

Reactive Power Compensators for Maintaining Voltage Stability of the Wind Farm Using STATCOM in the presence Nonlinear Load

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Abstract

In modern power system the non-renewable sources of energy are being replaced by renewable sources of energy such as wind, solar and hydro due to their advantage of pollution free and clean environment. But with the use of renewable sources of energy, the power system undergoes many problems, one of which is the voltage stability problem arising during grid integration. This problem can be overcome by using FACT devices such as STATCOM. This paper analyses the role of STATCOM in improving the voltage stability DFIG based wind farms located at different places which are connected to the grid. The STATCOM compensates the reactive power at the point of common coupling and thus improves the voltage and protects the system during grid faults. MATLAB/SIMULINK is used for simulating the developed system and results show that STATCOM improves the voltage and maintains the uninterrupted operation of the grid during grid fault.

Keywords: Wind Energy System, STATCOM, Harmonic Analysis, Nonlinear Load.

Introduction:

Inherent characteristics of renewable energy resources cause technical issues not encountered with conventional thermal, hydro or nuclear power. These issues make operation of the renewable energy resources and their integration with the grid system a technical challenge. The rapid development of the renewable energy power industry, together with the rising challenges, has drawn many of the world's leading professional associations and organizations into this fast growing field. Among all the rising

challenges, one important issue is how to integrate renewable energy sources with the grid through power electronic converters as well as associated control system design. Although traditional approaches have been developed for power converter control of renewable energy systems, there is a critical need to develop new and improved power converter control technologies for many reasons such as:

- The existing power converter control technologies in grid integrated renewable energy generation systems do not perform well in some cases.
- Unbalance and high harmonic distortion have been found in renewable energy conversion systems, which not only affect the grid system but also affect the renewable energy sources.
- The existing power converter control mechanism has an inherent deficiency, which can cause malfunctions of the system, such as abnormal DC capacitor voltage, active and reactive power, or output currents. These malfunctions may make the grid integration of the renewable energy sources unstable and may even cause power system trips [Sediki, Abdeslam, Otmame-cherif, Bechouche and Mesbah, 2012],[Zhang, Handschin and Yaoc ,2004].

This paper investigates the effectiveness of STATCOM, in increasing the system stability during fault condition and reducing Total Harmonic Distortion (THD). STATCOM is tested in a Distributed Generation system consisting of a grid interconnected wind farm.

Doubly fed induction generator (DFIG)

DFIG is an abbreviation for Doubly Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. A doubly fed induction machine is a wound-rotor doubly-fed electric machine and has several advantages over a conventional induction machine in wind power applications [Choudhury, Mohanty and Babu,2011],[Baijie, Qin, Tie-jiang and Hai-dong,2012]:

- First, as the rotor circuit is controlled by a power electronics converter, the induction generator is able to both import and export reactive power. This has important consequences for power system stability and allows the machine to support the grid during severe voltage disturbances (low voltage ride through, LVRT).
- Second, the control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine, especially during light wind conditions.
- Third, the cost of the converter is low when compared with other variable speed solutions because only a fraction of the mechanical power, typically 25-30 %, is fed to the grid through the converter, the rest being fed to grid directly from the stator. The efficiency of the DFIG is very good for the same reason.

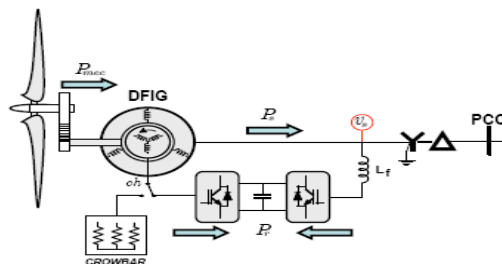


Figure 1- wind turbine and the doubly-fed induction generator

DFIG Construction and Working Principle

The principle of the DFIG in figure 1 is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed. The control principle used is either the two-axis current vector control or direct power control (DPC). DPC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator.

The doubly-fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher and currents respectively lower. Thus in the typical $\pm 30\%$ operational speed range around the synchronous speed, the rated current of the converter is accordingly lower which leads to a lower cost of the converter. The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage. Further, the voltage transients due to the grid disturbances (three- and two-phase voltage dips, especially) will also be magnified. In order to prevent high rotor voltages and high currents resulting from these voltages from destroying the IGBTs and diodes of the converter, a protection circuit (called crowbar) is used.

