Analysis of STATCOM with PSO Controller in Grid Connected Wind Energy System

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Abstract: Reliable power from renewable energy sources have become very important in today's energy scenario mainly due to the shortage of fossil fuels. Wind energy is one of the promising renewable energy sources for the future. But the fluctuating nature of wind introduces power quality issues like harmonics and deviations in voltage waveform in the grid, which in turn affects the stability of the entire grid. Another issue is that power system grid is a nonlinear and dynamic system which requires ample generation of real and reactive power to supply its loads , consumer and losses in the system. when the generation of real and reactive power is insufficient to meet its load and losses, it may not provide reliable and stable power supply. Increased demand may be satisfied without changing the existing power system infrastructure with the help of FACTS devices. This paper aims at reducing the power quality issues using STATCOM along with a controller. STATCOM is connected at the Point of Common Coupling (PCC) where the wind energy system is connected to the grid. The distortions in the waveform are reduced by the proper switching of the semiconductor devices of the STATCOM. The switching is controlled using a PI controller with space vector modulation (SVPWM). The gains of the PI controller are tuned using (Particle Swarm Optimisation Technique (PSO). The power quality is then analyzed with Total Harmonics Distortion (THD) as the main performance measure for which the system is simulated in SIMULINK/MATLAB. To analyze the performance, parameters like real power, reactive power, voltage and THD are evaluated at PCC. The THD of the proposed system is found to be 4.78% which is within IEEE std 519-1992 standards. It is found that the performance of the PSO controller connected wind energy conversion system is improved compared to the system without PSO.

Keywords-STATCOM, PSO, Grid Connected, Wind energy, SVPWM, FACTS, THD

I. INTRODUCTION

Renewable energy systems are the only hope of the future energy sector and due to the constant demand for energy; we have searched and found a wide variety of renewable sources to choose from [11]. The choice depends mainly on the availability of the resources in that geographical area. Wind energy systems are the fastest growing field due to their on shore and off shore generation capabilities. Wind energy is clean, abundant, consumes no water, and uses less land. Off shore wind is more steady and strong, so generation capabilities are more. With the advancement of aerodynamic designs, wind turbines which can capture hundreds of kilowatts of power are readily available. In a wind farm, individual turbines are connected through a medium voltage power collection system. Wind farms can be used as a standalone generating stations or can be connected to the grid. When such wind energy conversion systems (WECS) are integrated to the grid, they produce a substantial amount of power, which can supplement the base power generated by thermal, nuclear, or hydropower plant. But wind is highly variable both in space and time. The energy available from wind varies as the cube of the wind speed. This fluctuating nature of wind introduces power quality issues like harmonics and deviations in voltage waveform in the grid, which in turn affects the stability of the entire grid.

To maintain and control the power flow in interconnected AC transmission systems, the FACTS devices are used. It provides the effective power flow control with increased transmission capacity of the line. FACTS devices provide greater operating flexibility and better utilization from the already existing power system infrastructure.

II. GRID CONNECTED WIND ENERGY SYSTEMS

The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional power plants [1]. The integration of wind energy into existing power system presents various technical challenges that require consideration of voltage regulation, stability and other power quality problems. Power quality is an essential customer-focused measure and is greatly affected by the variation of the wind and thus the output of wind energy conversion system. There has been an extensive growth and quick development in the exploitation of wind energy in recent years. The individual units can be of large capacity up to 2 MW, feeding into distribution network, particularly with customers connected in close proximity [3]. Today, more than 28,000 wind generating turbines are successfully operating all over the world. The issue of power quality is of great importance to the wind turbine [2].In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. During the normal operation, wind turbine produces a continuous variable output power. These power variations are mainly caused by the effect of turbulence, wind shear and tower-shadow and of control system in the power system. In order to deliver reliable power, the network needs to manage for such fluctuations. Otherwise these fluctuations will be reflected in the generation, transmission and distribution network as voltage sag, swells, flickers, harmonics etc. The proposed grid connected WECS system implemented for power quality improvement at PCC is as shown in fig.1.

In this configuration, wind generators are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, non-requirement of a separate field circuit, acceptance of constant and variable loads and natural protection against short circuit.

