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Research Paper

POWER QUALITY ENHANCEMENT FOR FLEXIBLE OPERATION OF GRID INTEGRATED WIND FARM WITH STATCOM

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With rapid industrial development around the world, the demand of electrical energy is more than the generation. To meet the demand of electrical power, Renewable Energy Sources plays crucial role as alternative energy sources, and bring new challenges when it is connected to the power grid. Generated power from wind farm is always fluctuating due to the fluctuations in the wind and affects the power quality of injected electric grid. The system stability of a wind farm connected to medium voltage grid in different operating conditions and the behaviour of the system when using a Static Synchronous Compensator (STATCOM) for wind farm integration has been proposed in this paper. The proposed control scheme is simulated using MATLAB/SIMULINK.

Keywords: Flexible AC Transmission System (FACTS), Static Synchronous Compensator (STATCOM), Point of Common Coupling (PCC)

INTRODUCTION

Wind energy is attracting more attention from researchers and even utilities due to its benefits as a clean and abundant source of energy. When integrated to the power system, large wind farms pose stability and control issues. A thorough study is needed to identify the potential problems and to develop measures to mitigate them. Although integration of high levels of wind power into an existing transmission system does not require a major redesign, it necessitates additional control and compensating equipment to enable recovery from severe system disturbances.

Typically, most of the wind turbines are located at remote places or offshore where the power grid is usually long and weak characterized by under voltage condition. Because of the limited reactive power capability, DFIG cannot always supply required reactive power; as a result, its terminal voltage

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fluctuates (Kinjo and Senjyu, 2006; Heier, 2007; and Han *et al.*, 2008). Hence, a voltage regulation device is required for the secure operation of the overall wind turbine together with power grid during normal operation as well as disturbances in the grid. Flexible AC Transmission System (FACTS) devices, through their fast, flexible, and effective control capability, provide solution to this challenge. Therefore, the use of Static Synchronous Compensator (STATCOM) at the Point of Common Coupling (PCC) to regulate terminal voltage of the DFIG wind turbine system.

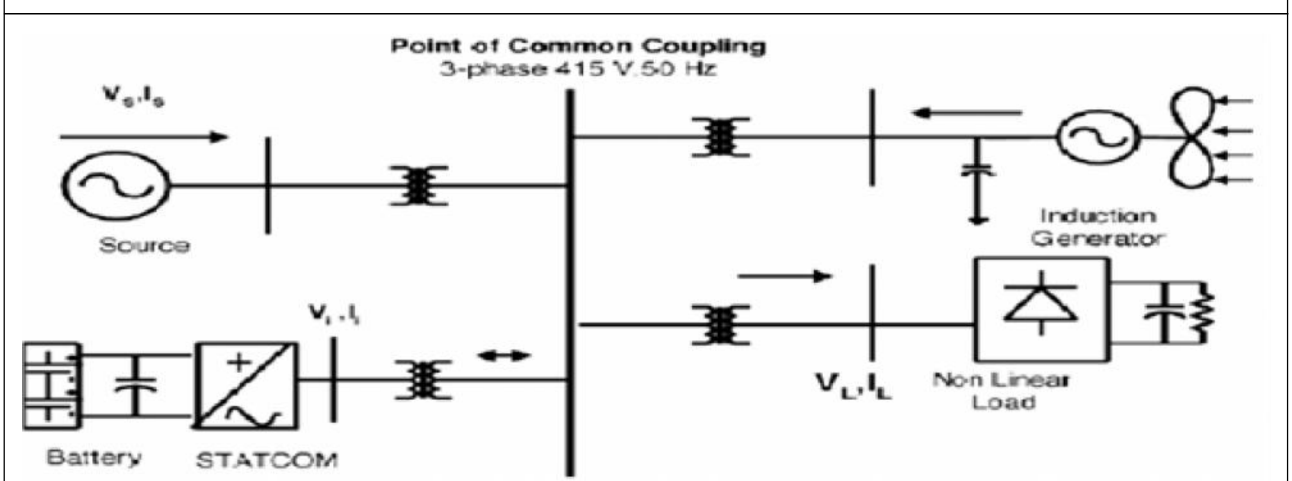
Reactive power compensation and harmonic reduction in a low voltage distribution networks for integration of wind power to the grid are the main issues. This paper proposes a control scheme for compensating the reactive power requirement of a three phase grid connected wind driven induction generator as well as the harmonics produced by the non linear load connected to the PCC by using STATCOM (Manel, 2006; Milands *et al.*, 2007; and Mohod and Aware, 2008). The intended results of the proposed scheme relive the main supply source from the reactive power demand of the load and the induction generator.

