thermal power plant. Hence, the plant load factor is comparatively lesser for a wind turbine.

A modern wind turbine produces electricity 80~85% of the time however the output may be different depending upon the wind speed. The load factor of wind turbines ranges between 28~30%, whereas the average plant load factor of conventional power plant such as thermal power plant is around 50%. The best performing wind turbine have the plant load factor close to 50% [Eleanor (2007)].

V. Advantages of Wind Energy Conversion

Wind energy systems are one of the most cost-effective renewable energy systems. Depending on wind resource, a small wind energy system being lifetime energy source can lower load on other energy sources helps to avoid the high costs of extending utility power lines to remote locations, prevent power interruptions and it is non-polluting green energy. A modern wind farm, when installed on land, has one of the lowest environmental impacts of all energy sources:

- It occupies less land area per kilowatt-hour (kWh) of electricity generated than any other renewable energy conversion system, apart from rooftop solar energy.
- It generates the energy embodied in its construction within just months of operation.
- Greenhouse gas emissions and air pollution produced by its construction are small and declining. There are no emissions or pollution produced by its operation.
- Modern wind turbines rotate so slowly i.e. revolutions per minute, that they are rarely a hazard to birds.

VI. Energy Security of a Village Through Wind Energy – Case Study

A feasibility study of a village Bhod (Khurd) is done for energy security through the wind energy. The village lies under Dharangaon Taluka in district Jalgaon of Maharashtra state of India. The village is 28 kms from the district head quarter and is on the right bank of river Ajani, which is one of the tributary of west flowing Tapi river.

VII. Data Collected

a) Wind Resource at Village Bhod

A wind rose diagram is a graphical tool which gives a succinct view of distribution of wind speed and direction at a particular location. The wind rose diagram of the surrounding area is shown in Figure – 3.

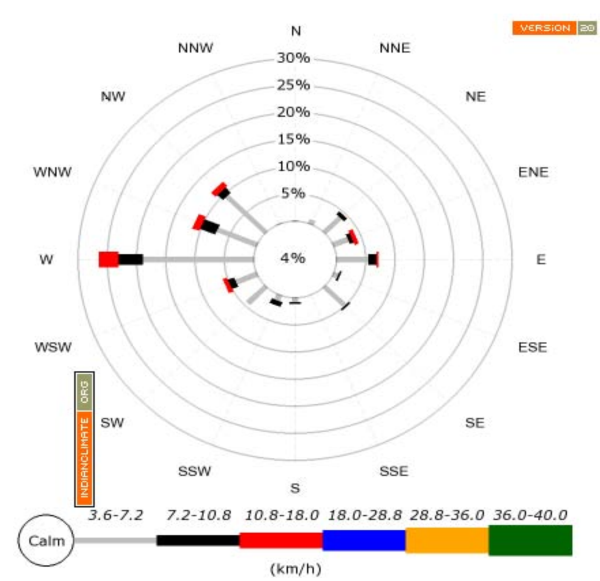


Figure 3 : Wind Rose Diagram

The monthly average wind speeds are given in the Table - 1.

Table 1 : "Monthly Average Wind Speed"

Month	Wind speed m/s
January	4.4
February	4.1
March	4.5
April	5.3
May	6.8
June	8.5
July	10.1
August	9.8
September	6.2
October	4.8
November	4.3
December	4.4
Minimum	4.1
Maximum	10.1
Average	6.3

b) Demand of Electrical Energy

The village is surveyed for the energy requirement at household level in year 2012. The survey revealed that there is a load shedding of more than 10 hours in a day. This signifies the necessity of proposed projects at village level. Out of the 120 total numbers of houses in the village, 68 houses are electrified. In the demand calculation, it is considered that the non electrified houses shall be given one point connection for lighting. The current average monthly requirement of the electrical energy of the entire village as per survey is 2887.90 kWh.

The demand forecasting curve is plotted for the data available for last five decades for consumption of electricity in rural sector in country. The extended part of the curve is shown in Figure 4.