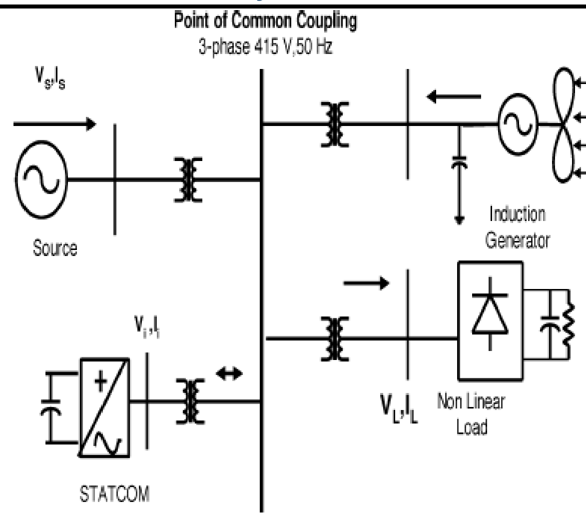

Fig.1. Grid connected system for power quality improvement

III. STATCOM MODEL WITH SMALL SIGNAL CONTROL STRATEGY

One of the main problems with the induction generator based WECS is the reactive power support which lead to power quality issues in the grid. Different solutions are found to support the cage induction generators in case of changes in the grid voltage. Mechanically switched capacitors, SVC, synchronous condensers and voltage source static Var compensators such as the STATCOM can be used to regulate voltage to improve the grid interface of directly connected asynchronous wind generators.

A STATCOM consists of a Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through an interfacing inductor. The VSC converts the dc voltage across the capacitor into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allows effective control of active and reactive power exchanges between the STATCOM and the ac system. The voltage source converter injects the current into the grid in such a way that the source current are harmonic free and their phase angle with respect to source voltage has a desired value [7]. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus improving the power factor and the power quality [3].

The static compensator with the ac system provides a multifunctional topology which can be used for three quite distinct purposes: voltage regulation and compensation of reactive power, correction of power factor and elimination of current harmonics. The DC side of the converter is connected to a capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the STATCOM is in the capacitive mode of operation and vice versa.

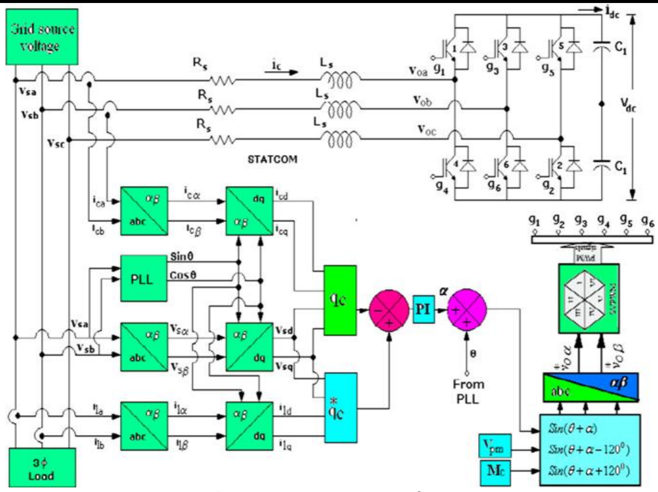

Fig.2 Implementation Diagram of STATCOM

The state space model of STATCOM has been linearized in small signal method and the small signal model is given by Equation (1).The linearized states $i_{cd\Delta}$, $i_{cq\Delta}$ and $v_{cd\Delta}$ are changes in the reactive component of the current, active component of the current and the dc-link voltage, respectively.