WIND FARM INTEGRATED POWER SYSTEM

Wind is a continuously varying source of energy and so is the active power generated by the wind turbine. If a WT is connected to a weak grid (which has low short circuit power), the terminal voltage also fluctuates, producing flicker, harmonics and interharmonics due to the presence of power electronics (Sannino, 2004).

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 re-establish the voltage 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 (Wind Turbine Generating System-Part 21, 2001). 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

Figure 1: Schematic Diagram of Grid Connected Wind Farm



and reinforce the power network as shown in Figure 1. This is also true for wind farms with all fixed speed wind turbines with no dynamic control or reactive power compensation.

Velocity and Power Relations

Energy of wind is definition as kinetic energy: movement of air mass *M*, with speed *V*. Formula below shows that dependence:

$$E = \frac{1}{2} M V^2 \quad ...(1)$$

Related to above, formula of wind stream power is (only for constant wind speed)

$$P_{wind} = \frac{dE}{dt} = \frac{1}{2} M' V^2 \quad ...(2)$$

M' – mass flow per second

If m is a mass flow rate of the air per second,

$$P_{wind} = \frac{1}{2} {}^\circ A V^3 \quad ...(3)$$

where

° – air density

A – area swept by the rotating blades

V – wind speed

From above equation mechanical power have a cubic relation with wind speed. It is considerable advantage in situation when the wind is blowing with constant speed but this condition is happens rarely in real. Therefore that cubic relation is significant disadvantages of wind turbine making them very floating resource.

Reliability and Stability of Wind Farm Connected to Grid

Power quality problems to the associated power system due to the presence of WTs are continuous power variations, voltage variations, flicker, harmonics, and transients. Likewise, the kind of power quality issues that the wind farm encounters due to the associated network are voltage dips, interruptions, voltage imbalances and frequency variations. In the past, wind power was exempted from some grid interconnection requirements like voltage regulation and frequency regulation. The wind power systems were allowed to disconnect on system events like three phase faults and blackouts.

Only recently, after the increase in wind power penetration, have some stringent interconnection rules, known as "grid codes" with which these wind plants have been conformed and developed. These grid codes require that wind turbine generators are treated more like conventional generating units and participate in grid voltage and frequency regulation. To facilitate WT participation in frequency control there are two major controls: turbine-based control and substation-based control. In turbine-based control systems, each turbine has to have some specific control capabilities, such as power factor or reactive power (Q) control.

In substation-based control, some kind of reactive power compensation is either provided by switched capacitors (manual or static compensation) or FACTS devices. They can be expressed as follows:

$$P = \frac{V_1 V_2}{x} \sin ¢ \quad ...(4)$$

$$Q = \frac{V_1 V_2}{x} \cos ¢ \; \frac{V_1^2}{x} \quad ...(5)$$

P and *Q* are active and reactive power of the VSC respectively

¢ = the phase difference between V_1 and V_2

As the angle ¢ is equal to zero, then P = 0. If AC voltage that generated by VSC is Higher or (lower) than system voltage V_1, then the STATCOM generate or absorbs Reactive power as shown in Table 1.