The crowbar in figure 1 will short-circuit the rotor windings through a small resistance when excessive currents or voltages are detected. In order to be able to continue the operation as quickly as possible an active crowbar has to be used. The active crowbar can remove the rotor short in a controlled way and thus the rotor side converter can be started only after 20-60 ms from the start of the grid disturbance. Thus, it is possible to generate reactive current to the grid during the rest of the voltage dip and in this way, it helps the grid to recover from the fault.

Power flow in DFIG

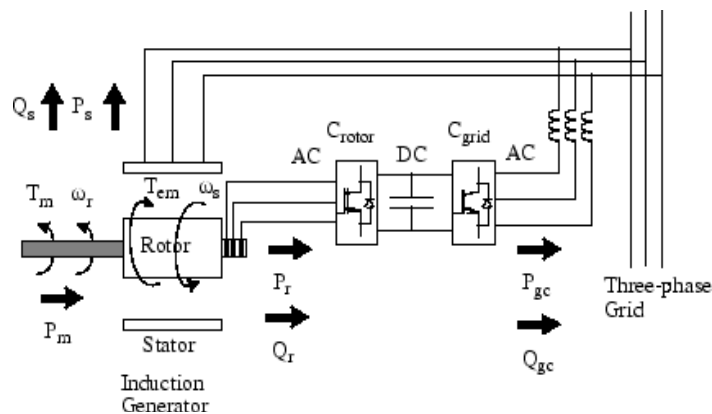


Figure 2- Power flow in DFIG

P_m	Mechanical power captured by the wind turbine and transmitted to the rotor
P_s	Stator electrical power output
P_r	Rotor electrical power output
P_{gc}	C_{grid} electrical power output
Q_s	Stator reactive power output
Q_r	Rotor reactive power output
Q_{gc}	C_{grid} reactive power output
T_m	Mechanical torque applied to rotor
T_{em}	Electromagnetic torque applied to the rotor by the generator
ω_r	Rotational speed of rotor
ω_s	Rotational speed of the magnetic flux in the air-gap of the generator, this speed is named synchronous speed. It is proportional to the frequency of the grid voltage and to the number of generator poles.
J	Combined rotor and wind turbine inertia coefficient

The mechanical power and the stator electric power output are computed as follows:

$$P_m = T_m \omega_r \quad (1)$$

$$P_s = T_{em} \omega_s \quad (2)$$

For a loss less generator the mechanical equation is:

$$J \frac{d\omega_r}{dt} = T_m - T_{em} \quad (3)$$

Generally the absolute value of slip is much lower than 1 and consequently, P_r is only a fraction of P_s . Since T_m is positive for power generation and since ω_s is positive and constant for a constant frequency grid voltage, the sign of P_r is a function of the slip sign. P_r is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super-synchronous speed operation, P_r is transmitted to DC bus capacitor and tends to raise the DC voltage. For

sub-synchronous speed operation, P_r is taken out of DC bus capacitor and tends to decrease the DC voltage. C_{grid} is used to generate or absorb the power P_{gc} in order to keep the DC voltage constant. In steady-state for a loss less AC/DC/AC converter P_{gc} is equal to P_r and the speed of the wind turbine is determined by the power P_r absorbed or generated by C_{rotor} .

The phase-sequence of the AC voltage generated by C_{rotor} is positive for sub-synchronous speed and negative for super-synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. C_{rotor} and C_{grid} have the capability of generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

Simulation of wind energy system

Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter modeled by voltage sources. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

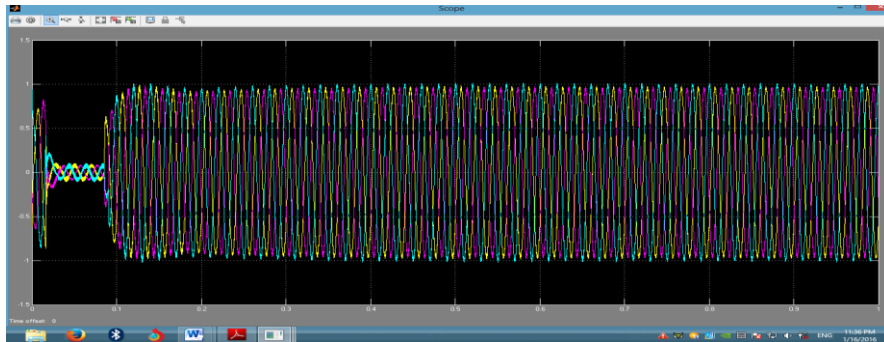


Figure 3- grid voltage

Figure 3 shows the grid voltage during normal conditions. The value of the grid voltage is maintained at 1 p.u. The initial transients in the waveform are due to the synchronization of DFIG with the Grid.

