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Life Cycle Analysis of Dual Generator Wind Turbine System – A Case Study

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Abstract

There is a need to develop a turbine system that can operate at low wind speeds of 2.0 to 3.0 m/s. This will require concerted efforts to improve the design. The dual generator model can be used to extract more wind power from sites with low wind speeds, such as those found in India. In this article economic feasibility analysis of dual generator model is conducted using data obtained from the B.B.Hills wind site of Karnataka State, India. Then the economic effectiveness of the dual-generator model is compared with single generator model. Financial assessment of the both the models done by calculating net present value (NPV), benefit to cost ratio (BCR), internal rate of return (IRR) and payback period.

Keywords: Wind power generation, Economic feasibility, NPV, BCR, IRR

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Introduction

In recent years, concerns about the cost and environmental impact of fossil fuels have increased the importance of wind turbines for wide range of electricity. There are many commercial wind turbines available for commercial use today. Even low speed turbines are usually designed for high wind speeds, usually around 4 to 5 m/s cut in wind speed and 12 to 15 m/s rated wind speed. Therefore, at the lower wind speeds these wind turbines extract the insufficient amount of power.

Therefore it is necessary to design wind turbines to generate power at lower wind speeds with higher efficiency.

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Table 1: Capital statement and energy production of conventional and dual generator model of 1 MW wind farm.

Sr. No.	*Particular*	*Parameter*	
1	Wind farm capacity	Single generator wind turbine model 225kW	Dual generator wind turbine model 2X112.5kW
2	Total installation cost a. Equipment cost b. Land cost	101.25 million	102.25 million
3	Annual capacity factor B.B.Hills wind site [1, 6, 7, 8]	0.47636	0.47534
4	Annual operation and maintenance cost	1.75% of capital investment with 5% annual escalation.	1.75% of capital investment with 5% annual escalation.
5	grid availability factor	97%	97%
6	Sale price of electricity	3.5 Rs. /kWh	3.5 Rs. /kWh
7	Discount rate / Annual fixed charge rate (FCR)	8%	8%
8	Project life time	20	20
9	Insurance	Rs 50,000	Rs 50,000
10	Administration costs	Rs 65,000	Rs 65,000

So there is a need to develop a turbine system that can operate at low wind speeds of 2.0 to 3.0 m/s of cut-in wind speed. One solution to achieve this is using a dual-generator wind turbine model. In dual generator wind turbine model one generator will start generating power at lower wind speeds, this will increase the overall extraction of power from wind turbines.

In this article, the economic feasibility study of the dual generator model is conducted using data obtained from the B.B. Hills wind site of Karnataka State, India. Then the economic effectiveness of the dual generator model is compared with single generator model. Financial assessment of both the models done by calculating net present value (NPV), benefit to cost ratio (BCR), internal rate of return (IRR) and payback period.

Table 1 shows the capital statement and energy production of conventional wind turbine and dual generator wind turbine model of 1 MW capacity.

Methodology

Annual gross power production is computed based on capacity factor of the B.B.Hills wind site (based on the turbine specification). Annual Gross Power Production (*GPP*) is computed as [2,3,15,20,21,22],

GPP= (CF) x (225)x(24x365) x GA kWh (1)

CF is capacity factor and *GA* is grid availability factor (97% consider).

Gross Surplus Available (*GSA*) is the difference between the revenue generated, operation, and maintenance cost. GSA is expressed as,

G.S.A (i)=(RG(i))-(OMC(i)) (2)

i=1, 2, ..., 20

Interest(*i*)= *Outstanding Loan*(*i*)×Rate of Interest

Net Surplus Available (*NSA*) can be calculated by using below expression

NSA(*i*)=(*GSA*(*i*))–(*Outstanding Loan*(*i*) + *Interest*(*i*) + Insurance + Administration charges) (3)

i=1, 2, ..., 20

Outstanding Loan (*i*+1) =*NSA* (*i*) if *NSA* ≤ 0

Theory For Analysis

The financial assessment of the wind power project is computed by estimating various wind energy costs and the project feasibility is determined by using the discounted cash flow technique. 11,12,13,14,16,17

The specific capital cost calculation of conventional wind model and two generator model by considering capital investment and the annual energy production per year. specific capital cost is calculated by the following formula

$$\text{Capital cost (C)} = \frac{\text{Installed capital cost}}{\text{Energy production per year}} \quad Rs/(\frac{kW}{yr}) \qquad (4)$$

After the computation, it is observed that the annual capacity factor of the conventional wind model is 0.47636 and the dual generator model is 0.47534. This shows the dual generator model has higher capacity than the conventional wind model.

Table 2: kWh Energy production, specific capital cost and the capacity factor calculation based on wind site data.

	SGM	*TGM*
Capacity factor of B.B.Hills wind site	0.47636	0.47534
Annual energy production	970720.128 kWh	979897.104 kWh
specific capital cost	104.30	104.35

Economic Feasibility of Wind Farm

Project evaluation method (discounted cash flows) is used to evaluate the economics of wind farms. The process evaluates the productivity of the investment and the expected cost of flow and return over the entire life of the wind farm. Comparison of the different sources of production capital used in the economic evaluation of the wind farm business are: net present value, benefit-cost ratio, payback rate and payback period [4, 5, 9, 10, 23].