Table 1: Active and Reactive Power Specifications of IG and Load

Parameters	Grid	Induction Generator	Load
Reactive power (var)	3307	1930	1377
Active power (w)	–6283	–8400	2117

STATIC SHUNT COMPENSATOR: STATCOM

Flexible AC Transmission Systems which abbreviated by FACTS forms a new domain in power system control engineering they can be connected to transmission line in series or shunt. STATCOM can be defined as "A static synchronous generator operated as a shunt connected static var compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage". Basically STATCOM is a FACTS device which is also known as electronic generator of reactive power. It consists of a VSC, a DC energy storage device (capacitor), and a coupling transformer which connects the VSC in shunt to the power network as shown in Figure 2.

Hysteresis Controller Scheme for STATCOM

The current control scheme for STATCOM is uses a "hysteresis current controller." Using this technique, the controller keeps the STATCOM current between boundaries of hysteresis area and gives correct switching signals for STATCOM operation.

It is a feedback current control method where the actual current tracks the reference current within a hysteresis band. The current controller generates the firing pulses to the VSI by comparing the reference and actual current.

The hysteresis current control scheme for generating the switching signals to the STATCOM is shown in Figure 3.

If the current exceeds the upper limit of the hysteresis band, upper switch of the inverter arm is turned off and the lower switch is turned

Figure 2: Single Line Diagram of the STATCOM Connected to Power Grid

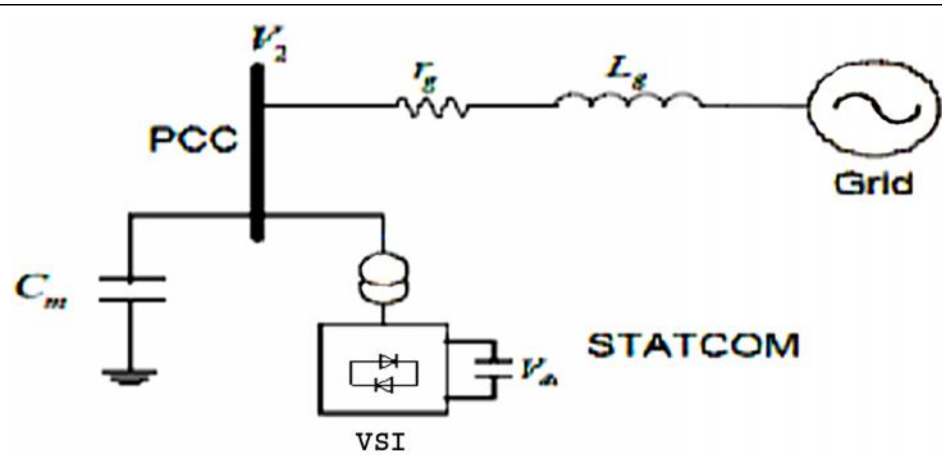
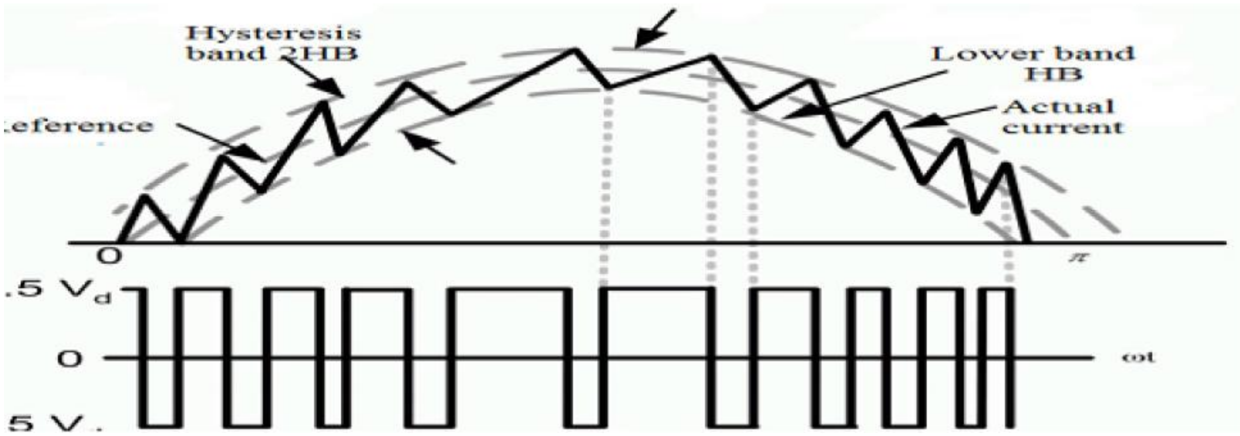


