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Optimization of Power Factor and Energy Management in Wind Energy Station

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***Abstract*-In the present day energy crisis, everybody is looking forward to utilize renewable energy sources. Due to this number of wind parks are growing day by day. Many wind parks have long transmission distances to the power control components, such situations are leading to high power losses. Hence it is required to think about internal power factor management. An adjustment of the wind turbine power factor can control the active power on the point on common coupling (PCC) at a maximum value. This allows maximum earnings for the wind park operator. Simulation is done for full wind park power, to make the active losses are below that of reactive power consumption in Wind Park.In this proposed work a detailed discussion on the control capabilities is to be done, as part of a wind park energy management. This proposed project is to manage two requirements, the internal reactive power flow in the Wind Park, and reaction on external control signals from the utility side for active and reactive power changes on the power control circuits. Sometimes new wind parks are only permitted, if control possibility exists. Wind Park can meet these requirements, if an automated power factor control is implemented. Wind Park operators and utilities show big interest on these solutions because of the financial and organizational advantages on both sides. Using MATLAB-SIMULINK the proposed system is to be simulated and results are to be presented.**

Keywords-Wind energy, Energy Station, Power Factor, Energy Management

1. INTRODUCTION

The energy management and power factor control is very important for an installation of a small wind station. A pressing demand for more electric power coupled with depleting natural resources has led to an increased need for energy production from renewable energy sources such as wind and solar. The latest technological advancements in wind energy conversion and an increased support have led to increased wind power generation in recent years. Wind power is the fastest growing renewable source of electrical energy.

The grid connection of large wind park installations requires a detailed investigation of the internal wind park structure. Common wind parks grow depending on the situation of financing and authorization. The proposed work discusses the conversion of the common state towards an optimized power factor and energy management in wind park installation.

A. Facts Devices

Flexible AC Transmission Systems (FACTS) such as the Static Synchronous Compensator (STATCOM) and the Unified Power Flow Controller (UPFC) are being used extensively in power systems because of their ability to provide flexible power flow control [2]. The main motivation for choosing STATCOM in wind farms is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power into the system.

When wind farms are connected to a strong grid, that is closer to a stiff source, voltage and frequency can be quickly re-established after a disturbance with the support of the power grid itself. To wait for the voltage to re-establish after the fault has been cleared in the case of a weak grid interconnection is not reliable because there is always a risk of voltage instability initiated by the disturbance. Hence, reactive power and voltage support that can be provided by mechanically switched capacitors, SVC or STATCOM is needed to help improve the short term voltage stability and reinforce the power network. This is also true for wind farms with all fixed speed wind turbines with no dynamic control or reactive power compensation.

B. Types of Wind Generators

Wind generators are generally of two types: fixed and variable speed. Fixed speed generators are induction generators with capacitor bank for self-excitation or two-pole pairs or those which use rotor resistance control. Variable speed generators are either DFIG (which is a round rotor machine) or full power converters such as squirrel cage induction generators, permanent magnet synchronous generators, or externally magnetized synchronous generators. Variable speed wind turbines are connected to the grid using power electronic technology and maximize effective turbine speed control. Variable speed wind turbines such as DFIGs are the most popular wind turbines being installed today because they perform better than the fixed speed wind turbines during system disturbances. DFIGs are the only class of wind generators capable of producing reactive power to maintain unity power factor at the collector bus. Fig. 1.1 shows the DFIG model used in the simulations.

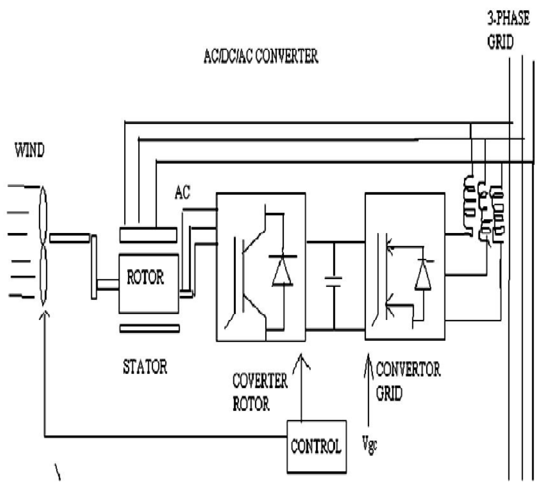


Figure 1 Block Diagram of a Doubly-fed-Induction-Generator

C. Energy Management

The purpose of the Energy Management Programs as well as a primary objective of the Energy Bureau is to improve energy efficiency and to promote the use of renewable energy technologies. The EM Programs provide access to the financing needed to implement cost-effective wind turbine projects.