Net Present Value

In this method, the discount rate, which usually reflects the value of the capital, is used to arrive at the cost and return of the time difference. Subtracting these costs from the returns results in the project's current cost. Positive net income indicates the investment is worthwhile The size of the net present value (NPV) indicates the value of the project in terms of the use of resources to obtain it. The following expression is used to calculate the present value: 18,19,24,26,27,28

Net present value (NPV) is the Total net profit (eg, The difference between the operating income of the project and its total cost over the project's economic life). All quantities are discounted on the day the project enters production. The following formula is used to calculate NPV, taking into account only the positive impact of NSA:

$$NPV = -K + \sum_{i=1}^{n} \frac{NSA(i)}{(1+d)^i} \qquad (5)$$

i=1, 2, ..., 25

where K is total capital investment costs, and

d is discount rate.

NSA is Net Surplus Available

If NPV>0 Investment is worthy

NPV=0 Neutral case

NPV< 0 Investment is not worthy

The Benefit-to-Cost Ratio (BCR)

The benefit-cost ratio (BCR) is defined as the ratio of a project's total revenue to its total cost over the life of a project. The following relationships provide a basic overview:

$$BCR = 1 + \frac{NPV}{K} \qquad (6)$$

If BCR>0, Investment is worthy

BCR=0 Neutral case

BCR< 0 Investment is not worthy

The Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is computed using an iterative process determining 'd' on the limiting condition, NPV=0, in the equation. IRR then is equal to 'd'.

Payback Period

It is the simplest method of evaluating investment strategies. It is defined as the period in which the initial investment is returned as profit. In other words, the project is long-term and the initial investment is repeated in the form of annual profit.

Results And Discussions

Financial assessment using existing method is conducted with annual OMC equal to 1.75% of capital investment with 5% annual escalation. Plant availability is considered to be 97%.

The data considered for the financial assessment B.B.Hills wind site is given in table 3

- The financial assessment is done in terms of Indian Rupees.
- The currency exchange rate is assumed to be US *$1 = Rs 82.81*

Various cash flows, namely revenue generated , operation and maintenance costs, gross surplus available, outstanding loan, interest on borrowed capital, and net surplus available for single generator model is given in Table 4. Various cash flows for dual generator model are given in Table 5.

Table 3: Data considered for the financial assessment

Capacity	*225 kW*
Capital Investment	Rs 101.25 Lakhs for single gen turbine Rs. 102.25 Lakhs for dual gen turbine
Equity	25% of capital investment
Loan	75% of capital investment
Borrowing rate	13%, annual
Discount Rate	08%, annual
Annual Insurance	Rs 50,000
Annual Administration costs	Rs 65,000
Wheeling	2% of the Annual power production
Transmission Loss	1% of the Annual power production
Energy Purchase rate	Rs 3.5 per unit

Table 4: Computed various cash flows for single generator wind turbine model.

Year	*Annual production (Lakh units)*	*Revenue generated (Lakh Rs)*	*OMC (Lakh Rs)*	*Insurance*	*Administration charges*	*Gross surplus (Lakh Rs)*	*Outstanding loan (Lakh Rs)*	*Interest (Lakh Rs)*	*Net surplus (Lakh Rs)*
1	9.0679	31.74	1.7719	0.5000	0.6500	28.8158	75.9375	9.8719	-56.99
2	9.0679	31.74	1.8605	0.5000	0.6500	28.7272	56.99	7.4092	-35.68
3	9.0679	31.74	1.9535	0.5000	0.6500	28.6342	35.68	4.6378	-11.68
4	9.0679	31.74	2.0512	0.5000	0.6500	28.5365	11.68	1.5183	15.34
5	9.0679	31.74	2.1537	0.5000	0.6500	28.4339	0	0.0000	28.43
6	9.0679	31.74	2.2614	0.5000	0.6500	28.3262	0	0.0000	28.33
7	9.0679	31.74	2.3745	0.5000	0.6500	28.2132	0	0.0000	28.21
8	9.0679	31.74	2.4932	0.5000	0.6500	28.0944	0	0.0000	28.09
9	9.0679	31.74	2.6179	0.5000	0.6500	27.9698	0	0.0000	27.97
10	9.0679	31.74	2.7488	0.5000	0.6500	27.8389	0	0.0000	27.84
11	9.0679	31.74	2.8862	0.5000	0.6500	27.7015	0	0.0000	27.70
12	9.0679	31.74	3.0305	0.5000	0.6500	27.5571	0	0.0000	27.56
13	9.0679	31.74	3.1820	0.5000	0.6500	27.4056	0	0.0000	27.41
14	9.0679	31.74	3.3411	0.5000	0.6500	27.2465	0	0.0000	27.25
15	9.0679	31.74	3.5082	0.5000	0.6500	27.0795	0	0.0000	27.08
16	9.0679	31.74	3.6836	0.5000	0.6500	26.9040	0	0.0000	26.90
17	9.0679	31.74	3.8678	0.5000	0.6500	26.7199	0	0.0000	26.72
18	9.0679	31.74	4.0612	0.5000	0.6500	26.5265	0	0.0000	26.53
19	9.0679	31.74	4.2642	0.5000	0.6500	26.3234	0	0.0000	26.32
20	9.0679	31.74	4.4774	0.5000	0.6500	26.1102	0	0.0000	26.11

Table 5: Computed various cash flows for dual generator wind turbine model.