Figure 3: Hysteresis Current Modulation



on. As a result, the current starts to decay. If the current crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. Hence, the actual current is forced to track the reference current within the hysteresis band. The choice of the current band depends on the value of compensation current and the interfacing inductance.

SIMULATION RESULTS

The dynamic Performance of Wind Turbine Using SCIG with Direct Grid Connection is analysed and simulated with and without STATCOM under various conditions.

Case 1: Grid Connected Wind Farm with Out STATCOM

During System Start-Up when the wind speed reaches cut-in speed level, the blades are

Figure 4: Simulation Diagram of 3 ph Separately Excited Induction Generator Feeding Non-linear Load with Out STATCOM

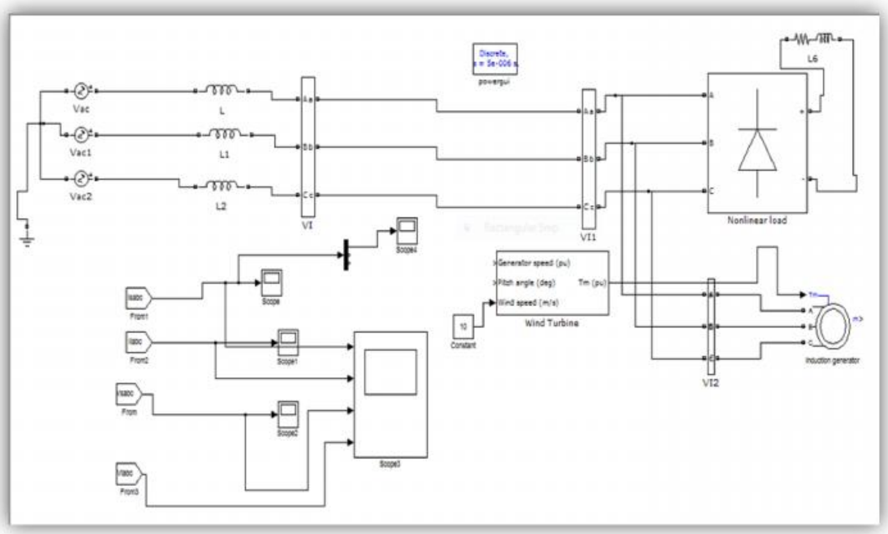


Figure 5: Instantaneous Grid Voltage and Current for Grid Connected System with Non-linear Load

