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Power Quality and Stability Improvement in Wind Park System Using STATCOM

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Abstract

Operation of wind turbines has an impact on the power quality and reliability at the connected electric network. Power quality problems such as voltage flicker and harmonic distortion along with reliability issues are some major concern and in this work the flicker & harmonics issues are considered. Wind turbine connected to an induction generator and synchronous generator is modeled using PSCAD to analyze power quality and reliability problems. STATCOM unit is developed to inject reactive power to mitigate power quality problems and to get stable grid operation. Due to continuously varying wind speed components, the active and reactive power along with terminal voltage fluctuates continuously. By connecting STATCOM into the grid, the active power, reactive power and terminal voltage is maintained constant. The wind electric generators have power electronic converters which are used to sweep maximum power at the available speed and for efficient control introduce harmonics. The STATCOM modified as shunt active filter which is used for mitigating harmonics provides good results

Keywords: Wind Energy; Simulation; Modelling; Power Quality; STATCOM

1. Introduction

In recent years wind power generation has experienced a very fast development in the whole world. As the wind power penetration into the grid **is** increasing quickly, the influence of wind turbines on the power quality is becoming an important issue. One of the important power quality aspects is flicker [1-2]. Flicker is induced by voltage fluctuations, which are caused by load flow changes in the grid. Grid connected wind turbines may have considerable fluctuations in output power, which depend on the wind power generation technology applied [3-4].

The flicker emission produced by grid connected wind turbines during continuous operation is mainly caused by fluctuations in the output power due to wind speed variations, the wind gradient and the tower shadow effect [5]. Regarding to variable speed wind turbines, which have the ability to reduce power fluctuations, flicker emission is quite different from that generated by fixed speed wind turbines. Variable speed operation of the rotor has the advantage that the faster power variations are not transmitted to the grid but are smoothed by the flywheel action of the rotor. Variable speed wind turbines fed induction generators and synchronous generators, the most popular installed variable speed wind turbines worldwide, are the main research interest here [6]. Even' though variable speed wind turbines have good performance with respect to flicker emission, flicker mitigation becomes necessary as the wind power penetration level increases. Flicker mitigation can be realized by appropriate reactive shunt compensation [7].

The most commonly used device for flicker mitigation is the Static Var Compensator (SVC). However, the STATCOM has received much more attention recently. Compared with the SVC, the STATCOM has many advantages, such as overall superior functional characteristics, better performance, faster response, smaller size, cost reduction, and capable of providing both active and reactive power [8-10]. The STATCOM, consisting of a voltage source converter, uses advanced power switches to provide fast response and flexible voltage control for power quality improvement, which is suitable to application with rapidly fluctuating loads. Using high frequency PWM, the converter will create smooth current with low harmonic content.

In this paper, a wind turbine fed induction generator and synchronous generator is modeled using PSCAD and flicker emission of grid connected wind turbines fed induction generators is investigated during continuous operation. The factors that affect flicker emission of wind turbines, such as wind speed, turbulence intensity, short circuit capacity and grid impedance angle, are analyzed [11]. Simulation results prove that STATCOM is an effective means to mitigate the flicker level during continuous operation of grid connected wind turbines. Also the converters, which are used to extract maximum power at the available speed, are connected between the induction generator and grid. Harmonics due to the non-linear load (converters) are compensated by designing STATCOM as a shunt active filter [12]

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2. Power Quality Issues

When a non-linear load or distorting load is connected to the power system fundamental sinusoidal waveform of current flowing through system will change. This will rise non-sinusoidal voltage drop across various network element connected to the system resulting in distorted waveform propagation through out the system to buses remote from the original source. Although the main issues of power quality are common to distribution networks, whether active or passive the addition of wind generation can have a significant impact on power quality. For wind turbine fed induction generator designs, which use power electronics converters, the issues of harmonic distortion of the network voltage must be carefully considered while the connection of fixed-speed turbines to the network needs to be managed carefully if excessive transients are to be avoided.

During normal operation wind turbines produce a continuously variable output power. The power variations are mainly caused by the effects of turbulence in the wind and tower shadow. These effects lead to periodic power pulsations at the frequency at which the blades pass the tower ,which are superimposed on the slower variations caused by meteorological changes in wind speed. There may also be higher frequency power variations (at a few Hz) caused by the dynamics of the turbine. Variable-speed operation of the rotor has the advantage that many of the faster power variations are not transmitted to the network but are smoothed by the flywheel action of the rotor. However, fixed speed operation using a low-slip induction generator, will lead to cyclic variations in output power and hence network voltage. A voltage dip is a sudden reduction in the network voltage to a value between 100 per cent and 0 per cent followed by a voltage recovery after a short period of time, conventionally 1ms to 1 min. Dips between 10 per cent and 15 per cent of the terminal voltage are commonly due to switching of loads, whereas larger dips may be caused by faults.

