Economic Assessment of Wind Power Plant

[1]V. Ramakrishnan and [2]S.S.K. Srivatsa
[1]Department of EEE, Vinayaka Missions University, AVIT, Chennai-603 104, India
[2]Department of ICE, St. Joseph's College of Engineering, Chennai-600 119, India

Abstract: This study describes the principles underlying the economic assessment of wind power plant. It explain the need to take account of all costs related to wind turbine construction under operations in an economic model including initial and capital cost, annual running cost (which includes maintenance and operations) and capital replacements such as major spares. The main method of economic assessment, discounted cash flow, is described in detail. Various methods of measuring the values of the project are described, including simple payback, net present value, internal rate of return and benefit cost to ratio. Although the study concentrates on wind turbines for electricity generation, the principle of economic assessment can be applied to the use of wind plant for any purpose.

Key words: Wind power plant, economic assessment, wind turbine, discounted cash flow

INTRODUCTION

The recent development in technologies have, in the past 20 years, decreased the cost of wind energy from 40 cents per kwh to 4 cents per kwh, making it comparable to energy generated from conventional energy sources, which cost about 1-2 cents kwh^{-1} (Fig. 1).

Wind power in the united state has increased from 10 MW installed capacity in 1981 to 2500 MW in 1999, with another 150 MW scheduled to be added in the year 2000. Thus, wind energy, with its advantages in reducing pollution and providing cost-effective energy, continues to be an increasing source of electric energy.

All generation prices start with installed cost for diesel and coal. They also depend on fuel prices and for wind power on wind speeds. Diesel, coal and wind prices are based on actual projects carried out in 2005.

Only realistic prices for wind are shown: low installed cost is unlikely to occur at a windy site with difficult access, while high installed cost is associated with wind remote sites where the strong winds make them economic to build.

With diesel prices predicted to go on rising, adding wind to power systems at its current cost instead of adding diesel still means cheaper power for consumers in the long run, at least until system is operating with very large volumes of wind. Besides being economical and non-polluting, windmills provide a clean source of renewable energy.
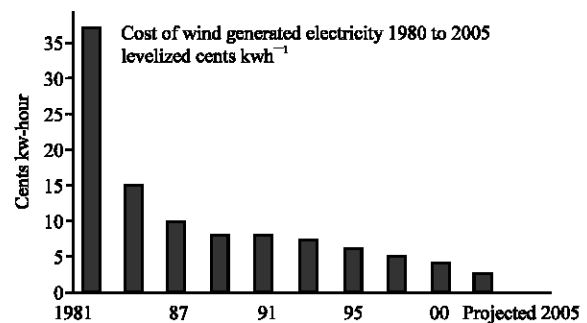

Fig. 1: Assumptions: Levelized costs at excellent wind sites: Large projected areas, not including the production tax credit (Post, 1994). Cost decline in the producing of wind energy (Source: American Wind Energy Association)

Wind turbine generator: Wind turbine generator consists of a variety of components. The rotor converts power of the wind to the rotation power of the shaft, a gearbox increases speed; and a generator converts the shaft power into electrical power. In some horizontal-axis machines, the pitch of the blades can be adjusted to regulate the speed during normal operation and also to shut down the machine when wind speeds are excessive. Others use stall, an aerodynamic phenomenon that naturally limits the power at high speeds (Siegfried, 2006).

Corresponding Author: V. Ramakrishnan, Department of EEE, Aarupadai Veedu Institute of Technology Chennai-603 104, Tamil Nadu, India

Usually, modern machines start operating when wind speeds reach about 19 km h⁻¹ (about 12 mph), achieve their rated power at about 40-48 km h⁻¹ (about 25-30 mph) and shut down in wind speeds of about 100 km h⁻¹ (about 60 mph).

The best sites for turbine generators have annual average wind speeds of at least 21 km h⁻¹ (13 mph). Scientists have estimated that as much as 10% of the world's electricity could be provided by wind generators by the middle of the 21st century.