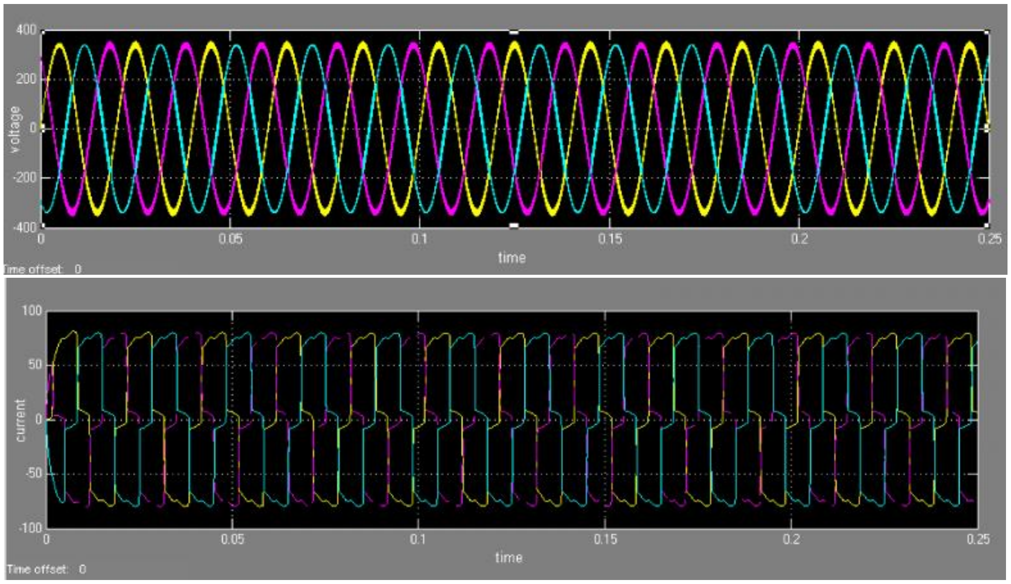


Figure 6: 3 ph Separately Exited Induction Generator Feeding Non-linear