2.1 Voltage flicker

Voltage flicker describes dynamic variations in the network voltage. Traditionally it was of concern when the connection of large fluctuating loads (e.g. arc furnaces, rock crushing machinery sawmills, etc.) was under consideration. However, it is of considerable significance for wind farms, which: (i) often use relatively large individual items of plant compared to load equipment; (ii) may start and stop frequently; (iii) may be subject to continuous variations in input power. Flicker produced during continuous operation is caused by power fluctuations, which mainly emanate from variations in the wind speed, the tower shadow effect and mechanical properties of the wind turbine. Flicker due to switching operations arises from the start and shut down of the wind turbines.

2.2 Harmonics

A wind turbine with an induction generator directly connected to the grid without an intervening power electronic converter is not expected to distort the voltage waveform. Power electronics applied for soft start may generate short-duration high-order current harmonics but their duration and magnitude are usually small. Hence for a system with fixed-speed wind turbines emission limits for harmonics are not a constraint. However, variable-speed wind turbines using power electronic converters should be assessed against given or calculated limits for harmonics. New wind turbine designs use transistor-based converters, which are operated at switching frequencies above 3 kHz and their impact on the voltage waveform is usually negligible. However, connection of electric equipment does in general change the harmonic impedance of the network. For example, capacitor banks employed in fixed-speed wind turbines may shift the resonant frequency of the harmonic impedance. Therefore, possible harmonic sources already present in the network may cause unacceptable harmonic voltages. Consequently, for networks with significant harmonic sources, connection of wind turbines with suitable filter should be carefully designed to avoid an ill-conditioned modification of the harmonic impedance..

3. Power Quality Improvement

The FACTS device are based on power electronic controllers that enhances the capacity of the transmission line .These controllers are fast and increases the stability operating limits of the transmission systems when their controllers are properly tuned. FACTS devices are mostly used to regulate voltage and schedule power flow through some lines. FACTS device has the potential to operate the more flexible and economic way.

STATCOM is a voltage source inverter which means a DC capacitor voltage source regularly switched by gate turn off thyristor to generate alternating voltage and by surrounding the capacitor with four GTOs, each with a reverse diode, its voltage can be switched in the positive or negative direction. By connecting six or seven of these in series and switching them at different times with in each 50 Hz cycle an accurate sine wave is developed. If the developed voltage is higher than system voltage the STATCOM will supply reactive power like a rotating synchronous compensator and improve the voltage and conversely if lower it will remove reactive power. STATCOM has potential to maintain its reactive current at low voltage since it has an essentially constant current characteristics while a thyristor SVC is constant impedance.

Reduced land use to about 40% of a thyristor SVC requirement gives the potential for limited storage, if batteries replace capacitor

Be applied as an active filter because each step can be switched in response to a harmonics

A STATCOM can provide fast capacitive and inductive compensation and is able to control its output current independently of the AC system voltage.

There are mainly two approaches to mitigate power quality problems. The first approach is load conditioning, which ensures that equipment is made less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning system that suppresses the power disturbances.

3.1 Mitigation of Flicker

The most basic configuration of the STATCOM consists of a two-level VSC with a DC energy storage device; a coupling transformer connected in shunt with the AC system, and associated control circuits. It is possible to change the reactive power flow on the connection line by using reactive shunt compensators, such as STATCOM, to mitigate the flicker level during continuous operation of grid connected wind turbines. Figure. 1 shows the block diagram of STATCOM based wind generator.

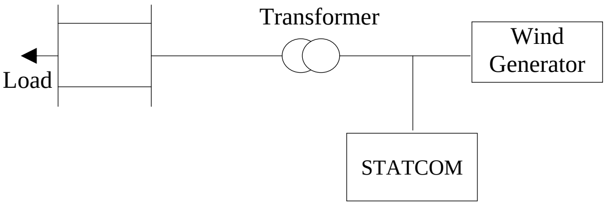

Figure. 1 Voltage Fluctuation Mitigation with STATCOM

The STATCOM consists of a controllable PWM voltage source converter. The voltage source converter is preferred to the current source converter because the devices are clamped against over-voltages by the voltage across the DC-link capacitor bank. The losses are lower and the devices do not have to able to withstand a large reverse voltage.

