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Reactive Power Compensation and Mitigation of Current Harmonics in Grid Connected Wind Turbine Generating System (GCWTGS) using STATCOM

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Abstract-The integration of the wind energy into the conventional power system mitigates the energy crisis but introduces other problems like degradation of the power quality, adding reactive power burden to the existing grid, etc. The modern power system should deliver power with minimal reactive power burden to the grid and also with good power quality. Hence the focus is made on this paper to compensate reactive power and to improve the power quality in grid connected wind turbine generation system (GCWTGS). This work demonstrates the power quality problem due to interconnection of wind turbine with the grid having high density of non linear load. A STATCOM is proposed to resolve the reactive power compensation and mitigation of the power quality problem like current harmonics in a grid connected wind turbine generation system. A control scheme is developed for this purpose. The simulation of the proposed system and validation of results is carried out in the MATLAB/SIMULINK software environment.

1. INTRODUCTION

In sustainable energy system, energy conservation and the use of renewable source are key factors that drive the system. The need to integrate the renewable energy like wind energy into power system is to mitigate the impact on the environmental pollution by the conventional power generation systems. The conventional power system refers to the grid with power generation systems like thermal, nuclear etc. The important technical challenges imposed by the integration of the wind energy system into the existing conventional power system are reactive power balance, power quality issues, grid stability and voltage regulation problems. The power quality issues gains maximum attention in the event integration of the wind energy system into the conventional power system.

In the fixed speed wind turbines, any deviations in the input wind speed results in the fluctuation in the mechanical torque which in turn fluctuate the electrical power and leads to large voltage fluctuation. The power variations are caused by the effect of wind shear, turbulence, tower shadow and of control system in power system. Thus the network needs to manage such fluctuations and the power quality problems such as harmonics, etc. There is also a need to compensate reactive power. These needs are mitigated by connecting STATCOM connected at PCC (Point of common coupling).

In [1], the author described about sustainable development. Sustainability must be the goal when building power systems of the future. Sustainability can be improved by reducing the losses in the power system. However, introduction of renewable-based generation, energy storage, and dc transmission and distribution are made possible by increased use of power electronics. So by using power electronics, a sustainable development of power systems can be produced in future. In [2], the author describes the current technology and future trends in variable-speed wind turbines. It is expected that current developments in gearless energy transmission with power-electronic grid interface will lead to a new generation of quiet, efficient, and economical wind turbines. It also describes about the power-conditioning systems used in grid connected photovoltaic systems and it describes about the present research and development trends in energy storage systems used for the grid integration of intermittent renewable energy sources. In [3-5], the author proposed an alternative filter and control approach for the design of a micro turbine's utility interface. The new method employed a unified current regulated controller to drive the system converter as a power conditioner for the grid-tied operation and an emergent generator for the stand-alone operation, where few current sensors are required to serve the controller for both operating modes. The proposed method had been examined under various scenarios, including the loss of grid and parallel operation. The results help consolidate the feasibility and practicability of the approach for the applications considered.

In this paper, Section II describes the various effects of the integration of the wind with the conventional power system. Section III presents the system description. Section IV describes the control strategies used to implement the needs required. Section IV discusses about the results. Section V presents the conclusions of this paper.

2. EFFECTS OF INTEGRATION OF GCWTGS

Integration of wind energy system with the grid creates the following problems in the power system:

2.1 Voltage variation:

The voltage variation issue results due to the deviation in generator torque and wind velocity. The voltage variation is directly related to and reactive and real power variations.

The variation of voltage can be any one of the following:

- Voltage Sag
- Voltage Swell
- Interruptions
- Long Duration Voltage Variations

Voltage sag is a temporary decrease in the RMS voltage at the fundamental frequency that lasts for periods ranging from a half cycle to a minute. Similarly Voltage swell is a temporary increase in the RMS voltage at the fundamental frequency that lasts for periods ranging from a half cycle to a minute.

Interruptions are momentary events that completely interrupt the power supply to a distribution system caused by recloser operation or transmission outages

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2.2 Harmonics:

The harmonics arises due to the presence of the non linear loads connected with the GCWTGS. The harmonic current and voltage should be limited to the acceptable level at the point of interconnection of the wind turbine to the network. To ensure the level of current and voltage harmonics under limit suitable control action has to be taken to mitigate it, which is enhanced by the connection of the STATCOM.