India is a Developing nation. Its per capita Energy Consumption is very low. To achieve Economic Growth, we need to and have to use more and more energy to increase the pace of development. We need to increase the manufacturing of good in Quality & Volume. It is estimated that Industrial energy use in developing countries constitutes about 45-50 % of the total commercial energy consumption. Much of this energy is converted from imported oil, the price of which has increased tremendously so much so that most of developing countries spent more than 50 % of their foreign exchange earnings. Not with standing these fiscal constraints, developing countries need to expand its industrial base like us if it has to generate the resources to improve the quality of life of its people.

2. POWER CONTROLLERS

A majority of the wind turbines installed in the past were induction generators that absorb reactive power from the system even during normal operating conditions. Under normal operating conditions the DFIGs operate at close to unity power factor and may supply some reactive power during system disturbances such as a three phase fault close to the wind farm in order to meet the Low Voltage Ride through (LVRT) grid code requirement. Mechanically switched capacitors are used in wind farms containing asynchronous generators to provide reactive power support during system disturbances. However, limited support provided by these small wind generators is required to meet the interconnection standards such as to ride through a fault.

Recently, FACTS-based devices have been used for power flow control and for damping power system oscillations. They can also be used to increase transmission line capacity; steady state voltage regulation; provide transient voltage support to prevent system collapse; and damp power oscillations. FACTS devices can be used in wind power systems to improve the transient and dynamic stability of the overall power system. The STATCOM is from the family of FACTS devices that can be used effectively in wind farms to provide transient voltage support to prevent system collapse. In other words a STATCOM is an electronic generator of reactive power.

A. STATCOM

A STATCOM is a shunt-connected reactive power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. The STATCOM is a static compensator and is used to regulate voltage. A STATCOM can supply the required reactive power under various operating conditions, to control the network voltage actively and thus, improve the steady state stability of the network. The STATCOM can be operated over its full output current range even at very low voltage levels and the maximum VAR generation or absorption changes linearly with the utility or AC system voltage.

B. STATCOM Model

The applicability of a STATCOM in wind farms has been investigated and the results from early studies indicate that it is able to supply reactive power requirements of the wind farm under various operating conditions, thereby improving the steady-state stability limit of the network [3]. Transient and short-term generator stability conditions can also be improved when a STATCOM has been introduced into the system as an active voltage/VAR supporter [2, 4]. The transient behavior of wind farms can be improved by injecting large amounts of reactive power during fault recovery. This thesis examines the use of STATCOMs in wind farms to stabilize the grid voltage after grid disturbances such as line outages or severe system faults. Fig. 2.1 shows the basic model of a STATCOM which is connected to the AC system bus through a coupling transformer. In a STATCOM, the maximum compensating current is independent of system voltage, so it operates at full capacity even at low voltages. A STATCOM's advantages include flexible voltage control for power quality improvement, fast response, and applicability for use with high fluctuating loads.

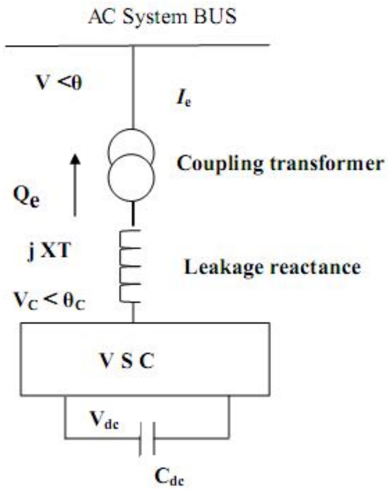


Figure 2. Basic model of a STATCOM

The output of the controller *Q c is* controllable which is proportional to the voltage magnitude difference (V_c -*V)*and is given by Eqn. (1).

$$Q_c = \frac{V(V_c - V)}{X} \quad \text{---------------- (1)}$$

A STATCOM was chosen as a source for reactive power support because it has the ability to continuously vary its susceptance while reacting fast and providing voltage support at a local node. Figure 2.2 show the block diagram of the STATCOM controller.