Year	*Annual production (Lakh units)*	*Revenue generated (Lakh Rs)*	*OMC (Lakh Rs)*	*Insurance*	*Administration charges*	*Gross surplus (Lakh Rs)*	*Outstanding loan (Lakh Rs)*	*Interest (Lakh Rs)*	*Net surplus (Lakh Rs)*
1	9.1074	31.88	1.7894	0.5000	0.6500	28.9365	76.6875	9.9694	-57.72
2	9.1074	31.88	1.8788	0.5000	0.6500	28.8471	57.72	7.5036	-36.38
3	9.1074	31.88	1.9728	0.5000	0.6500	28.7531	36.38	4.7290	-12.35
4	9.1074	31.88	2.0714	0.5000	0.6500	28.6545	12.35	1.6059	14.70
5	9.1074	31.88	2.1750	0.5000	0.6500	28.5509	0	0.0000	28.55
6	9.1074	31.88	2.2837	0.5000	0.6500	28.4422	0	0.0000	28.44
7	9.1074	31.88	2.3979	0.5000	0.6500	28.3280	0	0.0000	28.33
8	9.1074	31.88	2.5178	0.5000	0.6500	28.2081	0	0.0000	28.21
9	9.1074	31.88	2.6437	0.5000	0.6500	28.0822	0	0.0000	28.08
10	9.1074	31.88	2.7759	0.5000	0.6500	27.9500	0	0.0000	27.95
11	9.1074	31.88	2.9147	0.5000	0.6500	27.8112	0	0.0000	27.81
12	9.1074	31.88	3.0604	0.5000	0.6500	27.6655	0	0.0000	27.67
13	9.1074	31.88	3.2135	0.5000	0.6500	27.5124	0	0.0000	27.51
14	9.1074	31.88	3.3741	0.5000	0.6500	27.3518	0	0.0000	27.35
15	9.1074	31.88	3.5428	0.5000	0.6500	27.1831	0	0.0000	27.18
16	9.1074	31.88	3.7200	0.5000	0.6500	27.0059	0	0.0000	27.01
17	9.1074	31.88	3.9060	0.5000	0.6500	26.8199	0	0.0000	26.82
18	9.1074	31.88	4.1013	0.5000	0.6500	26.6246	0	0.0000	26.62
19	9.1074	31.88	4.3063	0.5000	0.6500	26.4196	0	0.0000	26.42
20	9.1074	31.88	4.5217	0.5000	0.6500	26.2042	0	0.0000	26.20

Table 6: NPV, BCR & IRR of TGM and SGM

	Single generator turbine model	*Dual generator turbine model*
Net Present Value (NPV)	139.52	138.82
Benefit-to-Cost Ratio (BCR)	2.38	2.36
Internal Rate of Return (IRR)	24.5%	24.2%
Payback period	3 years 7 months	3 years 6 months

Computed gross power production, revenue generated, gross surplus available, outstanding loan, annual interest and net surplus available are indicated in Tables 4 & 5, with the plant availability factor is constant 97%. Hence, the power generated remains constant to Rs 9.0679 Lakh units for the single generator model and 9.1074 Lakh units for the dual generator model throughout 20 years. Correspondingly, annual revenue remains constant equal to Rs 31.74 and 31.88 Lakhs, respectively.Due to an increase in the annual *OMC*, gross surplus available decreases from rupees 28.8158 Lakhs in first year to Rs 26.1102 Lakhs in the 20th year for the single generator model and that for the dual generator model decreases from rupees 28.9365 Lakhs in first year to Rs 26.2042 Lakhs in the 20th year.

Outstanding loan become zero in the 5th year. Net surplus available is negative in the initial years. Net surplus available becomes positive in the 4th year, indicating the net profit accumulation from 4th year.

Comparison of financial parameters

The economic feasibility results of the conventional wind and the two generator models are shown in Table 6.

The economic feasibility outcomes show that the dual generator model is a better payback period than the conventional wind models. Also dual generator model extracts more energy than the single-gene

Conclusion

Economic feasibility analysis of dual generator model is conducted using data obtained from the B.B.Hills wind site of Karnataka State, India. Then the economic effectiveness of the dual-generator model is compared with the single-generator model. Financial assessment of both the models done by calculating net present value (NPV), benefit to cost ratio (BCR), internal rate of return (IRR) and payback period. Results have shown that dual generator turbine model having a better payback period than the single-generator turbine model.

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