2.3 Self-excitation of wind turbine generating system:

It takes place after disconnecting WTGS with local load. The risk of self-excitation of WTGS with an asynchronous generator excitation arises especially when WTGS is equipped with the compensating capacitor. The capacitor connected to induction generator provides compensation of reactive power. However the voltage and frequency are determined by balancing of the system. The disadvantages of self-excitation are the safety aspect and balance between real and reactive power.

2.4 Voltage flicker:

The voltage flicker issue determines dynamic variations in the network caused by the wind turbine or by varying loads. Thus the power flow fluctuation from wind turbine occurs during continuous operation. The amplitude of voltage fluctuation depends on network impedance, grid strength, phase-angle and power factor of wind turbines. It is defined as fluctuation of voltage in a frequency in range of 10-35 Hz.

2.5 Consequences of the issue:

The voltage variation, harmonics exhibits its effect by mal-function of equipment connected to the system like programmable logic controller and adjustable speed drives, flickering of light and screen. It may leads to tripping of contactors, tripping of protection devices, stoppage of sensitive equipment like personal computer, programmable logic control system and may stop the process and even can damage sensitive equipment. Thus it degrades the power quality in the grid.

2.6 Problems caused by reactive power:

The following problems are created due to reactive power:

- Increase in the distribution system losses
- Reduces voltage regulation
- Decreases power factor
- Reduced life of equipment

3. SYSTEM DESCRIPTION

In the system under consideration, three phase source (i.e. grid) is connected with the non-linear load and wind generator. The STATCOM is connected with the interface of non-linear load and induction generator at the PCC in GCWTGS. The STATCOM compensator's output is varied according to the controlled strategy so as to maintain the power quality norms in the grid system. The single line diagram of grid connected wind energy system is shown in fig.1.

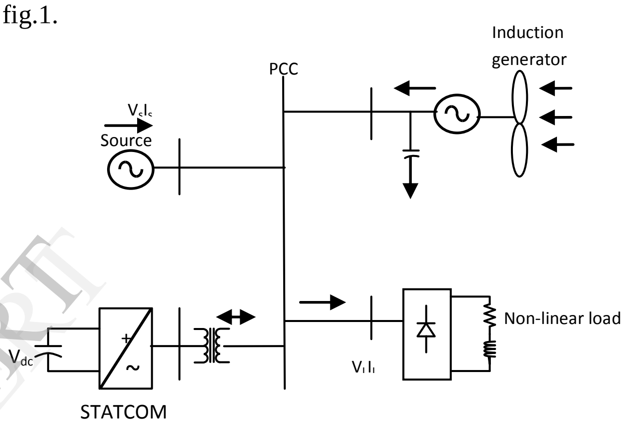

Fig. 1 Grid Connected Wind Energy System with STATCOM

3.1 Modelling of Wind Turbine

The induction generator is used in the proposed scheme because of its simplicity and it does not require any separate excitation circuit. It can accept constant and variable loads, and has natural protection against short circuit. The maximum power available in wind energy system is given below:

$$P_{wind}=1/2\rho AV^3 \quad \text{....(3.1)}$$

Where, ρ (kg/m) is the air density, A(m) is the area swept out by turbine blade. V is the wind speed in meters per second. It is not possible to extract all kinetic energy of wind, thus it extracts a fraction of power in wind, called power coefficient C_p of the wind turbine, and is given below:

$$P_{mech}=C_pP_{wind} \quad \text{... (3.2)}$$

Where, C_p is the power coefficient which depends on type and operating condition of wind turbine. This coefficient can be expressed as a function of tip speed ratio λ and pitch angle θ. The mechanical power produced by wind turbine is given below:

$$P_{mech}=1/2\rho\pi R^2V^3C_p \quad \text{... (3.3)}$$

Where, V is the velocity of wind in m/sec.
R is the radius of the blade in m.

To understand the characteristic behaviour of induction generator based wind turbine, many techniques have been developed under different d-q control conditions which are broadly divided into two categories:

- Transient approaches
- Steady-state technique

The transient approaches are essential to study dynamic performance of induction generator in a short period and steady-state techniques are important to examine the characteristics under different control conditions.