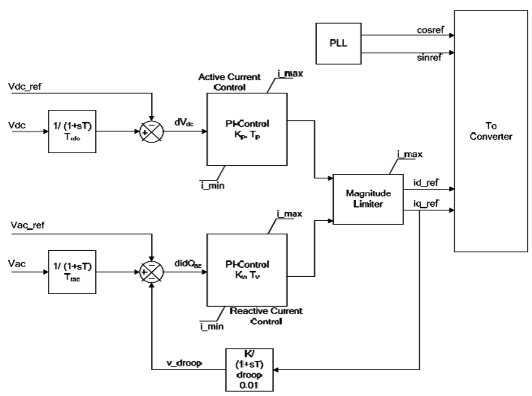


Figure 3. Control Scheme of the STATCOM

By controlling the phase and magnitude of the STATCOM output voltage, the power exchange between the ac system and the STATCOM can be controlled effectively. The outputs of the controller are id_ref and iq_ref which are the reference currents in the dq coordinates which are needed to calculate the power injections by the STATCOM as in Eqn.(2) and Eqn. (3).

$$P_{inj} = V_i(i_d \cos\theta_i + i_q \sin\theta_i) = v_d i_d + v_q i_q \quad \text{-- (2)}$$

$$Q_{inj} = V_i(i_d \sin\theta_i - i_q \cos\theta_i) = -v_d i_q + v_q i_d \quad \text{.. (3)}$$

Where, i*d and*i*q are* the reference d and q axis currents of the ac system. The control variables are the current injected by the STATCOM and the reactive power injected into the system.

C. Location of STATCOM

The location of STATCOM is generally chosen to be the location in the system which needs reactive power. To place a STATCOM at any load bus reduces the reactive power flow through the lines, thus, reducing line current and also the I^2R losses. Shipping of reactive power at low voltages in a system running close to its stability limit is not very efficient. Also, the total amount of reactive power transfer available will be influenced by the transmission line power factor limiting factors. Hence, sources and compensation devices are always kept as close as possible to the load as the ratio ($\Delta V/V_{nom}$) will be higher for the load bus under fault conditions. Generally, STATCOM is placed as close as possible to the load bus for various reasons. The first reason is that the location of the reactive power support should be as close as possible to the point at which the support is needed. Secondly, in the studied test system the location of the STATCOM at the load bus is more appropriate because the effect of voltage change is the highest at this point. Fig. 2.3 shows a test model used for simulation.

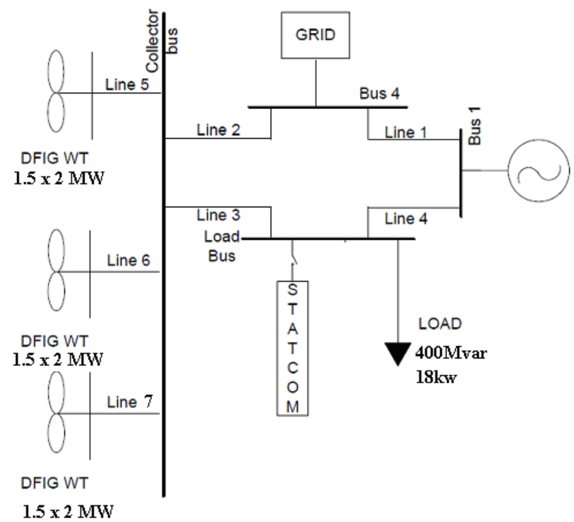


Figure 4. Test Model for SIMULATION

D. PWM Circuit for Control System

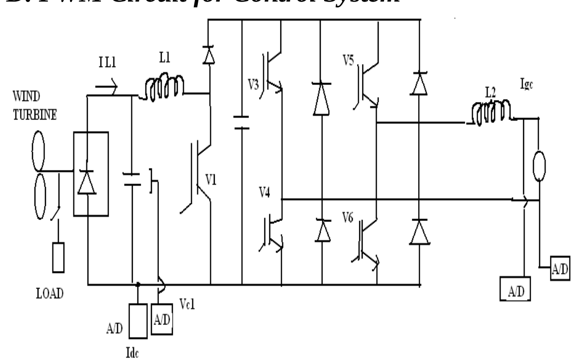


Figure 5. PWM circuit for control and DC-AC inverter

Fig.2.4 is diagram of wind power generation and control system in load. The maximum power control is through the chopper circuit constituted of capacity C2. InductanceL1, diodeD1, capacitorC1. Capacitor C1 is also for guarantee of steady current output. This control circuit is divided into 2 parts: the front part of Pulse Width Modulation (PWM) is to control the maximum power point tracking: rest part of PWM is to control the DC-AC inverter. If using element BJT or IGBT, the generator can be cut off softly. For example when the transient process is ended, the main LC part is closed and the IGBT will be excited so that the unit enters the running status.