3.2 Harmonics mitigation

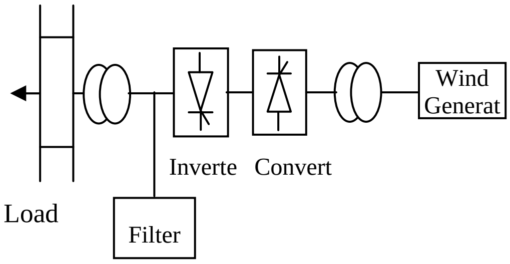

Figure. 2 Harmonics mitigation with shunt active filter

Among the different technology available active filters prove to be flexible to compensate current harmonic components compared to passive filters whose performance is limited to few harmonics and they can also introduce resonance in power system. Figure. 2 shows the active shunt filter system which is used to mitigate harmonics. Harmonics, one of the most important power quality problems results from the basic operating principle of converters in the wind energy generator-grid can be reduced by appropriately designing a shunt active filter. The shunt active filter has topology similar to that of STATCOM. Shunt active filter compensates current harmonics by injecting equal and opposite harmonic current acting as current source injecting harmonic current by the load but phase shifted by 180^0

4.Modeling and Simulation of Wind Power System

4.1 Induction generator

In this study, wind induction generator is modeled using PSCAD as shown in Figure. 3 and case studies are carried out in regarding to power quality and stability using STATCOM

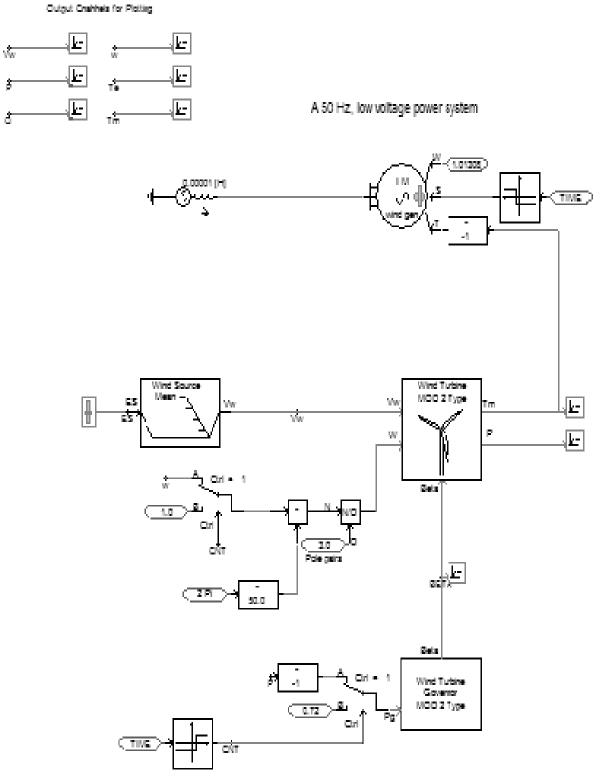

Figure. 3 modeling of wind induction generator

Case A: In this case wind induction generator connected to a grid is modeled. The results indicates the active power, reactive power and the terminal voltage varies continuously due to varying wind speed and the synchronization problem associated with wind generator connected to a grid.

Case B: In this case, wind induction generator connected to a grid with STATCOM is modeled. The results indicates the active power, reactive power and the terminal voltage variations are regulated by means of STATCOM which injects reactive power to regulate the system under study as shown in Figure. 5

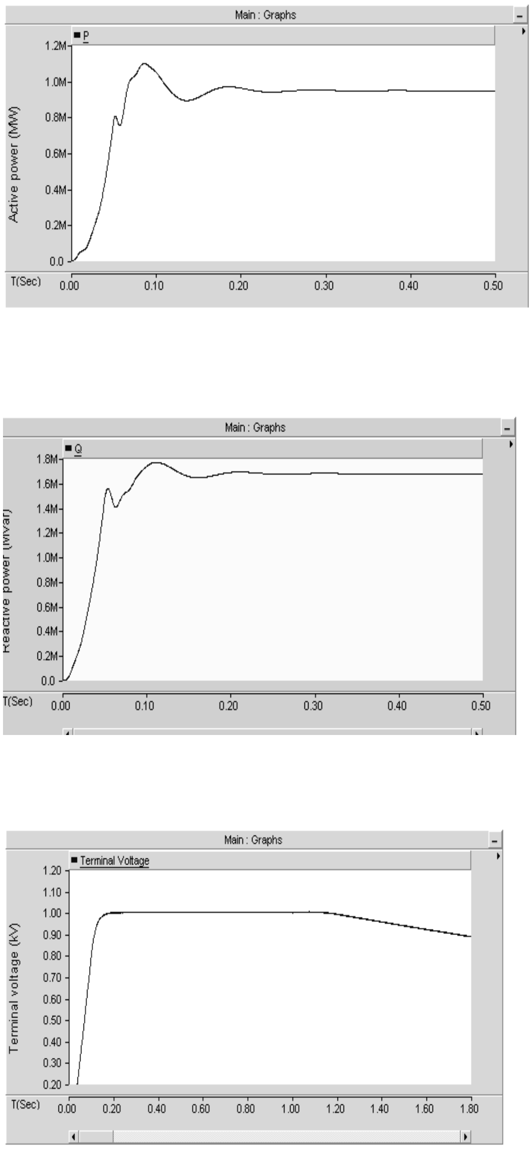

Figure. 4 Variation of Active power, Reactive power and terminal voltage of a induction generator connected to a grid