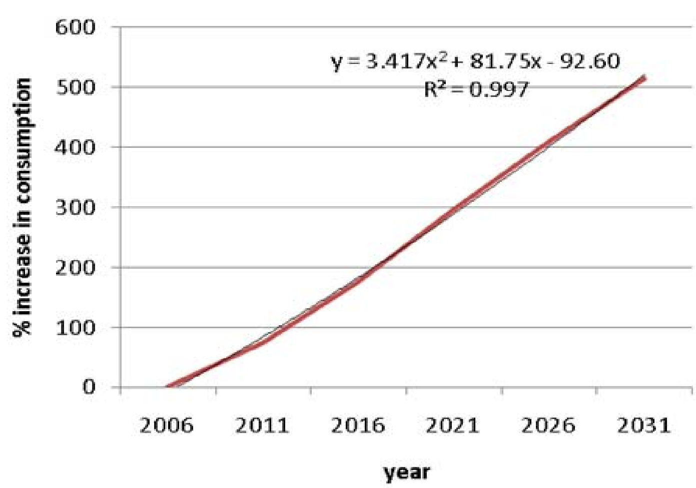


Figure 4 : "Demand Forecasting Curve"

The forecasted demand during the four phases of analysis period is calculated and is shown in Table – 2.

c) Proposal of Wind Turbine

It is found from the market survey and expert advice that the wind turbines of 5.00 kW capacities are suitable, economically and technically among all the ranges of small wind turbines. It is proposed to install the wind turbines of 5.00 kW capacities in four phases in a span of 5 year each, as per forecasted demand.

A plant load factor of 22.5% is considered as per usual practice and at this plant load factor, a turbine of 5.0 kW may generate 9855 electrical units (kWh). The number of turbines required in these four phases is 6, 8, 11 and 13 respectively. The base year is taken as 2012 and the service year is considered as end of year 2013.

d) Cost Estimation and Analysis

The life cycle cost analysis is done with the following assumptions -

i. The analysis period of the project is taken as 20 years.
ii. The rate of interest is considered as 8%.
iii. The plant load factor is taken as moderate i.e. 22.5%, which is the usual practice for turbines of 5 kW rating.
iv. Maintenance cost of small turbines is negligible and hence not taken into account, however provision of one mechanic and one helper at the monthly wage of Rs.8000.00 is considered for the maintenance of system.
v. The life of battery is considered as 5 years i.e. in the entire analysis period the batteries are placed three times.

vi. Maintenance cost of battery is taken as 10% of cost of capital cost.

vii. Residual value of battery is taken as 20% of original cost.

The residual value of turbines installed at first phase is considered as 20%, correspondingly the residual value of turbines in second, third and fourth installation is taken as 30%, 40%, and 50% of capital cost of turbine.

The cash flow diagram with the above stated assumptions is shown in the Figure – 5 [Kishk, Al-Hajj, and Pollock (2003)]

The cost of items appearing in the analysis period of 20 years and the residual values of items at the end of the analysis period is given in Table - 3. The life cycle cost analysis is done and the unit cost of electricity produced is calculated in four phases of analysis period of the project, is shown in Table – 4.

Table 2 : Demand Calculations

Description	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6	Lane 7	Lane 8	Lane 9	Lane 10	
Housewise daily consumption in units		0.07	0.07	1.13	1.57	0.53	1.87	4.77	3.07		
		0.07	0.07	1.43	1.27	0.57	1.50	0.97	3.40		
		0.17	2.00	1.37	0.27	1.30	0.80	1.00	3.87		
				1.30	0.30	1.30	0.93	1.07	4.17		
				1.13	0.37	0.60	0.67	1.07			
				1.13	0.27	0.53	0.07	2.07			
					0.3	1.67	0.93	2.10			
					0.43	1.40	0.83	2.23			
					0.53	1.60	1.63	1.13			
					0.57	0.63	1.50	1.13			
					1.37	0.73	1.77	1.13			
					1.57	0.73	1.80	1.13			
					1.7	0.70		2.37			
Actual	0.00	0.31	2.14	7.49	10.52	12.29	14.30	22.17	14.51	0.00	
Facilitated	2.10	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	4.65	
Total	2.10	0.31	2.14	8.69	10.52	12.29	14.3	22.17	14.51	4.65	
Transmission Losses @ 5%	0.105	0.016	0.107	0.435	0.526	0.615	0.715	1.11	0.73	0.23	
Total Consumption/ Day	2.21	0.33	2.25	9.125	11.046	12.90	15.015	23.28	15.24	4.88	
Total Consumption/ Month	66.15	9.77	67.41	273.74	331.38	387.14	450.45	698.35	457.07	146.48	
Total Consumption in 2012	793.80	117.18	808.92	3284.82	3976.56	4645.62	5405.4	8380.26	5484.78	1757.70	34655.04
Forecasted Consumption (2017)	1270.08	187.49	1294.27	5255.71	6362.50	7433.00	8648.64	13408.42	8775.65	2812.32	55448.06
Forecasted Consumption (2022)	1801.93	265.00	1836.25	7456.54	9026.79	10545.56	12270.26	19023.19	12450.45	3989.98	78666.94
Forecasted Consumption (2027)	2381.40	351.54	2426.76	9854.46	11929.68	13936.86	16216.2	25140.78	16454.34	5273.10	103965.10
Forecasted Consumption (2032)	2794.18	412.47	2847.40	11562.57	13997.49	16352.58	19027.01	29498.52	19306.43	6187.11	121985.70