Wind energy, which contributes very little pollution and few green house gases to the environment, is a valuable alternative to non renewable fuel, such as oil (Fig. 2).
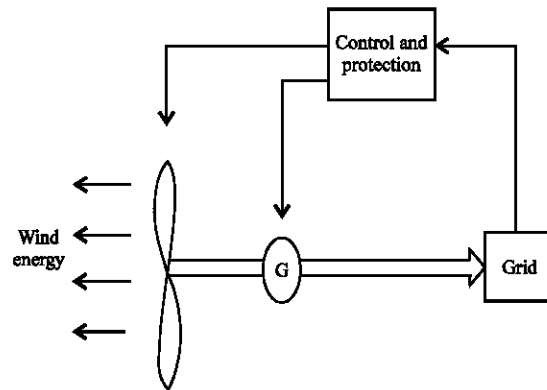
Description of main electrical components generator: An important part of the turbine is the asynchronous generator. It converts the mechanical energy from the gearbox to electrical energy. The generator is connected to the grid, which transfers the electrical energy to the customers. The public supply system is 50 Hz. The generator's rotational speed depends on the frequency.

Wind turbine control: The name of the controller for the wind turbine is the multi processor controller. The controller monitors and controls all functions in the turbine, in order to ensure that the performance of the turbine is optimal at any wind speed. The controller will stop the turbine if supervisor detects an error. At a operator panel, it displays data of the current operation (Shek *et al.*, 2007).

The controller collects continuously data about the performance of the turbine e.g.:

- Rotor and generator speed.
- Wind speed.
- Hydraulic pressure.
- Temperature.
- Power and energy production.
- Pitch.

The momentary wind conditions can be divided into 4 categories, shown by the power curve in Fig. 3.

- Low wind, the generator is not connected to grid. 2. Medium wind, the generator is connected, but does not produce nominal power.
- Higher wind, the generator is connected and produces nominal power.
- Stop wind, the generator is disconnected and the turbine is stopped.

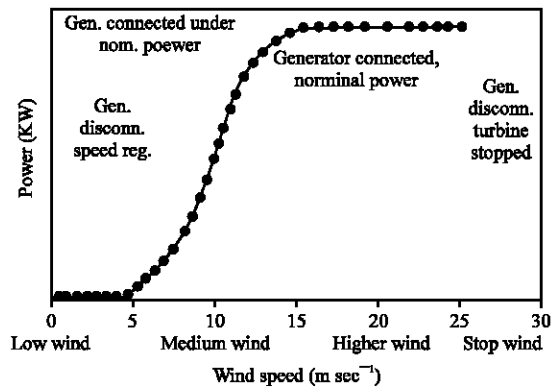

Fig. 2: Wind mill block diagram

Fig. 3: Sketch of power curve

When the wind is very low and the rotor does not rotate or rotate with a very low speed, the pitch angle will be approx 45°. This will give maximum start moment to rotor which gives a quicker start, when the wind increases.

The controller will then pitch the blades to 0° the rotating speed for the rotor and the generator will increase towards the nominal, which the controller will try to keep. The same situation is actually with connected generator and the wind decreases and the produced power becomes negative, the generator will be disconnected from the grid and the controller will control the speed.

If the wind decreases even more, the rotating speed will decreases below nominal value and the rotor will run freely.

By medium wind speed, the rotating speed is regulated to the nominal value and if the pitch angle can be kept at 5°, the generator is connected to grid.

With the generator connected but not enough energy in the wind to produce power, the pitch angle is regulated as a function of the wind speed.

When the generator is producing the power, it causes a torque, contra to the mechanical torque of the rotor.

The controller controls the produced power so that the rotor speed is kept constant within a narrow band which is called slip, which is the perceptual relation between actual and synchronous rotating speed.

US scenario: With soaring oil prices all over the place, electricity consumers in Colorado have been swapping to wind power as the cheapest option. Three months ago, Xcel Energies announced a 30% rate hike on electricity rates in Colorado due to the rising cost of national gas and oil; about half the power utility generated in the state comes from gas/oil, roughly the other half coal. Customers of the utility's green power product wind sources. On the other handsaw a credit on their bills. Suddenly, wind was not a first for the environmentally conscious customers. It was the cheapest option (Jackson, 2006).

Diesel supply was becoming too expensive and noisy. So 55 kW wind turbine generators were sought, when wind is strong. Then all load automatically switched on. When wind is slow, heating load automatically switched off and lighting load only exist. In some places in Europe, backed up by 2kWh of nickel-cadmium batteries, provides a 110V DC supply used for lighting load. Wind Mill life is 15 to 25 years. Maximum of DC supply and AC supply via an electronic box known as inverter can be produce AC from DC supply.