Table 1.System Parameters

S NO	PARAMETERS	RATINGS
1	Grid voltage	3phase,415V, 50Hz
2	Induction generator	3.35KVA, 415V,50Hz, P=4,speed=1440 rpm, Rs=0.01Ω,Rr=0.015Ω, Ls=0.06H, Lr=0.06H
3	Line series inductance	0.05mH
4	Inverter parameters	DC link voltage=800V DC link capacitance=100μF Switching frequency=2kHz
5	IGBT rating	Collector voltage=1200V, forward current=50A, gate voltage=20V
6	Load parameter	Non linear load(P=1000W,Q=1000 VAR)

Normally, the induction generator based wind energy system needs reactive power from the grid for its operation. Due to this reason, loss of power in the transmission system occurs and also voltage fluctuations take place in the grid. When the generated active power of an induction generator is deviated due to wind, the absorbed reactive power and terminal voltage of induction generator are varied. So, STATCOM is used to compensate the reactive power required by the induction generator. If the load connected to the grid is non-linear, it will generate harmonics. To mitigate power quality problems like harmonics, voltage variations and reactive power problems, STATCOM is used.

4. CONTROL TECHNIQUE

4.1 STATCOM

The STATCOM is a solid state device capable of providing adequate reactive power compensation for the system connected with it. It can generate or absorb the reactive power by varying the firing scheme of the voltage source converter present in it. The STATCOM can also be used to mitigate the power quality problems like harmonics etc. The STATCOM can mitigate the power quality issues only by providing proper firing scheme that is derived from a reference current extraction scheme.

4.2 Hysteresis Control Technique

The control scheme for STATCOM is based on injecting the currents into the grid using a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The waveform of hysteresis controller is shown in fig.2.

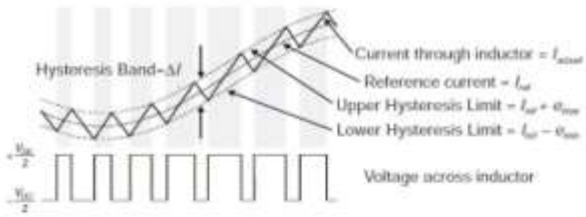

Fig.2. Waveform of hysteresis controller

The reference current and the actual current are subtracted for obtaining a current error for a hysteresis based “Bang-bang controller”. The ON/OFF switching signals for IGBTs of STATCOM are derived from hysteresis controller. The block diagram of hysteresis controller is shown in fig.3. The control algorithm requires the measurements of several variables such as DC link voltage in STATCOM and inverter currents with the help of sensors. The current control block receives the reference currents and actual inverter currents are subtracted so as to activate the operation of STATCOM in current control mode. The STATCOM compensator output is varied according to the control strategy so as to maintain the power quality norms in the grid system. The reference current for the STATCOM is extracted from the load current and the harmonics in current is mitigated using the hysteresis controller. In addition to the STATCOM, tuned passive filter is also used to mitigate the severity of the current harmonics in the source current so that total THD is reduced.

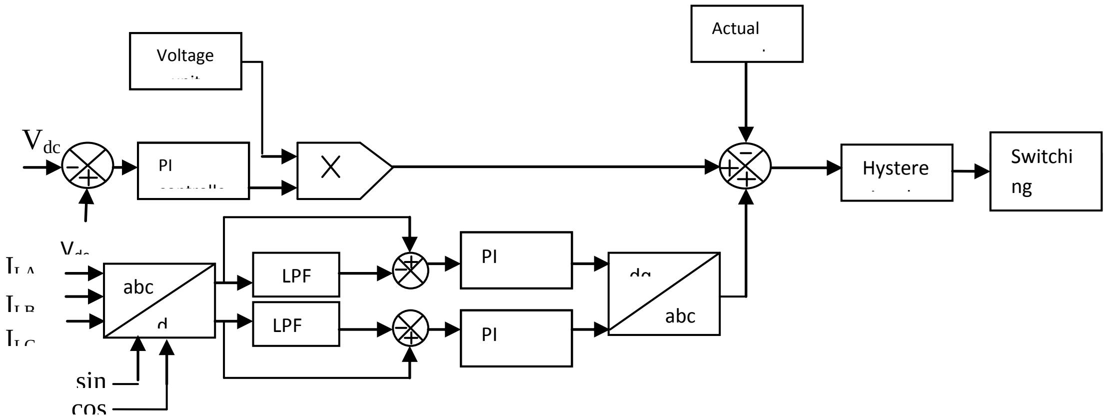

Fig.3 Block diagram of Hysteresis controller.