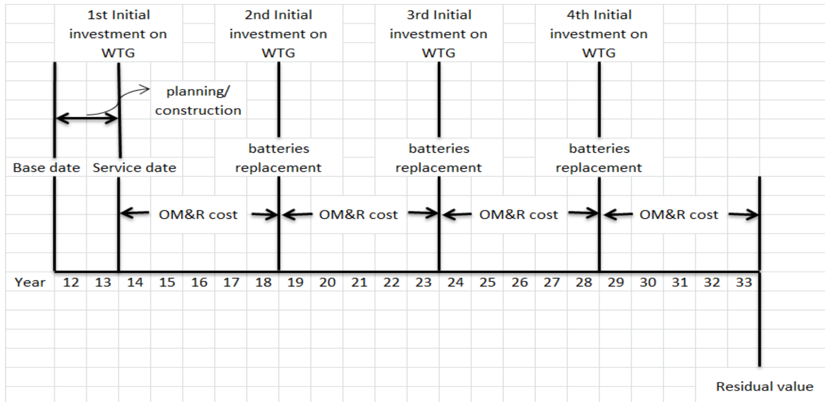


Figure 5 : "Cash Flow Diagram of Proposal"

Table 3 : Life Cycle Cost Estimation

Sr No	Description	Unit Cost Rs	Unit	Quantity	Cost Rs
Initial investment cost					
1	First installation of turbines (5KW)	508000.00	NO.	6	3048000.00
2	Second installation of turbines (5KW)	508000.00	NO.	2	1016000.00
3	Third installation of turbines (5KW)	508000.00	NO.	3	1524000.00
4	Forth installation of turbines (5KW)	508000.00	NO.	2	1016000.00
5	Batteries required in First installation	9000.00	NO.	60	540000.00
6	Batteries required in second installation	9000.00	NO.	20	180000.00
7	Batteries required in third installation	9000.00	NO.	30	270000.00
8	Batteries required in forth installation	9000.00	NO.	20	180000.00
9	Cable(with labour cost) at first installation	62.00	NO.	1500	93150.00
10	Sub meter (with labour cost) at first installation	1525.00	NO.	120	183000.00
Capital Replacement of Batteries					
11	After 5 years	7200.00	NO.	60	432000.00
12	After 10 years	7200.00	NO.	80	576000.00
13	After 15 years	7200.00	NO.	110	792000.00
Operation, Maintenance & Repair Cost					
14	Batteries maintenance first five years from first Installation	900.00	NO.	60	54000.00
15	Batteries maintenance 5 years after second installation	900.00	NO.	80	72000.00
16	Batteries maintenance 5 years after third installation	900.00	NO.	110	99000.00
17	Batteries maintenance 5 years after forth installation	900.00	NO.	130	117000.00
18	Salary of mechanic	5000.00	MONTH	12 months	60000.00
19	Salary of helper	3000.00	MONTH	12 months	36000.00
Residual value					
20	20 % of turbine cost for first installation	101600.00	NO.	6	609600.00
21	30 % of turbine cost for second installation	152400.00	NO.	2	304800.00
22	40 % of turbine cost for third installation	203200.00	NO.	3	609600.00
23	50 % of turbine cost for forth installation	254000.00	NO.	2	508000.00
24	Batteries	1800.00	NO.	130	234000.00
Residual Value at the end of Analysis Period					2266000.00