Wind turbine/battery applicationsand uses:

- Battery storage uses: starter motor, radio lights and fan.
- If there is a diesel generator it may beswitched to a standby mode when the wind turbine is generating.
- If diesel generator is operated due to low thermal efficiency, low load operation and fuel consumed is more for friction and parasitic losses. Engine life decreases and increased maintenance cost for only 20000 h without repair and more than 20000 h increased wear and maintenance problem due to carbonization and bore glazing at low load.
- Nuisance problems caused by light load at low ambient temperature.
- Diesel engine combustion and low load problem.
- With the upward drift in diesel prices of about 10% during the year, its generation costs are in the range from lower to higher before any maintenance cost are added.

XCEL fact check: Xcel energy is a major US electricity and natural gas company with annual revenues of $7.9 billion. It operates 15339 MW of generating capacity,

850 MW of which is wind powermaking it the nation's second largest supplier of wind power after FPL energy with 3100 MW.

Based in Minneapolis, Minnesota Xcel Energy operates in eight western and Midwestern states. Xcel has 3.3 million electricity customers and 1.8 million natural gas customers through its regulated operating companies, Northern state power company of Wisconsin, public service company of Colorado and South Western public service company. Xcel energy is the fourth longest combination natural gas and electricity company in the U.S. in term of customer volume.

In autonomous, an island in Europe, Caralis and Zervos (2007), the wind penetration is restricted due to technical reasons related with safe operation of the electrical system. The combined use of wind power with diesel or gas electrical system is considered as a means to exploit the abundant wind potential, increase the wind installed capacity and substitute conventional peak supply.

Results of diesel fuel consumption measurements, one given for the diesel units operated in parallel with the wind turbine and again without the wind turbine are given. The fuel consumption data are used to calculate the amount of fuel displaced by wind energy. The amount of displaced fuel depends on operating conditions and system load. Increased wind generation drive diesel output down, causing the diesel to operate at lower efficiency and tending to increase specific fuel consumption as shown in Fig. 4.

The diesel engines throttle activity resulting from wind gusts which change the wind turbine output and does not significantly influence fuel consumption.
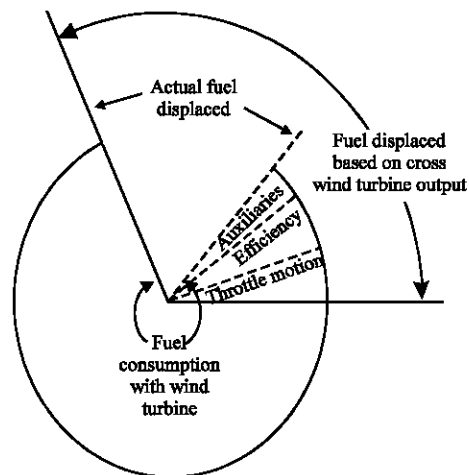

Fig. 4: Complete circle equals fuel consumption without the wind turbine

Economic assessment of wind power plant: We now outline the principles underlying the economic assessment of wind power plant. The main method of economic assessment viz, discounted cash flow, is described in detail (John *et al.*, 1997).

Economic considerations: The factors which have to be taken into account when approaching the economics of power generation are complex and interrelated. An electricity utility is carrying out an economic appraisal and this will include some less obvious costs concerned with the rest of the electricity generating systems. Non economic constraints must also be considered, which may be environmental, ecological, social, or political. In pursuit of its economic objectives, an electricity utility must secure the best use of its resources by selection of the project that gives the best value for money, within constraints.

MATERIALS AND METHODS

We now describe how to determine which project would be best, taking into account economic and non economic factors.

Discounting: The solution is to discount all costs in theb future to a fixed starting date to derive a single Present Value (PV) of the project. This future money has to be discounted to produce its PV using an interest rate, or discount rate.

Now let us consider the case where we pay \$A at yearly intervals for a period of n years. What is the present value of this benefit stream (Cost to us, benefit to someone else).

$$PV = A\left(\frac{1}{1+r} + \frac{1}{(1+r)^2} + \frac{1}{(1+r)^3} + \ldots \frac{1}{(1+r)^n}\right) \quad (1)$$

The right hand side of Eq. 1 is a geometric series that sums up to

$$PV = A\left(\frac{(1+r)^n - 1}{r(1+r)^n}\right) = \frac{A}{r}\left[1 - (1+r)^{-n}\right]$$

Measuring the value of an investment: The difference between the PVs of costs and the benefits is net present value or NPV. NPV is not the only measure of economic worth. There are others including.

- Internal rate of return IRR.
- Benefit - to cost ratio (B/C ratio).
- Single payback period.

This method is useful as an approximate measure for projects.