Load Without STATCOM

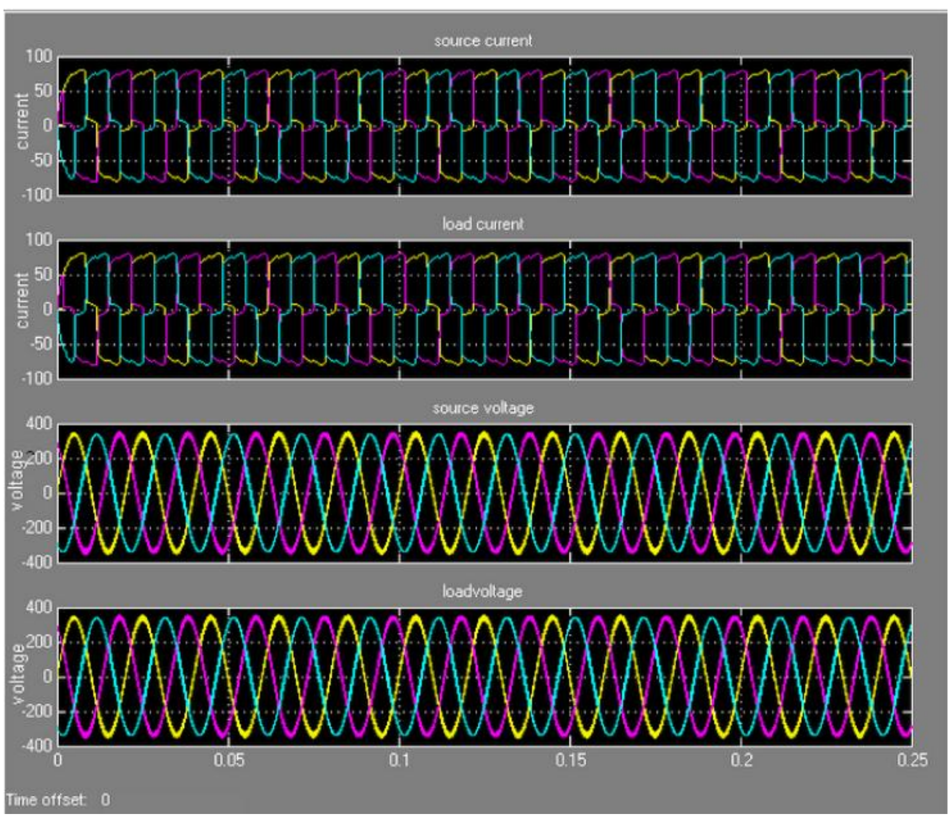
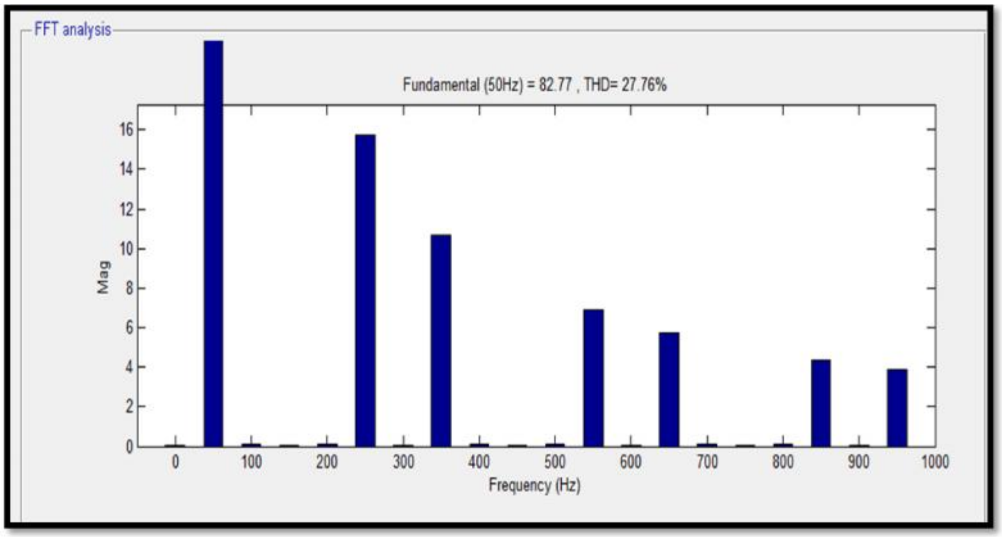