3. ENERGY MANAGEMENT IN WIND ENERGY STATIONS

The energy management is very important for a wind energy station. Generation of power needs resources. Resources available on earth are of Diminishing Nature. It is getting depleted very fastwith time as use is increasing exponentially. There are some resources, which are Renewable e.g. Solar Power, Wind Power and Geothermal Power. Technology is also being developed to harness these Renewable Resources to generate Power. The capital investment requirement is very high as compared to normally available resources. It can be quoted here that with the available technology, we could hardly generate 5% of total power generation as on date. Hence, to restrict the use or increase the life of diminishing type of resources. To establish any work / motive or task, energy in one or other form is an essential component. Thus the need to conserve energy, particularly in industry and commerce is strongly felt as the energy cost takes up substantial share in the overall cost structure of the operation.

A. Strategy / Methodology of Energy Management

Having established the need of Energy Management and Conservation. A systematic approach needs to be discussed and concluded. Same of steps to reach to the target of Energy Conservation can be listed as below: -

1) Identification of Inefficient areas / Equipments: -
   - Enlistment or knowledge of type of energy being used.
   - Study of machines / Technology employed.
   - Process study and identification of major energy consumption areas.
   - In depth process study to identify the inefficient use of energy.
2) Identification of Technology / Equipment requirement.
3) Discussion, Brain storming & Conclusion of resources requirement.
4) Management of resources like Manpower, Machine or Technology.
5) Evaluate your actions / efforts to estimate the Rate of Return
6) Implementation of New Process / New Technology / New Machines.
7) Re-evaluate your actions / Your Efforts.

B. Life Cycle Cost (LCC) Method

LCC are summation of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced in consideration for the time value of money.

Engineering details drive LCC cost numbers for the economic calculation process. The basic tree for LCC combines the acquisition and sustaining costs. Acquisition and sustaining costs are found by gathering the correct inputs, building the input database, evaluating the LCC and conducting sensitivity analysis to identify cost drivers.

The most used now are the power wind turbines; they are much efficient and have a lower cost then those ones of strong power. The performance wind turbine designs of small power are the advanced technologies from the area of energy generation for electric energy from the wind.

B. Objective of LCC

The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives to achieve the lowest long-term cost of ownership.

The life cycle costing process has the following steps:

Define the problem requiring LC, Alternatives and acquisition/sustaining costs

- Prepare cost breakdown structure/tree
- Choose analytical cost model
- Gather cost estimates and cost model
- Make cost profiles for each year of study
- Make break- even charts for alternatives
- Pareto charts of vital few cost contributors
- Sensitivity analysis of high costs and reasons
- Study risks of high cost items and occurrences
- Select preferred course of action using LCC.

4. RESULTS AND ANALYSIS

To evaluate the voltage support provided by a STATCOM this is connected to a weak grid, simulations have been performed in MATLAB/SIMULINK Version 7.4.

The total system has a load of 18 MW and 400 Kvar connected at bus 3 (the load bus). The DFIG WTs operate at close to unity power factor and hence the reactive power generated from these machines is almost zero. The total demanded reactive power is therefore mostly generated by the synchronous generator. The active power of the load is shared by the WTs and the synchronous generator. As per the previous analysis, a STATCOM, an active voltage supporter, is connected to the load bus. The STATCOM is connected to the system via a 0.4 kV/30 kV transformer.