$$\frac{d}{dr}\begin{pmatrix} i_{cd\Delta} \\ i_{cq\Delta} \\ v_{dc\Delta} \end{pmatrix} = \begin{pmatrix} \frac{-R_S}{L_S} & \omega_1 & -\frac{m_C}{L_S} \\ -\omega_1 & \frac{-R_S}{L_S} & 0 \\ \frac{m_C}{C_{dc}} & 0 & 0 \end{pmatrix}\begin{pmatrix} i_{cd\Delta} \\ i_{cq\Delta} \\ v_{dc\Delta} \end{pmatrix} + \frac{V_S}{L_S}\begin{pmatrix} -\sin\alpha_\Delta \\ -\cos\alpha_\Delta \\ 0 \end{pmatrix}(\alpha_\Delta) \tag{1}$$

$$Q_{c\Delta} = \begin{bmatrix} -V_S Sin\alpha_\Delta & -V_S Cos\,\alpha_\Delta & 0 \end{bmatrix}\begin{pmatrix} i_{cd\Delta} \\ i_{cq\Delta} \\ v_{dc\Delta} \end{pmatrix} + \left(-\frac{(V_S Sin\alpha_\Delta{}^2)}{R_s}\right)(\alpha_\Delta) \tag{2}$$

The transfer function relating the reactive power $Q_{c\Delta}$ to the variation in angle α_Δ is found to be,

$$P_q(s) = \frac{Q_{c\Delta}}{\alpha_\Delta} = \hat{C}\left[sI - \hat{A}\right]^{-1}\hat{B} + \hat{D} \tag{3}$$

A simplified block diagram of the internal control for purely reactive compensation, based on the indirect approach of dc capacitor voltage control is given in Fig.3. The inputs to the internal control are: the ac system bus voltage v, the output current of the converter, io, and the reactive current reference, i_{lq},i_{cq}. Voltage V operates a phase-locked loop that provides the basic synchronizing signal, angle θ . Accordingly, angle α is summed to θ to provide angle θ + α, which represents the desired synchronizing signal for the converter to satisfy the reactive current reference. Angle θ + α operates the gate pattern logic (which may be a digital look-up table) that provides the individual gate drive logic signals to operate the converter power switches.

Space vector PWM refers to a special switching scheme of the six power semiconductor switches of a three phase power converter. The classic space-vector PWM (SVPWM) strategy, first proposed in [2] and [3], and very popular nowadays because of its simplicity and good operating characteristics, consists of the generation of a specific sequence of states of the inverter. Durations of the individual states are determined from simple formulas that are easy to implement in a microprocessor. The complex plane of the voltage space vectors of the inverter is divided into six 60 wide sectors (0 –60, 60 –120, etc.) corresponding to 60 long sub cycles of the cycle of the output voltage of the inverter. In turn, each sub cycle is divided into N equal switching intervals. Three states, X, Y and Z of the inverter are imposed within each switching interval. A given state S, of an inverter is defined by values of the phase A, B, and C switching signals a,b and c as S = $(abc)_2$. The duty ratios, d_{Xi}, d_{Yi},and d_{Zi} of the individual states in i th switching interval are calculated as where is the center angle of the switching interval, measured with respect to the beginning of the sub cycle.

S.No.	Table Column Head	
	System Parameter	*Values*
1	Vs	415 V
2	f=f1	50Hz
3	ω=ω1	314 rad/sec
4	Rs	1.0 Ω
5	Ls	5.44 Mh
6	Cdc	680 µF
7	M	0.866,1.0
8	Mc	0.979,1.2
9	Rl	23 Ω
10	Ll	60Mh

Table.1 System Parameters

IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is an evolutionary computation technique that has been applied to many power engineering problems, giving better results than classical techniques and with less computational effort. It is developed by Eberhart and Kennedy in 1995, which was inspired by the social behavior of bird flocking and fish schooling. PSO has its roots in artificial life and social psychology, as well as in engineering and computer science. PSO is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in many problems where most analytical methods fail to converge.so it can be applied to many of the power system problems like economic dispatch, Unit commitment, droop setting problem and gives the better results.

A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate solutions (called particles). These particles are moved around in the search-space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The error voltage that is generated is considered as function takes a candidate solution as argument in the form of a vector of real numbers and produces a real number as output which indicates the objective function value of the given candidate solution. The goal is to find a solution a for which f(a) ≤ f(b) for all b in the search-space, which would mean a is the global minimum.