Figure 7: THD Analysis of Source Current Without STATCOM



pitched into the wind slightly, and wind turbine starts to rotate slowly. When the generator is accelerated to the synchronous speed, 1200 rpm 1 pu, the circuit breaker is closed and the generator is directly connected to the grid. The simulated diagram and waveforms for the generator are shown in Figures 4-7, where the system is simulated at the rated wind speed for the turbine which is 9 m/s.

Case 2: Grid Connected Wind Farm with STATCOM

The Simulation results shows the grid voltage and current are in-phase, making the power factor unity, which implies that the reactive power demand of Induction generator and load is no longer, fed by the grid rather it is supplied by the STATCOM as in Figures 8-9. Also the shape of the grid current is almost sinusoidal

Figure 8: Simulation Diagram of 3 ph Separately Excited Induction Generator Feeding Non-linear Load with STATCOM

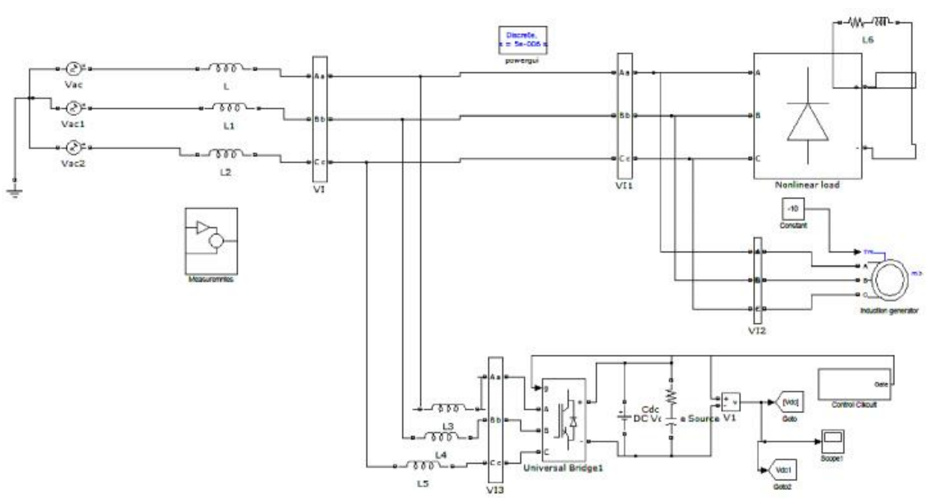


Figure 9: Source Current, Load Current, Source Voltage Waveforms with STATCOM

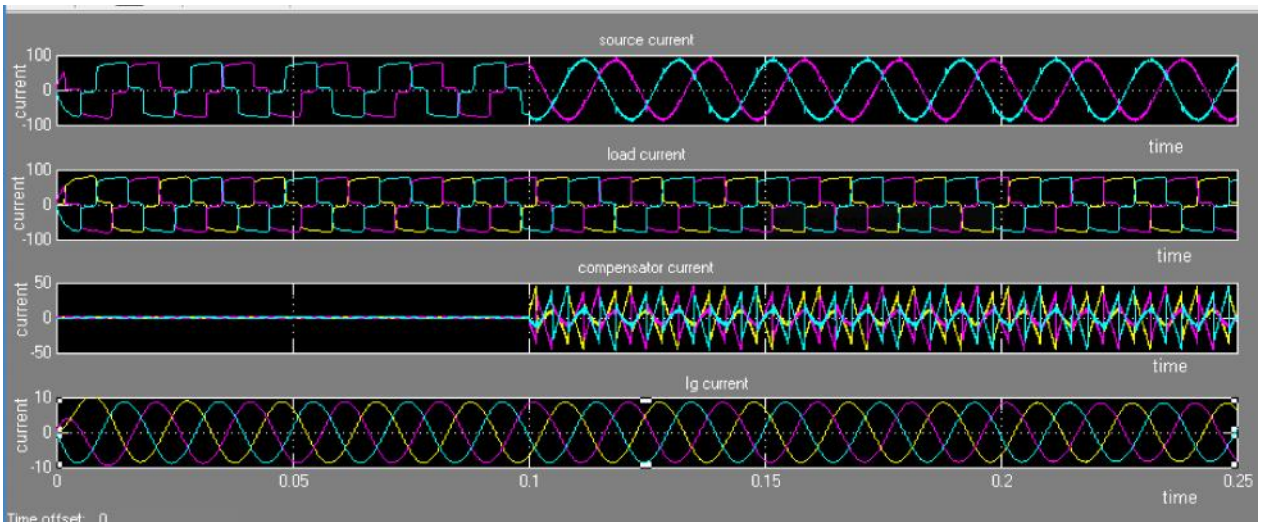


Figure 10: STATCOM Compensator Output Current

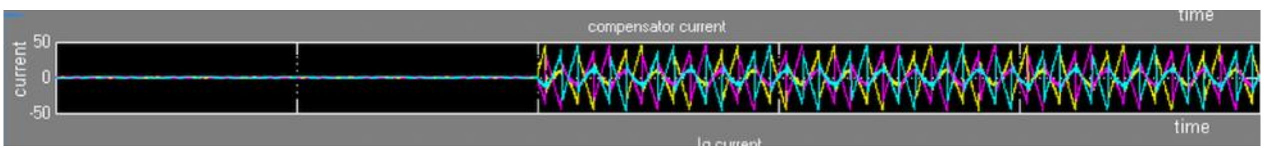


Figure 11: Source Current with STATCOM

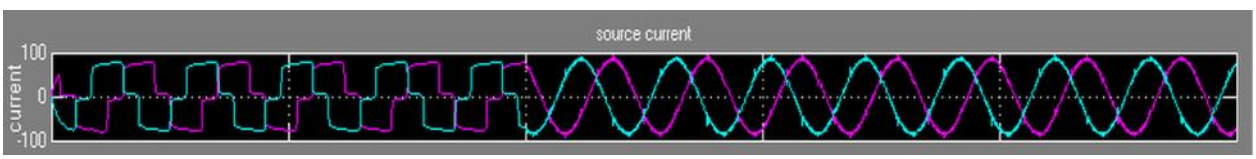


Figure 12: Power Factor of Grid with STATCOM

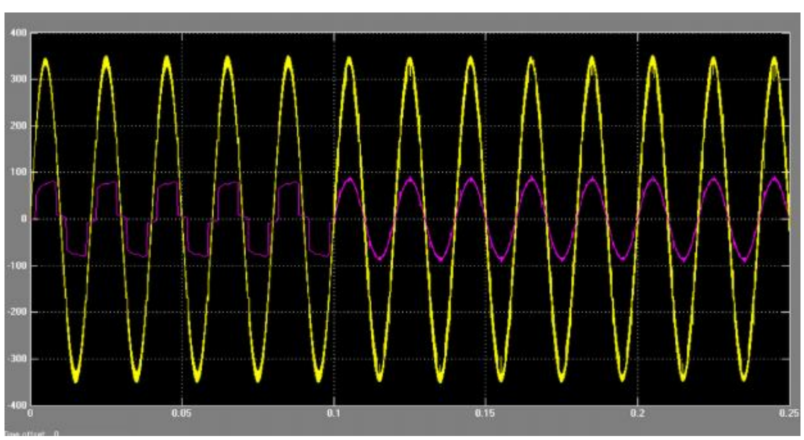