A. Simulation Results

Symmetrical Fault

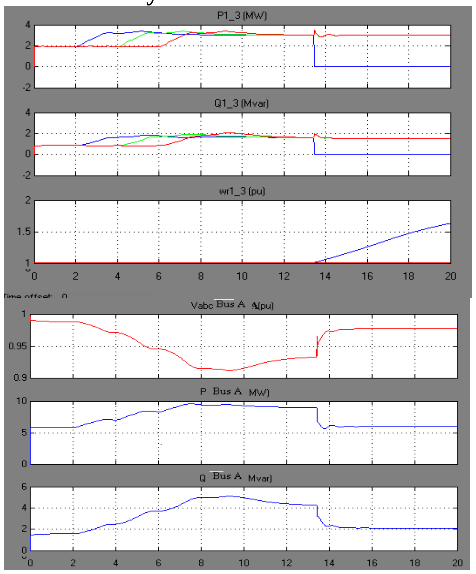


Figure 6. LLL fault in wind farm and bus without STATCOM

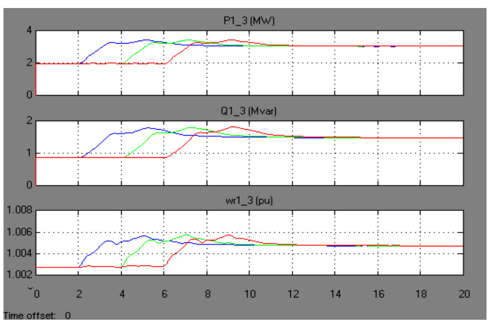


Table 1Power factor at Bus_A in LLL-fault with STATCOM

Time (sec)	Vabc_Bus-A(PU)	P_Bus-A(MW)	Q_Bus-A(MVAR)	POWER FACTOR
0	1	6	1.2	0.980
4	0.99	7	1.8	0.9684
8	0.98	9.3	2.3	0.9707
12	0.98	9	2.1	0.9703
16	1.01	9	2.1	0.9703
20	1.01	9	2.1	0.9703

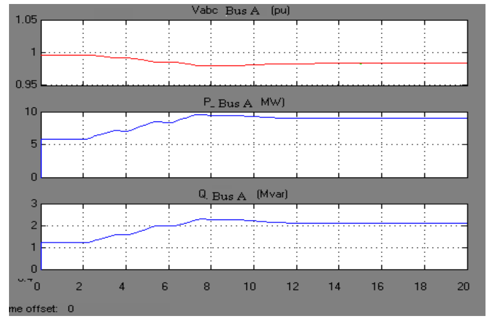


Figure 7. LLL fault in wind farm and bus with STATCOM

Fig.6 and fig 7 shows the operation with out and with STATCOM and with STATCOM time taken for voltage in bus is less compared to with out STATCOM. STATCOM generates to the wind form reactive power and voltage and providing the required power in fault line of wind turbine. And wind farm generates the rated power 9MW.From the above results when the LLL-fault the voltage is controlled and recovered with in 2-12 m/s.

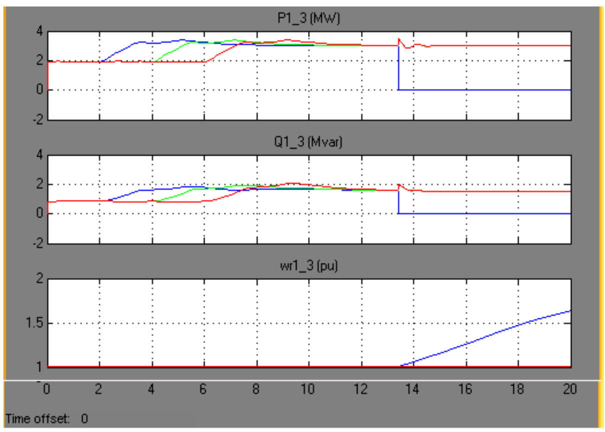
With STATCOM the reactive power, active power, voltages of the both wind farm and bus is controlled. Here the faulted wind turbine speed controlled and recover to its normal position. The power factor in wind farm for LLL-fault with and with out STATCOM is shown in below table

Table2. Power factor in wind turbine with and with out STATCOM

TIME (sec)	WITH OUT STATCOM			WITH STATCOM		
	COS Φ1	COS Φ2	COS Φ3	COS Φ1	COS Φ2	COS Φ3
0	0	0	0	0	0	0
0.0167	0.926	0.926	0.926	0.926	0.926	0.926
4	0.8900	0.914	0.916	0.89	0.91	0.91
8	0.878	0.8628	0.8707	0.89	0.88	0.89
12	0.8814	0.88	0.8780	0.934	0.9417	0.9455
16	0	0.89	0.89	0.947	0.9475	0.9475
20	0	0.89	0.89	0.9479	0.9475	0.9475