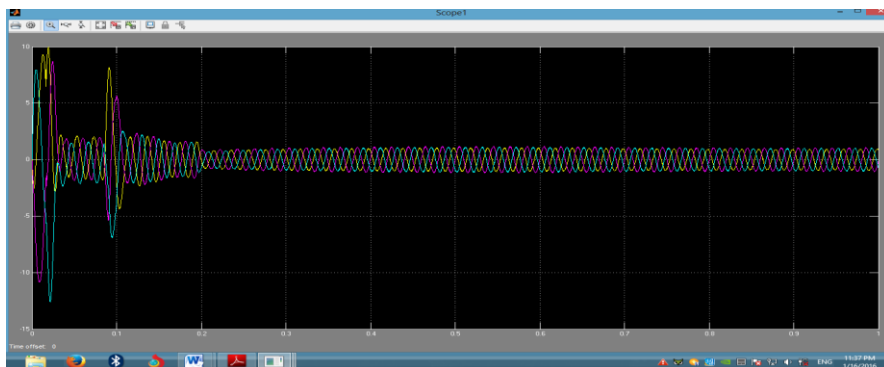


Figure 4- grid current

The figure 4 shows the grid current during the normal condition. A constant load is connected and hence the grid current is maintained a constant value.

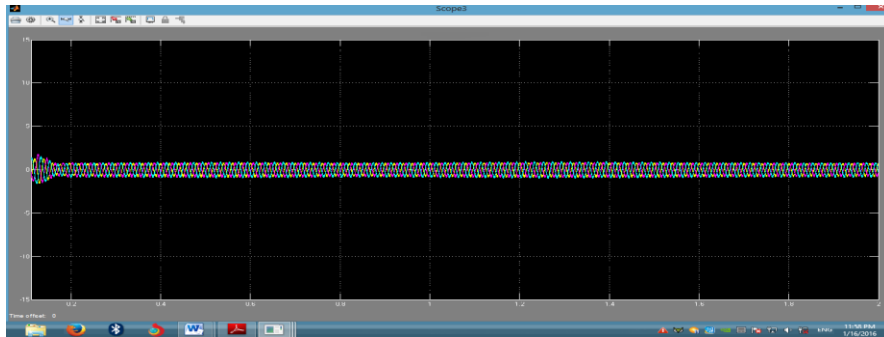


Figure 5- rotor voltages

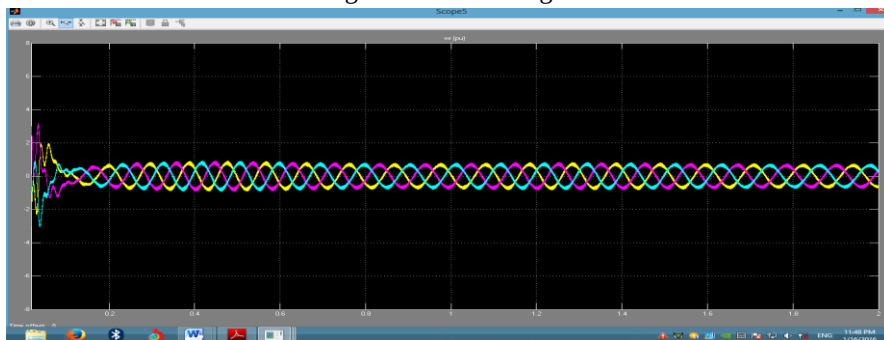


Figure 6- rotor currents

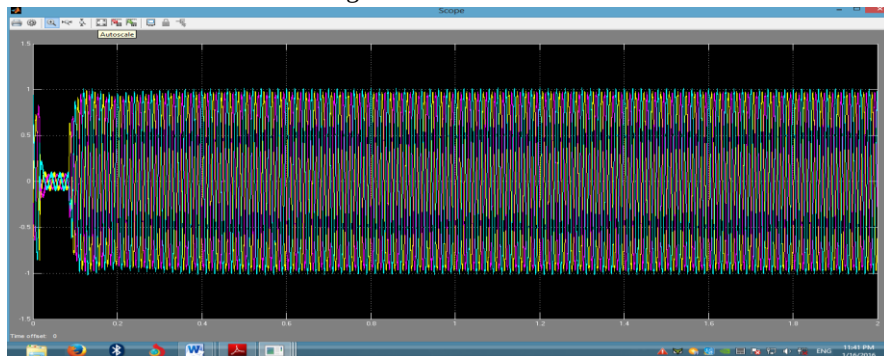


Figure 7- stator voltages

The rotor voltage, rotor current and the stator voltages of the DFIG is shown in the figure 5, 6 and 7 respectively. The wind speed is set to 5m/s initially and then increased to 14m/s at time $t=1$ second. The reactive power produced by the wind turbine is regulated at 0 Mvar as in figure 8.