Let S be the number of particles in the swarm, each having a position $x_i \in \mathbb{R}^n$ in the search-space and a velocity $v_i \in \mathbb{R}^n$. Let p_i be the best known position of particle i and let g be the best known position of the entire swarm. A basic PSO algorithm is then:[7]

- For each particle i = 1, ..., S do:
  - Initialize the particle's position with a uniformly distributed random vector: xi ~ U(blo, bup), where blo and bup are the lower and upper boundaries of the search-space.
  - Initialize the particle's best known position to its initial position: pi ← xi
  - If (f(pi) < f(g)) update the swarm's best known position: g ← pi
  - Initialize the particle's velocity: vi ~ U(-|bup-blo|, |bup-blo|)
- Until a termination criterion is met (e.g. number of iterations performed, or a solution with adequate objective function value is found), repeat:
- For each particle i = 1, ..., S do:
  - Pick random numbers: rp, rg ~ U(0,1)
- For each dimension d = 1, ..., n do:
  - Update the particle's velocity: vi,d ← ω vi,d + φp rp (pi,d-xi,d) + φg rg (gd-xi,d)
  - Update the particle's position: xi ← xi + vi
- If (f(xi) < f(pi)) do:
  - Update the particle's best known position: pi ← xi
- If (f(pi) < f(g)) update the swarm's best known position: g ← pi
- Now g holds the best found solution.

In this paper, PSO is used to optimize the value of KP and KI, so that effective compensation is provided by selecting appropriate value of α with improved power quality. The power quality at PCC of the grid connected system is analyzed using the FFT analysis by simulating the wind energy conversion system model at MATLAB Simulink. Total harmonic distortion (THD) is analyzed by considering the source current at PCC. The results shows that THD reduced with PSO trained PI controller at STATCOM.

V. SIMULATION RESULTS

The variable wind causes changes in the real and reactive power and distorts the voltage waveform. To overcome this problem, the FACTS controller STATCOM is connected at the point of common coupling (PCC). The test system parameters considered for the analysis are as follows,

S.No	Parameters	Ratings
1.	Grid Voltage	3-Phase, 415V,50Hz
2.	Induction motor/ generator	3.5KVA,415V,50Hz,P=4, Speed=1440rpm,Rr=0.1Ω ,Rs=0.15Ω,Ls=Lr=0.06H
3.	Line series Inductance	0.05mH
4.	IGBT rating	Collector Voltage=1000V, Forward Current=50A,Gate Voltage=20V,Power Dissipation=310w
5.	Load Parameter	Non-Linear Load=25kw

Table.3. System Parameters for test system

The system has been simulated with and without the PSO algorithm and the results are compared below.