5. RESULTS AND DISCUSSIONS

The real and reactive power flows on source side, STATCOM side, and load side and wind generator under different cases are shown in Tables 2 and 3

Table.2 Non-linear load without STATCOM

SOURCE (GRID)		LOAD		WIND GENERATOR	
P(W)	*Q(VAR)*	*P(W)*	*Q(VAR)*	*P(W)*	*Q(VAR)*
2400	3000	3800	1800	1500	1300

From Table.2, it can be inferred that the real power requirement for the load is supplied from the grid and the wind turbine. The reactive power requirement of the load as well as the wind generator is supplied entirely from the grid. Hence the reactive power burden on the grid increases. The reactive power burden on the grid can be minimized by using adequate reactive power compensation devices like STATCOM.

Table 3 Non- linear load with STATCOM

SOURCE (GRID)		LOAD		STATCOM		WIND GENERATOR	
P(W)	*Q(VAR)*	*P (W)*	*Q (VAR)*	*P(W)*	*Q(VAR)*	*P(W)*	*Q(VAR)*
2400	1800	3800	1800	0	-1300	1500	1300

From Table.3, it can be inferred that the real power for the load is supplied by the grid along with the wind generator. The total reactive power requirement of the load is 1800VAR and that of the wind turbine is the 1300VAR. Hence an overall reactive power requirement of 3100VAR is expected from the grid and real power requirement of 2300W is expected from the grid. This in terms of apparent power is equal to 3860VA which is to be delivered by the grid.

Now we make use of the STATCOM to support the reactive power requirement of the load and also to improve the power quality. The STATCOM proposed is capable of supplying 1300VAR (which is indicated by negative sign in Table 3). Hence the real power requirement of the load from the grid remains the same but the reactive power requirement from the grid decreases by 1300VAR. Now the overall apparent power requirement from the grid is 2920VA. Thus 940VA of apparent power requirement from the grid has been reduced along with the improvement of the power quality by mitigating the current harmonics.

Output Waveforms

The output waveforms of load current, source current without STATCOM, and current harmonics mitigated source current with STATCOM are shown in fig.4, fig.5 and fig.6 respectively.

From the fig.4 and fig.5 shows the load current drawn by the nonlinear load and the source current from the grid respectively. It can be observed that the load current is distorted and it is visibly clear that the harmonic content would be certainly higher. The source current is smooth and less distorted than the load current is shown in fig.6. The quantitative analysis with THD of the both waveforms is presented in the Fig.7, 8 and 9.

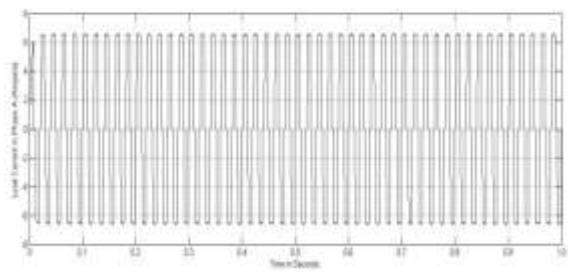

Fig.4. load current

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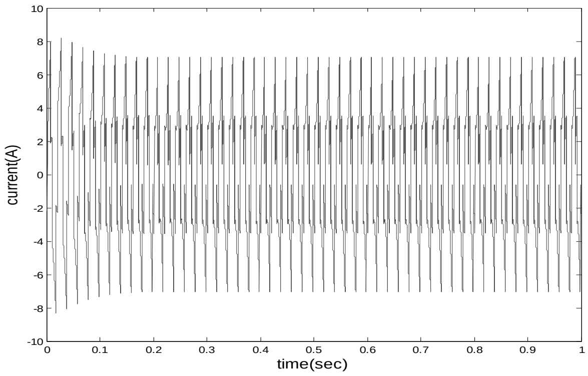