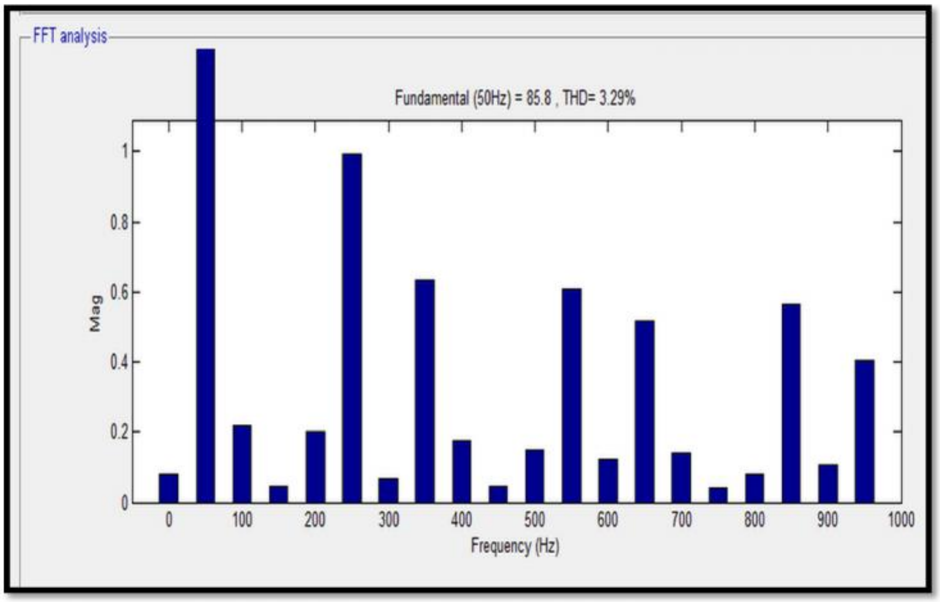


Figure 13: THD Analysis of Source Current (THD = 3.79%)



and the % THD has been improved from 27.76% to 3.79% after compensation. The proposed control scheme has improved the power quality requirement of a low voltage grid connected wind driven IG system feeding a non-linear load.

A STATCOM injects the compensation current which is a sum of reactive component current of IG, non-linear load and harmonic component current of non-linear load. Before compensation the reactive power required by induction generator is supplied by grid so the grid voltage and current are not in phase so power factor is not unity by connecting STATCOM after 0.1 sec the grid voltage and current are in phase and power factor become unity and grid current get sinusoidal Figures 10-13.

CONCLUSION

The STATCOM-based control scheme for reactive power compensation and harmonic reduction in grid connected wind farm feeding non linear load to provide efficient control is presented in this paper. Simulation studies have shown that the dynamic performance of wind farms in a power grid and additional voltage/var support provided by an external device such as a STATCOM can significantly improve the wind turbines fault recovery by more quickly restoring voltage characteristics.

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