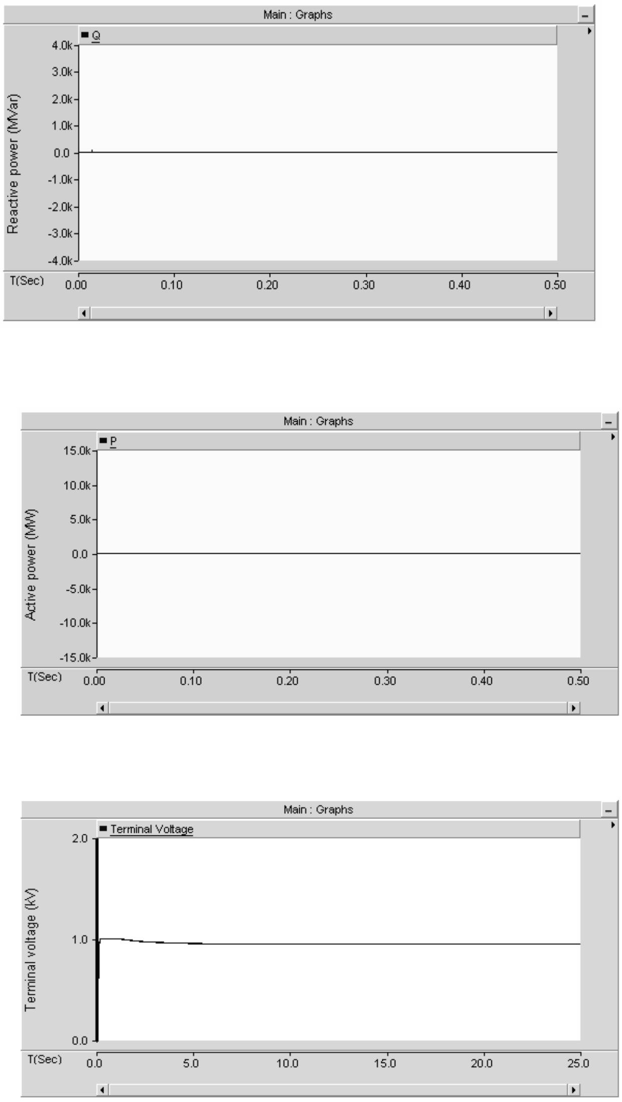

Figure 5 Variation of active & reactive power and terminal voltage of an induction generator connected to a grid with STATCOM.

Case C: In this case the induction generator driven by a wind turbine connected to a grid with converters is modeled. The main use of converters is to sweep maximum power at the available speed but such converters acting as a non-linear load will result in harmonics. The effect of harmonics is studied with and without active filter which is shown in Figure. 6. The current harmonics spectrum analyzed on both source side and load side due to the non-liner converters without filter is given in Figure. 7.

Case D: In this case, the induction generator driven by a wind turbine connected to a grid with converters and filters is modeled. The filter connected to the grid side will reduce the harmonics as shown in Figure. 8. shows the active shunt filter modeled using PSCAD and current harmonics spectrum with filter is shown in Figure. 8.