Table 3 power factor at Bus_A in LLLG-fault with STATCOM

Time (sec)	Vabc_Bus-A(PU)	P_Bus-A(MW)	Q_Bus-A(Mvar)	POWER FACTOR
0	1	6	1	0.986
4	1	7	1.5	0.9778
8	1	9.7	2	0.9793
12	1	9	2	0.9761
16	1	9	2	0.9761
20	1	9	2	0.9761



Line to Line to Line to Ground Fault

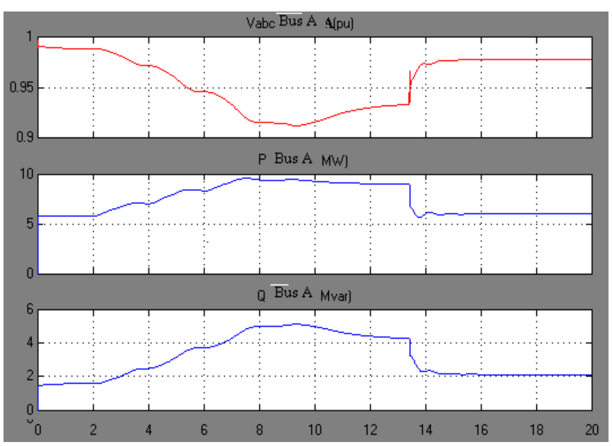


Figure 8.Three phase fault in wind farm and bus with out STATCOM

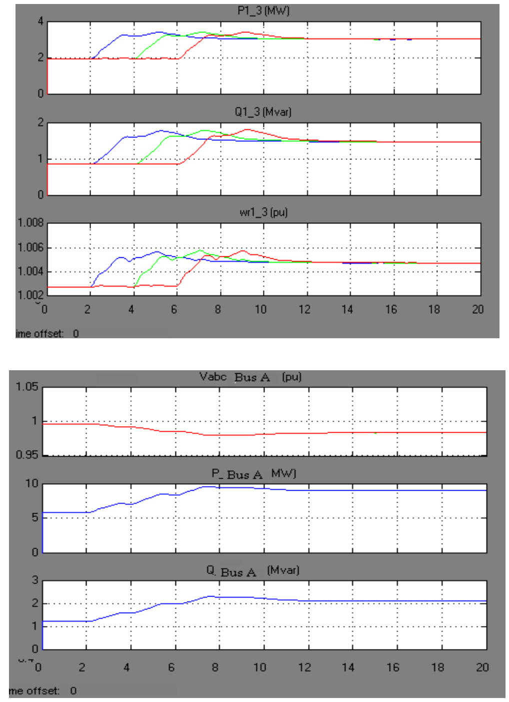


Figure 9.Three phase fault in wind farm and bus with STATCOM

The operation with out and with STATCOM and with STATCOM time taken for voltage in bus is less compared to with out STATCOM. STATCOM generates to the wind form reactive power and voltage and providing the required power in fault line of wind turbine. And wind farm generates the rated power 9MW.From the above results when the LLG-fault the voltage is controlled and recovered with in 2-12 m/s. With STATCOM the reactive power, active power, voltages of the both wind farm and bus is controlled. Here the faulted wind turbine speed controlled and recover to its normal position. The power factor in wind farm for LLG-fault with and with out STATCOM is shown in below table

Table 5 Power factor in wind turbine with and with out STATCOM

TIME(sec)	WITH OUT STATCOM			WITH STATCOM		
	COS Φ1	COS Φ2	COS Φ3	COS Φ1	COS Φ2	COSΦ3
0	0	0	0	0	0	0
0.0167	0.926	0.926	0.926	0.926	0.926	0.926
4	0.8900	0.914	0.916	0.891	0.91	0.89
8	0.878	0.8625	0.8625	0.892	0.88	0.895
12	0.8814	0.88	0.881	0.935	0.9470	0.9379
16	0	0.894	0.8941	0.947	0.9479	0.9479
20	0	0.894	0.894	0.9479	0.9479	0.9479

B. Life Cycle Cost Method

Table f6 Power loads, PVmodues, PeakpowerPV

PL(KW)	PVmoduels	PeakpowerPV(W)
0.1	5	150
0.154	3	55
0.172	4	80
0.172	4	100
0.167	4	125
0.146	4	165
0.146	4	170
0.146	4	175
0.167	4	120

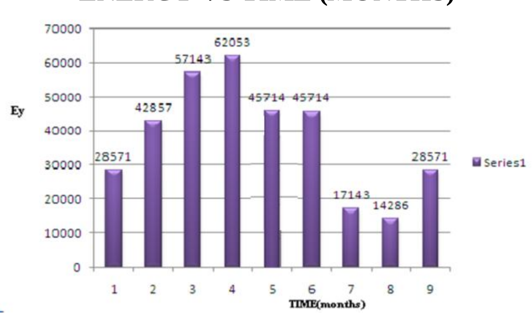
Above table input for the LCC method selection of different PVmoduels and for that peak power can selected from the table.