Allowing for inflations: The advantage of discounting is that it removes the need to take account of general inflation. An inflator must be used when the price of fossil fuels will rise when the supply becomes less than the demand.

Inflation and levellised prices: So far, whatever the rate of inflation, we all know that fuel prices rose sharply in real terms after 1974. A fourfold increase in oil prices almost overnight produced increases to a lesser extent in the price of coal, because of the rise in demand for it. A technology may have high capital costs, like wind power, but it can be a very good investment in time of high fuel cost inflation.

Non-economic factors and external costs: Energy development on a large scale, which includes wind power projects, can have a profound effect on society and this may not always be beneficial. Environmental, social, political and aesthetic factors must be considered. This economic objective of the project must be sought within a framework impressed by these non economic factors.

A thermal production station may produce emissions which are damaging. Acid rain may cause damage to buildings which can be quantified in terms of repair or maintenance costs. Carbon dioxide will contribute to the green house effect. Their effects of damaging emissions on human health may be affected in the cost of medical treatment. Wind turbines, will not produce emissions, but may cause the loss of visual amenity which is difficult to quantify. A carbon tax on fossil fuel (which increases annual variable costs) is an example of how soot can internalize the effects of the carbon dioxide emissions taking step to reduce fuel usage and carbon tax. The overall effect is to improve the economic position of non-polluting energy sources such as wind or hydro power, thus encouraging its use.

Examples: Some of these ideas are concerned with coal/diesel and wind power electricity generation. Break even costs and their implications are considered. Table 1 shows the basic data for these examples. The payments are discounted to the date of commission and some after. The sum of their PVs is the single capital cost use and we are considering.

This sum will be greater than the undiscounted sum. The ratio of the sum of the PVs to the undiscounted sum is called Interest During Construction (IDC).

Table 1: The basic data for the examples

Cost+performance figures for electricity generating plant

Costs	$	Coal/diesel	Wind
Capital	$/Kw	1000	600.0
Fixed	$/KW Pa^{-1}	15	4.0
Fuel	cent KW^{-1}	1.7	0.1
Variable	cent kwh^{-1}	0.2	0.2
Load factor	(%)	75	25.0
Life	Years	40	25.0

Table 2: Calculation of interest during construction

Percentage of capital cost	Years before (-) or after (+) commissioning	PV of cost of commissioning ($/KW)
25	–8	302
50	–4	497
15	0	123
10	+1	78
PV of capital cost	=	1000

It is agreed that their payments will be made as in column 1 of Table 2. The PV of each payment is calculated, for example, the PV of 25% of $818/KW paid 8 years before commissioning with a 5% discount rate is 818×25/100×1.05^8 $/KW.

The value of interest during construction IDC is calculated as follows:

$$IDC = (1000-818) \times 100/88 = 22.2\%$$

A capital will have to be spent during the life of the project after it has been operated for a number of years. Let us consider the wind power capacity where we have assumed a life of 25 years in contrast to the 40 years assumed for coal/diesel plans. We must either buy a completely new replacement or we must refurbish the old wind plant; each will require capital expenditure after 25 years. This expenditure is discounted to the start date of the project. The two projects have differences of 25 and 40 years. Assuming the value depreciates linearly with time, we can work out the remaining capital value of the wind turbine plant, which is discounted and taken as a credit when working out the total PV of the project (Table 3).

For coal or diesel power plant, an annual load factor = 25%. The wind power capacity required to produce the same number of units as the other plant must have, an our assumption, 3 times the capacity of the coal or diesel plant. This is because it produces one third of the electricity in a year, as indicated by the load factor.

The capital loss of wind power plant to produce the same as diesel or coal plant is therefore 672×(75/25) = $ 2016 / kW.

This includes rent, rates, insurance, research and development, salaries and training. The PVs of the fixed annual cost one is calculated as follows:

Table 3: Capital costs incurred during the life of the project

Initial capital loss	$600/Kw
Cost of refurbishment	(50%) $300 / Kw
PV of this cost 300 / 1.05^2 =	$89 / Kw
Capital cost of year 40:	300 (1-15/25) = $120/Kw
PV of D:	120/1.05^{40} = $17/Kw
Net Capital PV (A+C - E) =	$672/Kw

Table 4: PV ($) costs for electricity generating plant

Cost ($/kw)	Diesel	Coal	Wind
Capital	1500	1000	2015
Fixed	377	257	207
Fuel	565	1922	-
Variable	225	225	75
Total	2667	3404	2297