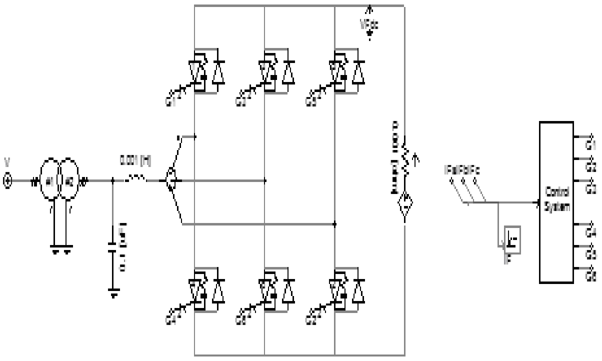

Figure. 6 STATCOM as a shunt active filter

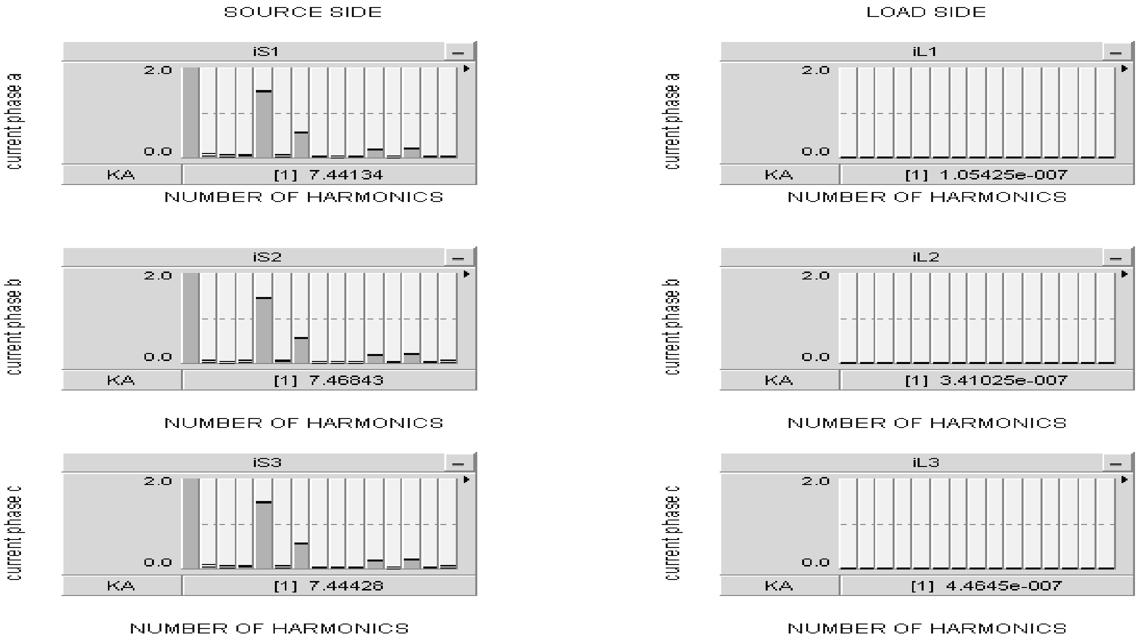

Figure. 7 Current harmonics spectrum without filter

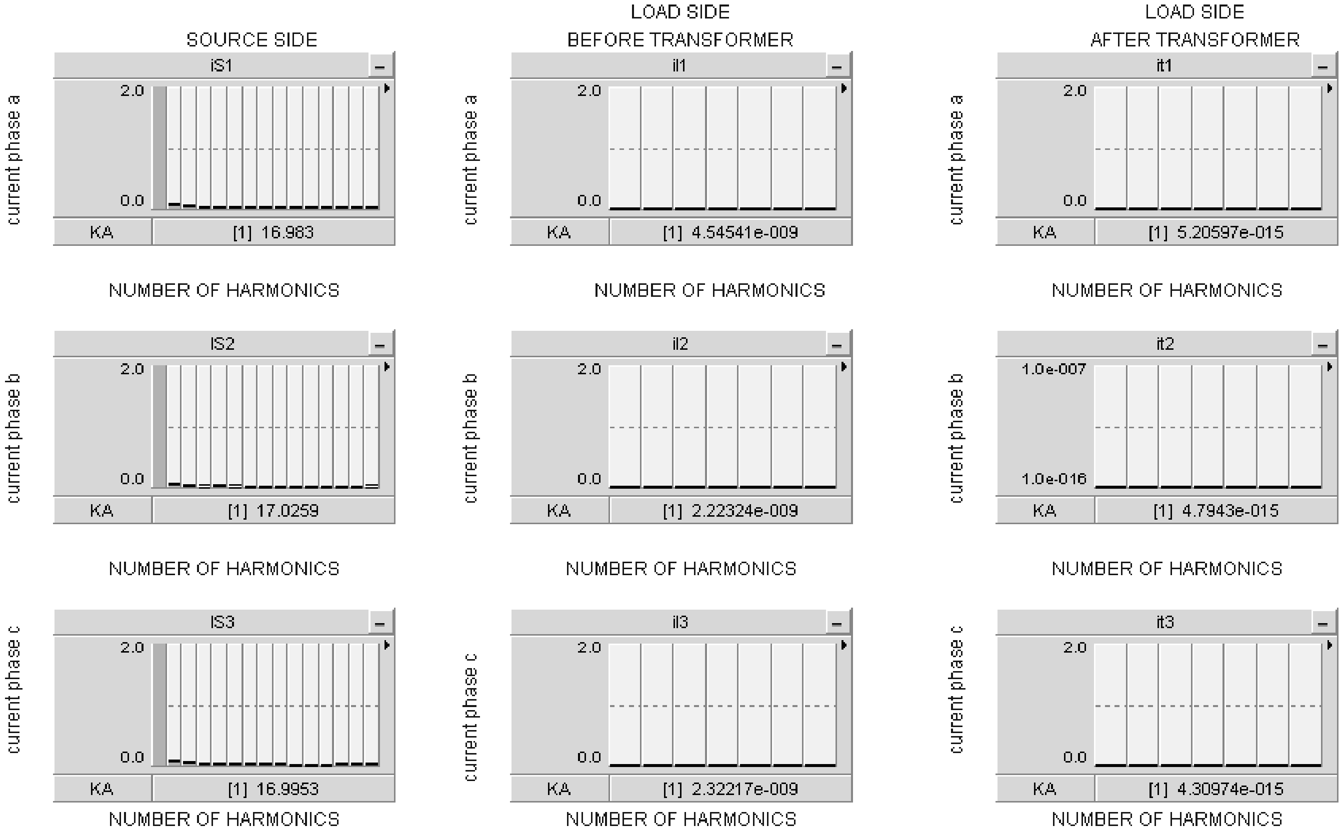

Figure. 8 Current harmonic spectrum with filter

5.2 Synchronous generator

Synchronous generator based wind turbine which is more advantageous than induction generator, supplies reactive power and the maintenance is high. In this study wind synchronous generator is modeled using PSCAD and case studies have been carried out in regard to power quality and stability

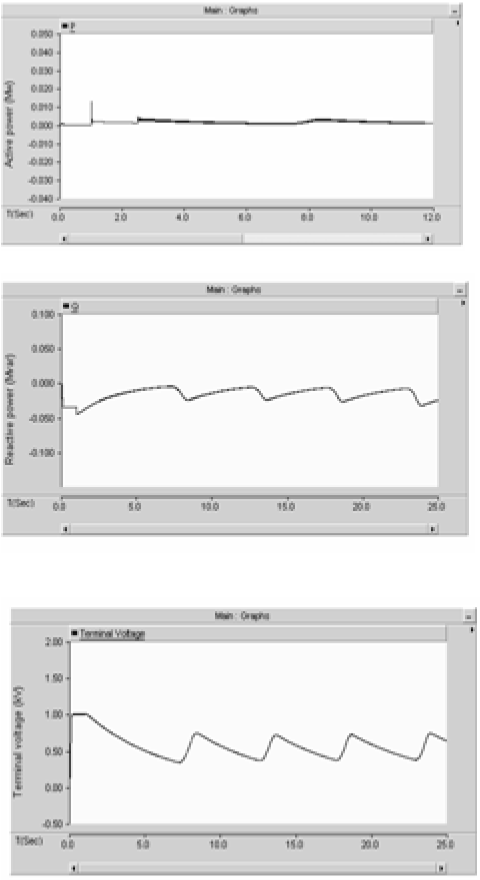

Figure. 9 Variation of active power, reactive power and terminal voltage of a wind synchronous generator connected to a grid