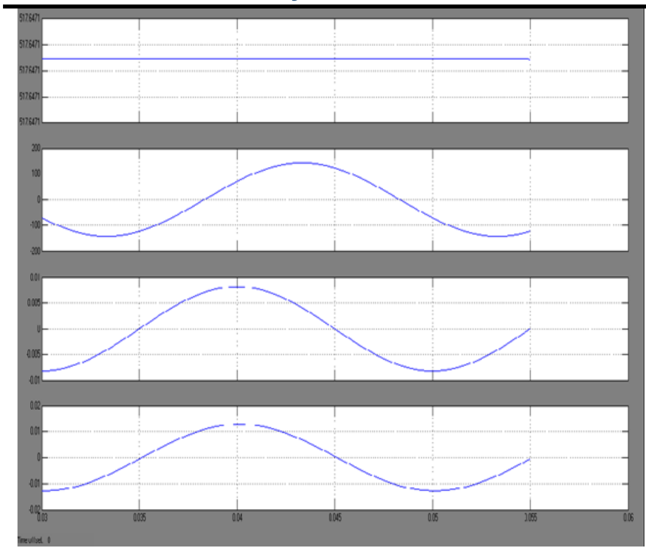

Fig.3.Real power, Voltage, Current, Reactive power waveforms without PSO

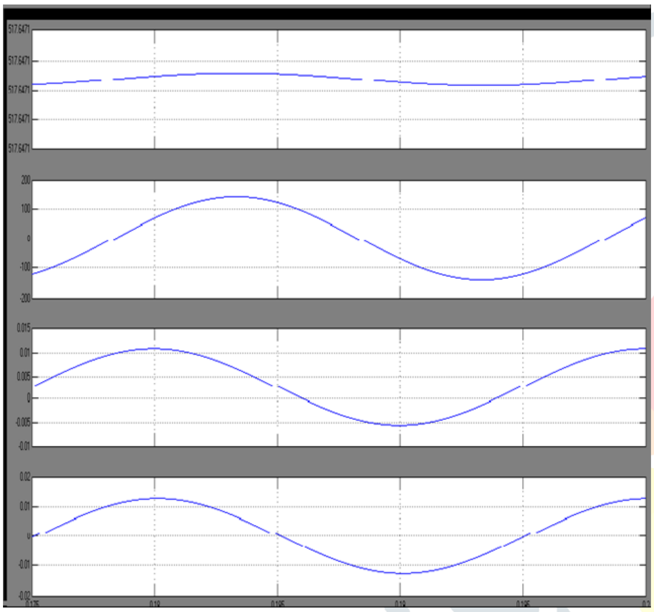

Fig.4.Real power, Volatge, Current, Reactive power waveforms with PSO

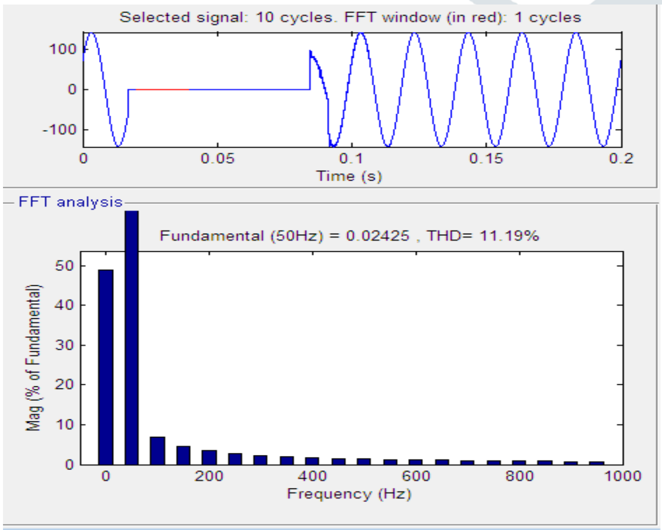

Fig.5. FFT analysis without PSO

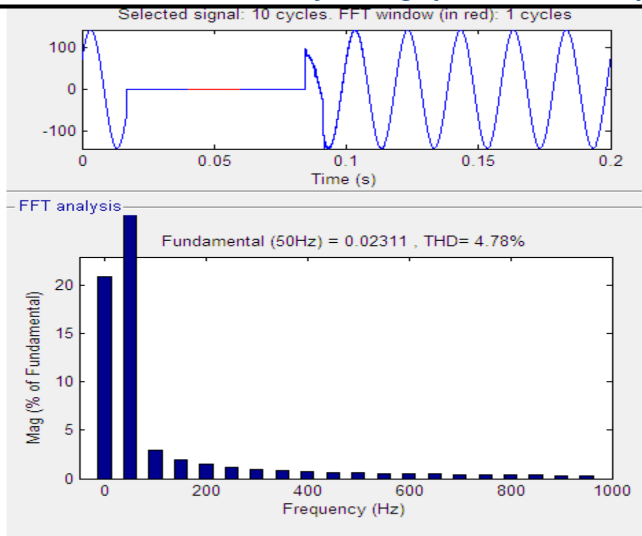

Fig.6. FFT analysis with PSO

It is evident from the waveforms that the PSO tuned PI controlled STATCOM has improved the performance of the grid connected WECS .the power quality is analysed using FFT analysis at PCC. The THD is calculatd with the both the conditionsi.e before introducing PSO and afte introducing PSO. The results show that there has been considerable reduction in the THD after tuning the PI controller ans is under the limits specified by IEC64100.

VI. CONCLUSION

The results show that the THD has been reduced from 11.9% and 4.78% and the voltage and current profiles have been improved. The distortions in the waveform are reduced by the proper switching of the semiconductor devices of the STATCOM. The switching is controlled using a PI controller with space vector modulation (SVPWM). STATCOM is controlled using (Particle Swarm Optimisation Technique (PSO) to tune the gains of the PI Controller. The power quality is then analyzed using Total Harmonics Distortion (THD) as a performance measure which is simulated in SIMULINK/MATLAB.

V.REFERENCES

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