C. Results

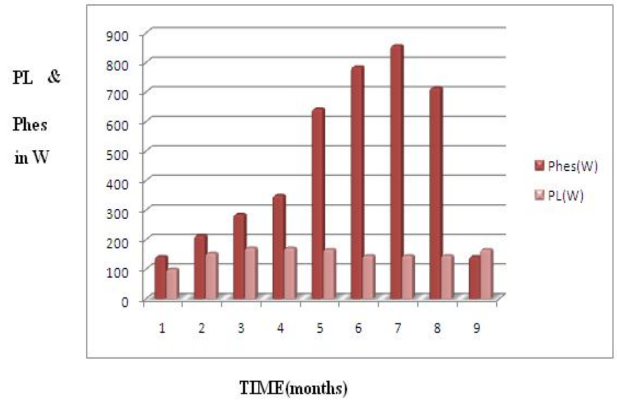
Table 7 Life Cycle Cost method for Energy Management

C_{HES}(RS)	P_{HES}(W)	LCC(RS)	EY	COE(RS)
17,71,910	142.86	67,19,930	28571	18.8727
8,57,570	214.29	32,54,020	42857	6.09266
10,22,560	285.71	12,23,460	57143	17.1801
12,25,000	350	19,11,560	62053	15.3391
7,87,500	642.86	29,866,90	12857	18.6403
13,72,140	785.71	52,03,940	45714	26.5734
1,96,560	857.14	55,24,120	17143	25.8573
15,43,500	714.29	58,53,820	14286	32.8804
7,25,760	142.86	27,52,540	28571	77.308

ENERGY VS TIME (MONTHS)



PL &P_{hes} (W) Vs TIME (months)



5. CONCLUSION AND FUTURE SCOPE

CONCLUSION

A pressing demand for more electric power coupled with the depleting natural resources have led to an increased need for energy production from renewable sources such as wind and solar energy. The electrical output power generated from these sources of energy is variable in nature and hence, efficient power control is required for these energy sources. Wind power has seen increased penetration in the recent past and certain stringent grid interconnection requirements have been developed. Wind turbines have to be able to ride through a fault without disconnecting from the grid.

This thesis explores the possibility of connecting a STATCOM to the wind power system in order to provide efficient control. In this thesis, the wind turbine modeled is a DFIG that is an induction machine which requires reactive power compensation during grid side disturbances. An appropriately sized STATCOM can provide the necessary reactive power compensation when connected to a weak grid. Also, a higher rating STATCOM can be used for efficient voltage control and improved reliability in grid connected wind farm but economics limit its rating.

Simulation studies have shown that the additional voltage/var support provided by an external device such as a STATCOM can significantly improve the wind turbine's fault recovery by more quickly restoring voltage characteristics. The extent to which a STATCOM can provide support depends on its rating. The higher the rating, the more support provided. The interconnection of wind farms to weak grids also influences the safety of wind turbine generators. The dynamic performance of wind farms in a power grid is improved by the application of a STATCOM. The STATCOM helps to provide better voltage characteristics during severe faults like three phase impedance short circuit faults as well.

Energy management in any system is to minimize the losses and cost estimation for system can modify the system. Energy management in wind station is to fulfill the necessary power for more reliable cost

FUTURE WORK

In this thesis, simulation studies show that the dynamic performance of wind farms is improved with the use of a STATCOM. Future work can involve analyzing the harmonics in the system and evaluate methods to reduce the system harmonics. A multilevelSTATCOM can be modeled to reduce lower order harmonics. Three phase high impedance short circuit faults have been studied in this thesis that can be extended to observe the response of the system to other types of faults. The wind turbines here are modeled as individual turbines, which could be extended to represent a wind farm by modeling them as a single equivalent wind turbine. The study has been based on the performance for DFIG that could be further extended to various types of wind turbines. This study can be extended to a larger system to evaluate the support provided by the use of a STATCOM**.**

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