Case A: In this case wind synchronous generator connected to a grid without STATCOM is modeled. Results indicates the active power, reactive power and the terminal voltage varies continuously due to varying wind speed and the synchronization problem associated with wind generator connected to a grid as shown in Figure. 9.

Case B: In this case wind synchronous generator Connected to a grid with STATCOM is modeled. Here the STATCOM is connected to compensate the voltage fluctuation and maintain the voltage with in limits. The results indicates the active power, reactive power and the terminal voltage variations are regulated by means of STATCOM which injects reactive power to regulate the system under study as shown in Figure. 10

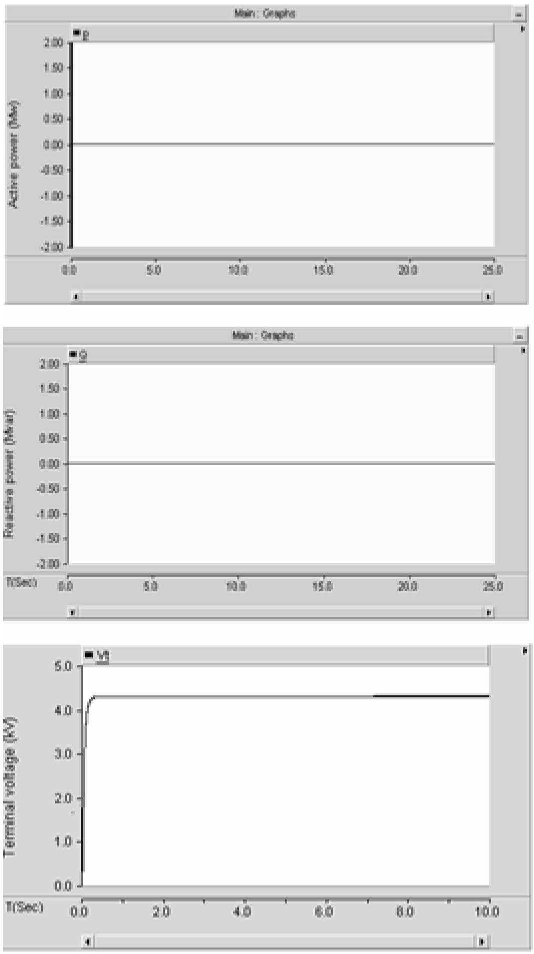

Figure. 10 Variation of active power, reactive power and terminal voltage of a wind synchronous generator connected to a grid with STATCOM