Table 5: Comparison of PVs, annualized cost and unit cost

Cost	Diesel	Coal	Wind
Annualized cost ($/Kw year^{-1})	155.0	198	134
Unit (Cent kwh^{-1})	2.4	3	2
PV ($ Kwh^{-1})	2667 .0	3404	2297

$$PV = A \left(\frac{(1+r)^n - 1}{r(1+r)^n} \right) = \frac{A}{r} \left[1 - (1+r)^{-n} \right]$$

Where, A Total of fixed annual costs per year. For a discount of 5% (r = 0.05), n = 40 years, PV = 17.159A. So, if A = $4 per kW for wind power, PV = 17.159 x 4 = $69 per kW of wind power capacity or 3×69 = $206 of capacity equivalent to coal or diesel plant.

The calculations for diesel or coal plant are similar in principle and are given in Table 4.

The fuel cost for coal fired plant are 1.7 cent kwh^{-1} of electricity generated. The total annual fuel cost is calculated as following:

Annual fuel cost = 1.7*8760 * (75/100×100) = $ 112 kwh^{-1}

PV of fuel cost = 112* 17.159 = $1922 kwh^{-1}

We can see that wind power plant is the cheapest. The costs for all the technologies are given in the above Table 5 and 6.

In the case of hydro, gas or stream and diesel power stations, the delivery of energy can be regulated and adjusted to match demand by end users as shown in Fig. 5a. In contrast, the conversion system of a wind turbine is subject to external forces as shown in Fig. 5b. The delivery of energy can be affected by changes in wind speed, by machine-dependent factors such as disruption of the air stream around the tower or by load variations on the consumer side in weak grids.

Table 6: Comparison of PVs, annualized cost and unit costs including inflation in fuel prices

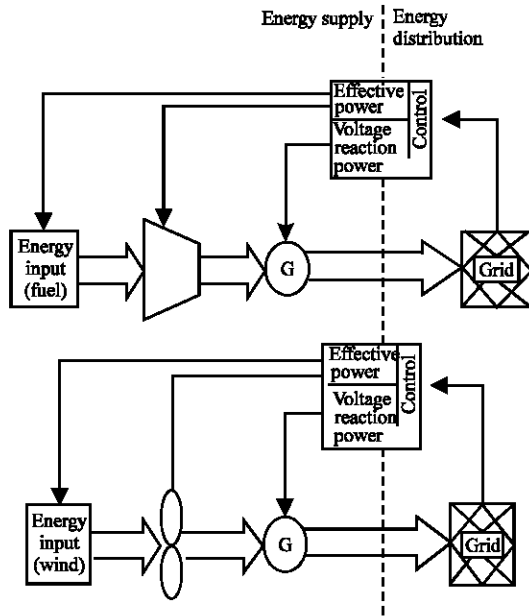| Cost	Diesel	Coal	Wind
Annual cost ($/ Kw year^{-1})	160.0	235.0	134
Unit cost (Cent kwh^{-1})	2.4	3.6	2
PV ($ Kw^{-1})	2752.0	4038.0	2297

Fig. 5: Energy delivery and control in electrical supply systems (a) Diesel generator, etc and (b) wind turbines

The principal components of a modern wind turbine are the tower, the rotor, the nacelle and for horizontal axis devices, the yaw systems, lines and may be also transformers and grids, which are required for supplying end users or power storage systems. In response to external influences, a unit for operational control and regulation must adapt the flow of energy in the system to the demands placed upon it.

COST COMPARISON IN INDIA

Wind mill with diesel generator: To prove the cost benefits of wind mill it is important to do the cost comparison of wind mill with some other conventional method of generating electricity.

The initial cost of diesel generator = 35 lakhs ($ 87500)

The initial cost of wind mill =2 cr 50 lakhs ($ 625000)

This will not be the case for wind power plant, which will have an annual load factor of above 25%. The wind power capacity required to produce the same number of units as other plant must have, on our assumption 3 times the capacity of the coal or diesel plant. This is because it produces 1/3rd of the electricity in a year, as indicated by the load factor. Actually what is needed is 2/3 of other conventional energy from electricity board. The total cost of HT supply, erectionand,commissioning of transformer including civil and other cable and structure works is Rs.41,02,800/- = ($102570).