Table 4 : Life Cycle Cost Analysis for Analysis Period 20 Years and Depreciation @ 8%

Year	CC (WTG)	CC(BATTERY)	RC (BATTERY)	TCC	EACCF	EACC(2)	EACC(7)	EACC(12)	EACC(17)	AO&MC	ALCC(GROSS)	ALCV	ALCC(NET)	APGC	UNIT COST
	(Rs)	(Rs)	(Rs)	(Rs)		(Rs)	(Rs)	(Rs)	(Rs)	(Rs)	(Rs)	(Rs)	(Rs)	(kWh)	(Rs)
0															
1															
2	3048000.00	540000.00		3588000.00	0.1019	365445.73				150000.00	515445.73	-230797.11	284648.62		
3						365445.73				150000.00	515445.73	-230797.11	284648.62		
4						365445.73				150000.00	515445.73	-230797.11	284648.62	59130	4.81
5						365445.73				150000.00	515445.73	-230797.11	284648.62		
6						365445.73				150000.00	515445.73	-230797.11	492847.12		
7	1016000.00	180000.00	432000.00	1628000.00	0.1168	365445.73	190198.50			168000.00	723644.22	-230797.11	492847.12		
8						365445.73	190198.50			168000.00	723644.22	-230797.11	492847.12		
9						365445.73	190198.50			168000.00	723644.22	-230797.11	492847.12	78840	6.25
10						365445.73	190198.50			168000.00	723644.22	-230797.11	492847.12		
11						365445.73	190198.50			168000.00	723644.22	-230797.11	492847.12		
12	1524000.00	270000.00	576000.00	2370000.00	0.1490	365445.73	190198.50	353199.89		195000.00	1103844.11	-230797.11	873047.01		
13						365445.73	190198.50	353199.89		195000.00	1103844.11	-230797.11	873047.01		
14						365445.73	190198.50	353199.89		195000.00	1103844.11	-230797.11	873047.01	108405	8.05
15						365445.73	190198.50	353199.89		195000.00	1103844.11	-230797.11	873047.01		
16						365445.73	190198.50	353199.89		195000.00	1103844.11	-230797.11	1388954.44		
17	1016000.00	180000.00	792000.00	1988000.00	0.2505	365445.73	190198.50	353199.89	497907.43	213000.00	1619751.54	-230797.11	1388954.44		
18						365445.73	190198.50	353199.89	497907.43	213000.00	1619751.54	-230797.11	1388954.44		
19						365445.73	190198.50	353199.89	497907.43	213000.00	1619751.54	-230797.11	1388954.44	128115	10.84
20						365445.73	190198.50	353199.89	497907.43	213000.00	1619751.54	-230797.11	1388954.44		
21						365445.73	190198.50	353199.89	497907.43	213000.00	1619751.54	-230797.11	1388954.44		
22	RESIDUAL VALUE OF WT & BATTERIES			2266000.00											

CC – Capital Cost, WTG – Wind Turbine, BATT – Battery, RC – Replacement Cost, TCC – Total Capital Cost, EACCF – Equivalent Annual Capital Cost Factor, EACC – Equivalent Annual Capital Cost,
AO&MC – Annual Operation & Maintenance Cost, ALCC – Annual Life Cycle Cost, ALCRV – Annual Life Cycle Residual Value, APGC - Annual Power Generation Capacity

e) Sensitivity Analysis

The rate of interest is an important parameter in life cycle cost analysis of a project and thus the unit cost of generation. The variation in unit cost of electricity (Rs/kWh) with the rate of interest is calculated for all four phases of life cycle and is shown in Figure – 6.