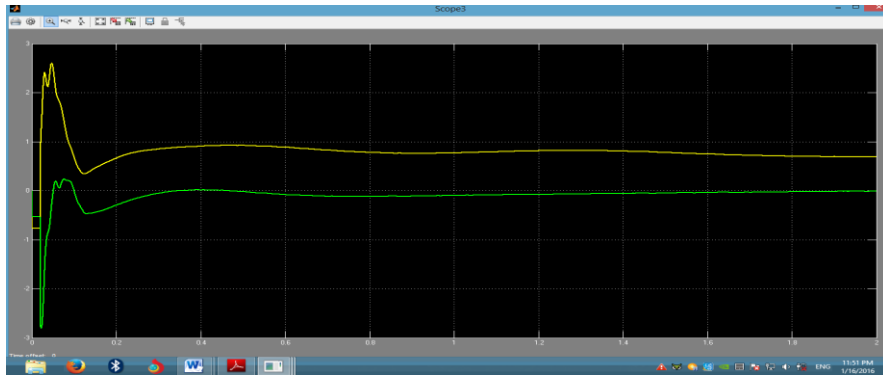


Figure 8- P, Q in pu

Harmonic Analysis of DFIG for a Wind Energy Conversion System

Doubly Fed Induction Generators (DFIGs) are widely used in wind generation. The possibility of getting a constant frequency ac output from a DFIG while driven by a variable speed prime mover improves the efficacy of energy harvest from wind. Unlike a squirrel-cage induction generator, which has its rotor short-circuited, a DFIG has its rotor terminals, which are accessible. The rotor of a DFIG is fed with a variable-frequency (ω_r) and variable-magnitude three-phase voltage. This ac voltage injected into the rotor circuit will generate a flux and a stator voltage/current with a frequency ω_r if the rotor is standing still. When the rotor is rotating at a speed ω_m , the net flux linkage and the stator voltage/current will have a frequency $\omega_s = \omega_r + \omega_m$. When the wind speed changes, the rotor speed ω_m will change, and in order to have the net flux linkage at a frequency 60 Hz, the rotor injection frequency should also be adjusted.

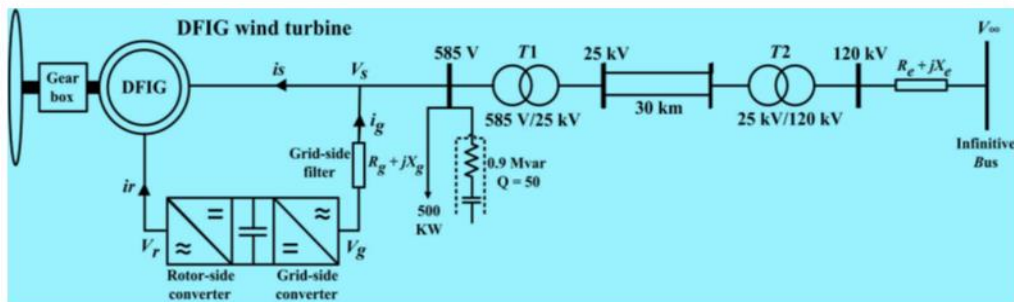


Figure 9- Basic System

The above system is considered for performing Harmonic analysis of the based STATCOM. A nonlinear load is connected in the system to create harmonic currents. The amount of harmonics injected by the load will be compensated by the STATCOM itself. The above analysis is carried out by calculating the harmonic content (THD) present in the current waveform at PCC. The THD calculation has been done by implementing the following three cases.

Case 1: Without nonlinear load.

Case 2: After connecting nonlinear load.

Case 3: After connecting STATCOM.

Case 1

The test system is modeled by connecting DFIG and Solar farm to the grid as shown in the figure 10 The current waveform at the point of common coupling without any nonlinear load is as shown in figure 10 The waveform has no harmonics.

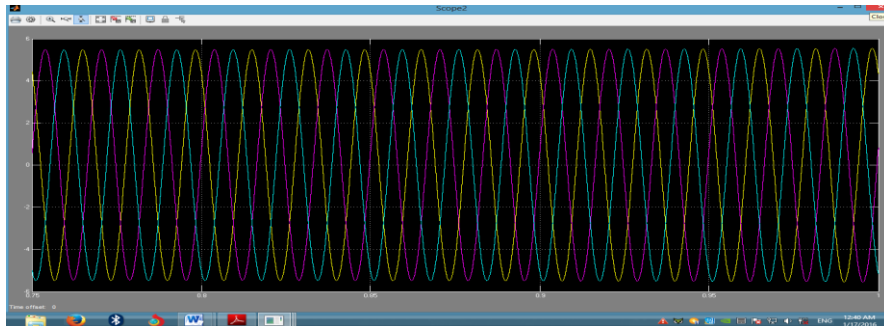


Figure 10-Current at PCC without Nonlinear Load

Case 2

A non-linear load is added to the system, and hence the current waveform at PCC is distorted due to the harmonics injected by it. The waveforms of current at PCC is as shown in the figure 11.