Fig.5 Source current without STATCOM

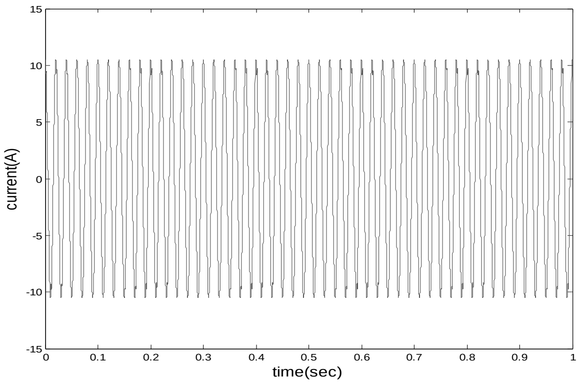

Fig.6 Source current with STATCOM

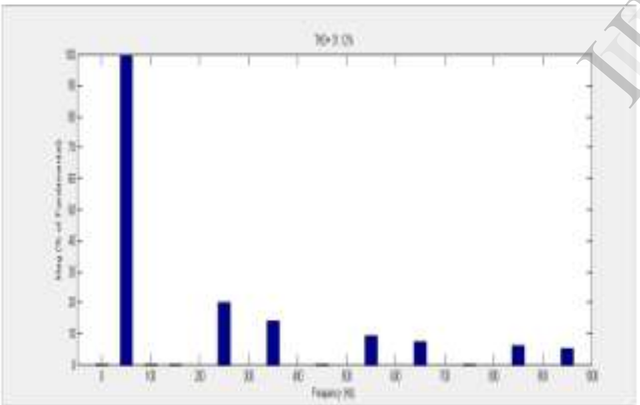

Fig.7 .Harmonic spectrum of load current

From the figure 8, it is clearly seen that the THD in the source current without STATCOM is 41.42%. In fig.9.it clearly seen that THD in the source current with STATCOM is minimized to 2.12%. Hence the current harmonics is mitigated evidently.

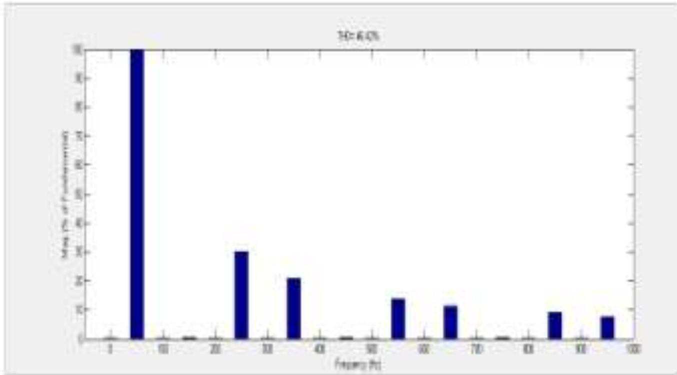

Fig.8 Harmonic Spectrum of the source current without STATCOM

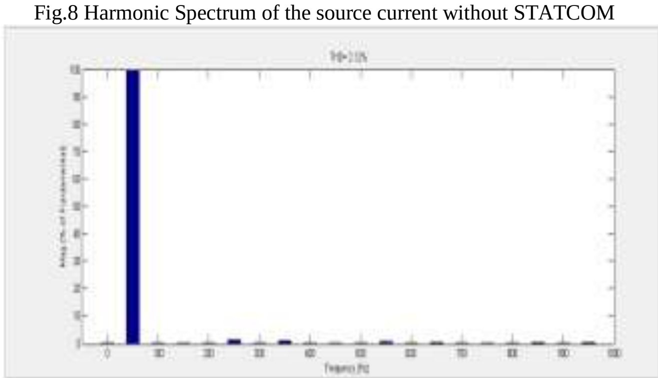

Fig.9. Harmonic spectrum of source current with STATCOM

6. CONCLUSION

The integration of the wind energy into the conventional power system and presence of nonlinear load in power system imposes serious technical challenges. The important technical challenges are reactive power compensation, mitigation of power quality problems and improving grid stability. In this paper, focus is made on the reactive power compensation and the mitigation of the current harmonics on the grid current in a grid connected wind energy generation system. A STATCOM was developed using the Bang-Bang controller specially to compensate the reactive power burden on the grid and to mitigate the current harmonics on the grid current. Detailed simulation is developed and executed in the MATLAB\SIMULINK environment and the result confirms the successful operation of the STATCOM.

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