Case C: In this case the synchronous generator driven by a wind turbine connected to a grid with converters is modeled. The converters used to seep maximum power act as non-linear load. Figure. 11 shows the current harmonics spectrum on both source side and load side due to the non-liner converters. High amount of harmonics are measured due to power electronic converters

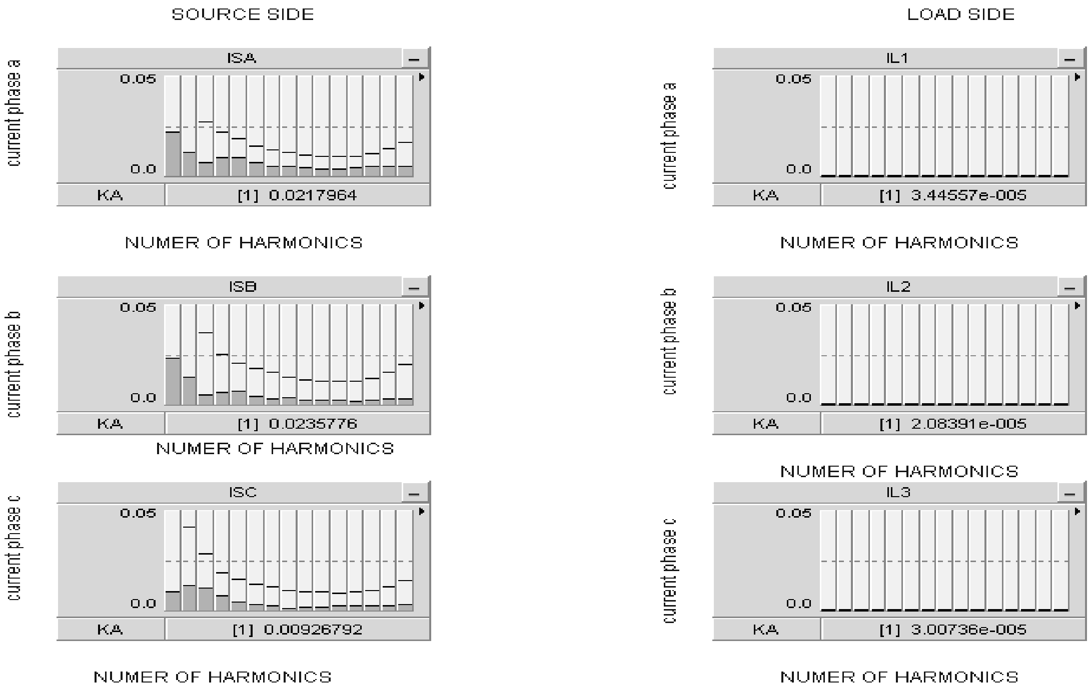

Figure. 11 Current harmonics spectrum without filter

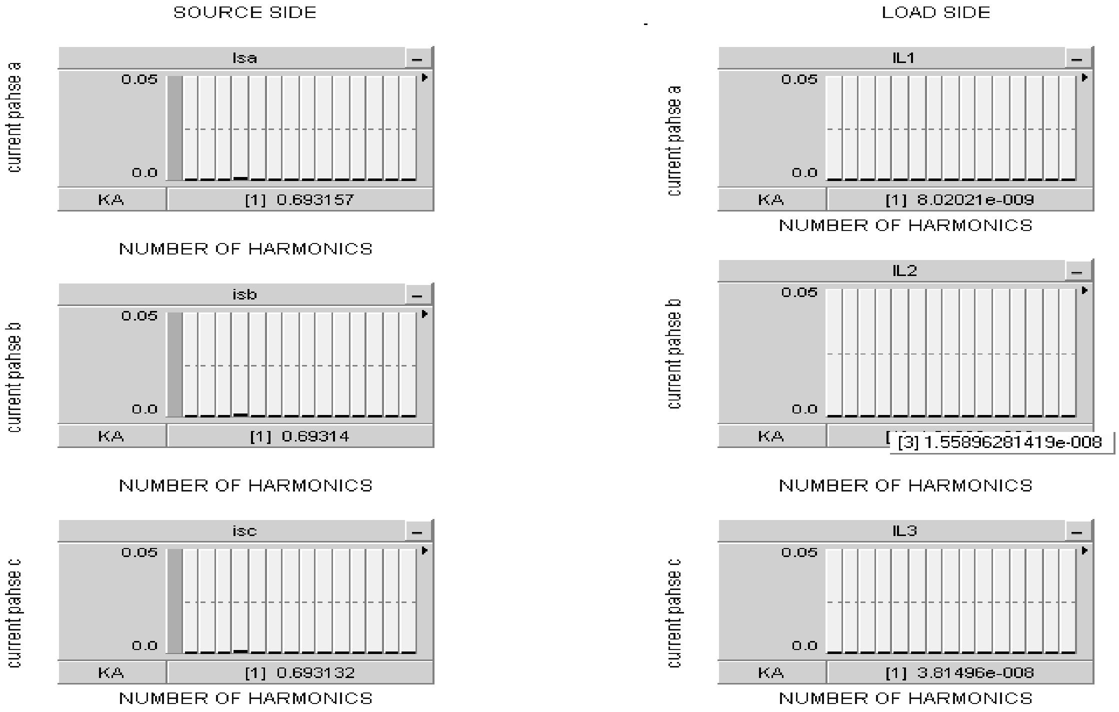

Figure. 12 Current harmonic spectrum with filter

Case D: In this case, the synchronous generator driven by a wind turbine connected to a grid with converters and shunt active filter are modeled. The filter connected to the grid side is reducing the harmonics. It is clearly reflected in the current harmonics spectrum shown in Figure. 12

5. Conclusions

In this work, power quality issues such as voltage fluctuation, harmonics are analyzed with respect to wind generator connected to a grid. The modeling and simulation techniques of a wind power converter and connected power system had been analyzed using PSCAD.

From this analysis, it was found that voltage fluctuation occurs frequently due to synchronization problem associated with connection of wind generator to grid. Hence STATCOM was used to inject reactive power to maintain voltage level with in limits and also eliminates power fluctuations and this confirms the excellent performance of the proposed system for power quality improvement. It was proved that the STATCOM modified as a shunt active filter can be used to eliminate the harmonics generated by the power converters.

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References

[1] C.Carrillo, A.E.Feijoo & J.Cidras, Power fluctuations in an isolated wind plant, IEEE Trans. on Energy Conversions, Vol. 19, No. 1, 2004, 217-221.

[2] Z. Chen & E. Spooner, Grid interface for renewable energy sources, Proc. 2nd International conf. on Power Electronics and Motion Control Conference(IPEMC’97), Hangzhou, China, 1997, 256–261.