EB Energy charges per year in
Rs. 15,11,600/- = ($37790)
Total cost of the energy = 3,06,14,400/- = ($765360)
For diesel generator,
Amount of diesel required h^{-1} = 22 L
Amount of diesel required day^{-1} =22×24 L
Amount of diesel required year^{-1} = 22×24×365 L
Cost of 1 L of diesel = Rs. 35 ($ 0.875)
Cost of diesel year^{-1} = 22×24×365×35
= Rs. 67,45,200 ($168630)
Total cost = 35,000,00+67,45,200
= Rs.1,02,45,200($256130)

For wind mill, there is very low running cost, which is negligible compared to the diesel generator.

Thus, for wind mill, initial cost + conventional energy cost = 2 crore 50 lakhs ($ 625000) +Rs. 56,14400 ($140360).

Total cost of the energy = 3,06,14,400/- = ($765360)

The comparison between the wind mill and diesel generator is shown graphically in Fig. 6.

Thus, from this study, we can conclude that wind mill is more economical than the other conventional energy sources. Also, introduction of numerical relay into this will make wind mills one of the leading sources of energy in the future. These environmentally friendly technologies in particular require a suitable development period to establish themselves in a market place of high technical standards.

The worldwide potential of wind power means that its contribution to electricity production can be of significant proportions. In many countries, the technical potential and once established the economically usable potential of wind power far exceeds electricity consumption.

Good prospects and economically attractive expectations for the use of wind power are, however, inextricably linked to the incorporation of this weather-dependent power source into existing power supply structures, or the modification of such structures to take account of changed supply conditions. Not surprisingly, the competitive position of wind is improved against both
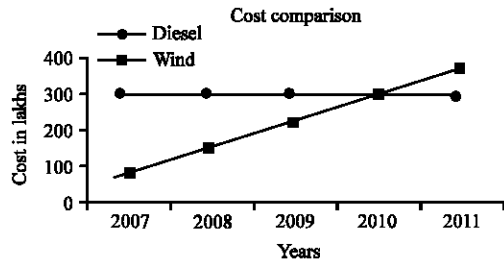
Fig. 6: Cost comparison graph of diesel and wind generator

diesel and coal plant and the economics of coal plant are worsened by comparison with diesel because a more rapid rise was assumed in the real cost of coal. These results show that lower cost energy sources improve their economic position in times of high fuel cost inflation, as is intuitively obvious.

RESULTS

Different factors must be taken into account when carrying out economic assessments of power generation projects. There is a need to consider initial and other capital costs and annual cost which include maintenance and operations. Although the simple payback period may be a useful measure of the short term economic performance of simple projects, the need to use discounted cash flow techniques is emphasized for long time capital projects.

CONCLUSION

Diesel engine throttle activity resulting from wind gusts which change the wind turbine output does not significantly influence fuel consumption. Calculated reduction in fuel consumption is 6.7% while generating 11% of the total electrical energy.

The overall effect is to improve the economic position of non polluting energy sources such as wind or hydropower, thus encouraging their use. However, in the long term, it would be beneficial to have a national wind

energy credits market and national renewable standards with consistent criteria across the country that have RPS (Renewable portfolio standards).

Wind is a real important part of our supply and rapid growth of electricity generation in the world. While tax credits are in place, we plan to add wind and stay ahead of all the RPS.

Clearly, within wind generation, there are opportunities to look beyond the expirations of the PTC (Production Tax Credit).Wind power generation can provide both financial and environmental benefits and is strongly recommended. More creativity is needed in contract structures, finance structures equipment. Our need for wind energy will increase overtime.

NOTATION AND UNITS

n	=	No. of years.
r	=	Interest or discount rate.
A	=	Annualized value or constant yearly payment.
B/C	=	Benefit to Cost ratio.
IRR	=	Internal Rate of Return.
NPV	=	Net Present Value.
PV	=	Present Value.

REERENCES

Caralis, G. and A. Zervos, 2007. Analysis of the combined use of wind and power storage system in autonomous Greek Islands. IET Renew Power Gen., 1: 49-60.

John, F. Walker, Wood Gen, Waltham Chase and Nocholas Famkins, 1997. Wind Energy Technology. UMIST, Manchester, UK., UNESCO.

Shek, J.K.H., D.E. Macpherson, M.A. Mueller and J. Xiang, 2007. Reaction force control of linear generator for direct wave energy conversion. IET Renew Power Gen., 1: 17-24.

Siegfried Heir, 2006. Grid Integration of Wind Energy Conversions Systems. 2nd Edn. Kassel University, Germany. John Wiley and Sons Ltd.