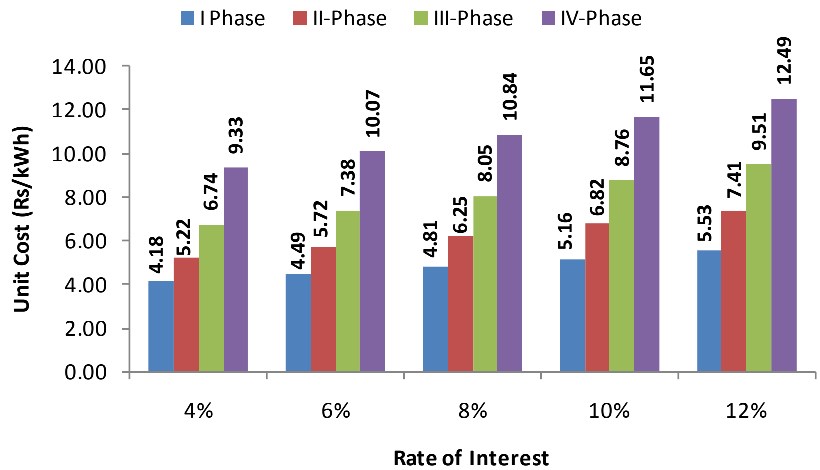


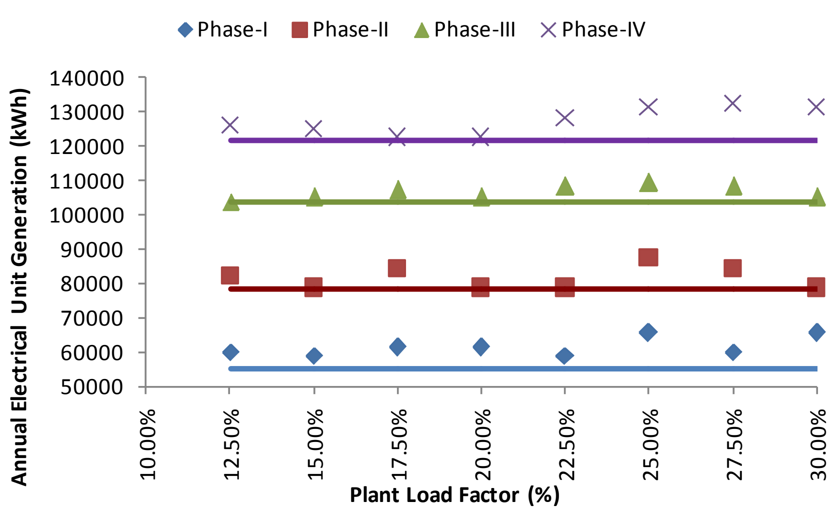
Figure 6 : "Variation in Unit Cost with Rate of Interest"

The another parameter which affects the life cycle cost is the plant load factor, which in turn depends upon many technical parameters of wind turbine generation and ambiance. The number of wind turbines required to fulfill the demand is a function of plant load factor. The numbers of wind turbines for different PLF are calculated and are shown in Table – 5.

Table 5 : "Wind Turbine for Different Plant Load Factors"

Phases	Plant Load Factor (%)							
	12.50%	15.00%	17.50%	20.00%	22.50%	25.00%	27.50%	30.00%
	Total Number of Wind Turbine							
Phase-I	11	9	8	7	6	6	5	5
Phase-II	15	12	11	9	8	8	7	6
Phase-III	19	16	14	12	11	10	9	8
Phase-IV	23	19	16	14	13	12	11	10

The demand in different phases corresponding annual generation of electrical units is shown in Figure – 7.



(Points & Lines indicate Generation and Demand respectively)

Figure 7 : "Annual Electrical Unit Generation (kWh) from WECS at Different Plant Load Factors"

The unit cost of electricity (Rs/kWh) with the plant load factor is calculated for all four phases of life cycle and is shown in Figure – 8.

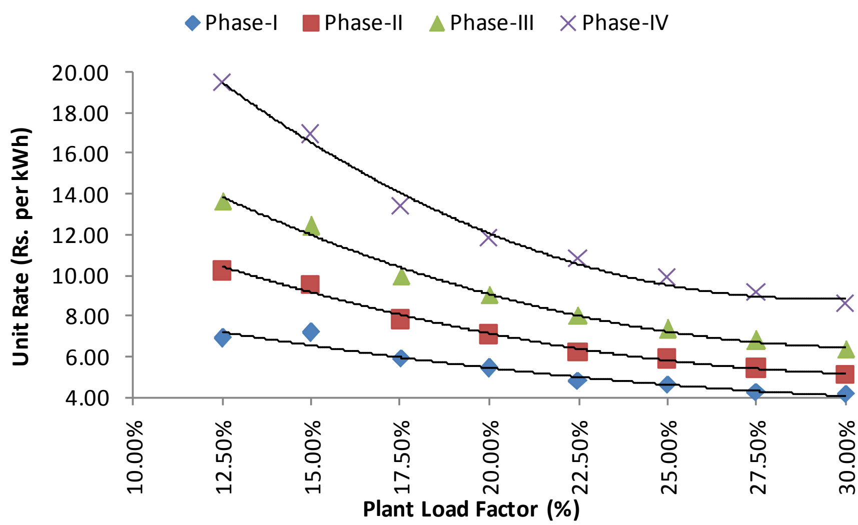


Figure 8 : "Variation in Unit Cost with Plant Load Factor"

The % variation in unit cost of electricity (Rs/kWh) with the plant load factor is calculated for all four phases of life cycle and is shown in Table – 6.