[3] M. P. Papadopoulos, Investigation of the flicker emission by grid connected wind turbines, Proc. 8th International conf. on Harmonics & Quality Power, Athens, Greece, 1998, 14–16.

[4] Neris, N. Vovos, & G. Giannakopaulos, A variable speed wind energy conversion scheme for connection to weak ac systems, IEEE Trans. Energy Conversions, Vol. 14, No. 1, 1999, 122–127.

[5] Z. Chen & E Spooner, Grid power quality with variable speed wind turbines, IEEE Trans. Energy Conversions, Vol. 16, No. 2, 2001, 148–153.

[6] M.Davidson, Interaction of a wind farm with the distribution network and its effect on voltage quality, Proc. IEE Colloquium on the impact of Embedded Generation on Distribution Networks (Digest 1996/194), 1996, 9/1–9/5.

[7] S.K.Salman, & A.L.J.Teo, Windmill modelling consideration and factors influencing the stability of a grid-connected wind power based embedded generator, IEEE Trans. Power Systems, Vol. 18, No. 2, 2003, 793–802.

[8] A.Arulampalam, M.Barnes & N.Jenkins, Power quality and stability improvement of a wind farm using STATCOM, Proc. IEE Generation, Transmission & Distribution, Vol. 153, No.6, 2006, 701-710.

[9] Z.Saad-Saoud, M.L.Lisboa, J.B.Ekanayake, N. Jenkins & G.Strbac, Application of STATCOMs to wind farms, Proc. IEE Generation, Transmission & Distribution, Vol.145, No. 5, 1998, 511–516.

[10] A.Arulampalam, J.B.Ekanayake & N.Jenkins, Application study of a STATCOM with energy storage, Proc. IEE Generation, Transmission & Distribution, Vol. 150, No. 3, 2003, 373–384.

[11] Z. Chen & S.B. Tennakoon, Harmonic filter considerations for voltage source inverter based advanced static Var compensator, Proc. International Universities Power Engineering Conference (UPEC’92), Bath, UK, 1992, 640–643.

[12] Z. Chen & E. Spooner, Wind turbine power converters: comparative study, Proc. IEE Conf. on Power Electronics and Variable Speed Drives (PEVD’98), London, UK, 1998, 471–476.