Table 6 : % Increase in Unit Cost with Plant Load Factor

PLF	% Increase in PLF	% Increase in Unit Cost with respect to PLF = 12.5%			
		Phase-I	Phase-II	Phase-III	Phase-IV
12.50%	0.00%	0.00	0.00	0.00	0.00
15.00%	20.00%	4.31	-6.39	-9.18	-13.04
17.50%	40.00%	-13.81	-23.44	-27.16	-31.42
20.00%	60.00%	-21.22	-30.43	-34.00	-39.47
22.50%	80.00%	-30.25	-38.83	-41.28	-44.47
25.00%	100.00%	-32.25	-42.43	-46.30	-49.16
27.50%	120.00%	-37.82	-46.82	-50.32	-52.90
30.00%	140.00%	-39.58	-49.87	-53.28	-55.74
PLF - Plant Load Factor					

VIII. Conclusions

The electrical has become a basic need in the Indian rural culture too. The conventional sources of energy have its limited life as the sources have finite quantum. These sources are distributed unevenly across the globe, and thus lead to a non uniform economy. At the same time, the transformation of these conventional energy sources into electrical energy affects the atmosphere adversely. The non conventional energy sources such as wind and solar are unlimited and mostly distributed by the nature across the globe evenly and need the attention of scientists and engineers to develop the technology to tap these sources economically. The economical feasibility of non-conventional sources for generation of electrical energy should be ascertained by life cycle cost analysis, instead of capital cost at initial level. The life cycle cost analysis of a proposed wind power generation system for a village is done, in which the unit cost of electricity is obtained for four phases in analysis period of 20 years. The following conclusions are drawn from the analysis -

- The current annual demand of electricity in the village as per survey is 34655 kWh, which is forecasted at the end of four phases during the analysis period of 20 years as 55448 kWh in 2017, 78667 kWh in 2022, 103965 kWh in 2027 and 121986 kWh in year 2032.

- The small wind turbines each of 5.00 kW capacities with average plant load factor of 22.5 % are proposed for installation. The numbers of wind turbines required in four phases are 6, 8, 11 and 13.
- The life cycle cost analysis is done for analysis period of 20 years, considering the rate of interest 8%. The unit cost of electricity increases with capital investment in different phases and thus does not follow the economies of scale. It is Rs.4.81, Rs.6.25, Rs.8.05 and Rs.10.84 in four phases.
- The unit cost of the electricity of the proposed wind power generation in the first and second phase of analysis period tunes with the existing unit rates of Maharashtra Electric Supply and Distribution Company. The rates in third and fourth phases of analysis period are higher with respect to the current rates; however the same may be justified by considering the natural rise in the rates with time due to escalation in prices.
- The unit cost of generation is sensitive to rate of interest, which is demonstrated in Figure – 6. The unit rate of electricity varies from 23.46 to 30.51% in all phase of life cycle, for rate of interest 4% to 12%.
- The plant load factor of any generation depends on many technical and management factors. Any improvement in the plant load factor reduces the unit cost of generation. The sensitivity of unit cost with respect plant load factor is analysed and it is observed that improvement in plant load factor from 12.50% to 30.00% reduces the unit cost by 39.58 % & 55.74% for phases I & IV respectively.

IX. Limitations and Future Scope

The case study presented in this paper is an attempt to justify the economical feasibility of wind turbine at village level. The strength and characteristics of wind in the area plays an important role in success of wind power generation. At the same time efficiency of battery system also plays a vital role in an isolated door step supply. The renewable energy sources such as bio-mass and solar are available in the village, which can also be used for electric power generation. A hybrid system using biomass, solar and wind energy may be a more realistic solution for the energy security for the village.

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