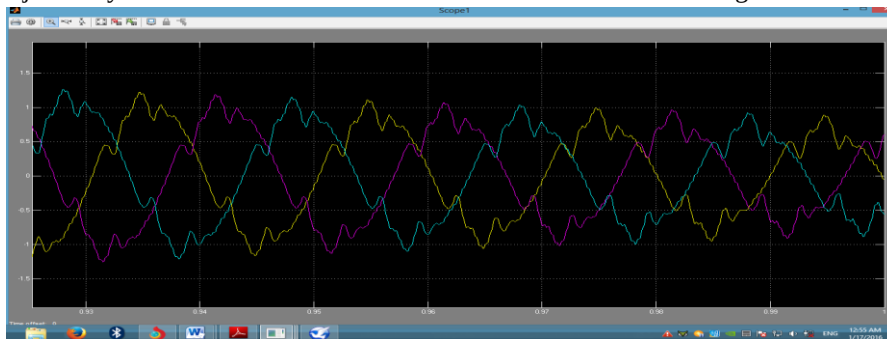


Figure 11- Current at PCC with Non-linear load

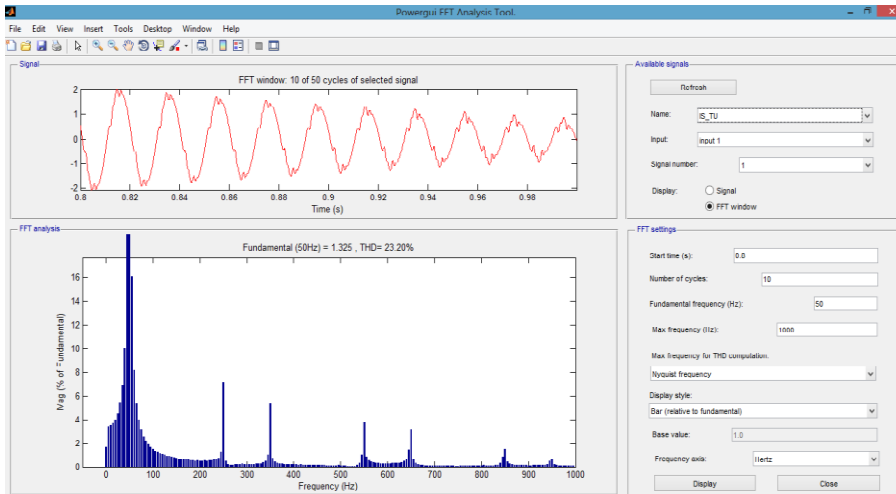


Figure 12- FFT analysis with THD 23.20%

The harmonics injected by the load is measured by the FFT analysis and the THD is found to be 23.20%

Case 3

STATCOM acts upon the system with nonlinear load. The current waveform at PCC is as shown in the figure 13. The amount of harmonic content is reduced to a great extent by the filtering action of the STATCOM.

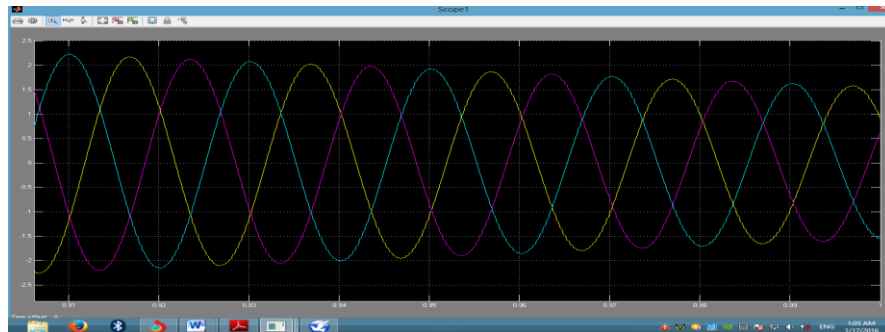


Figure 13- Current at PCC after harmonic compensation

After the compensation of the harmonics the THD in the current wave is brought to 5.41%.

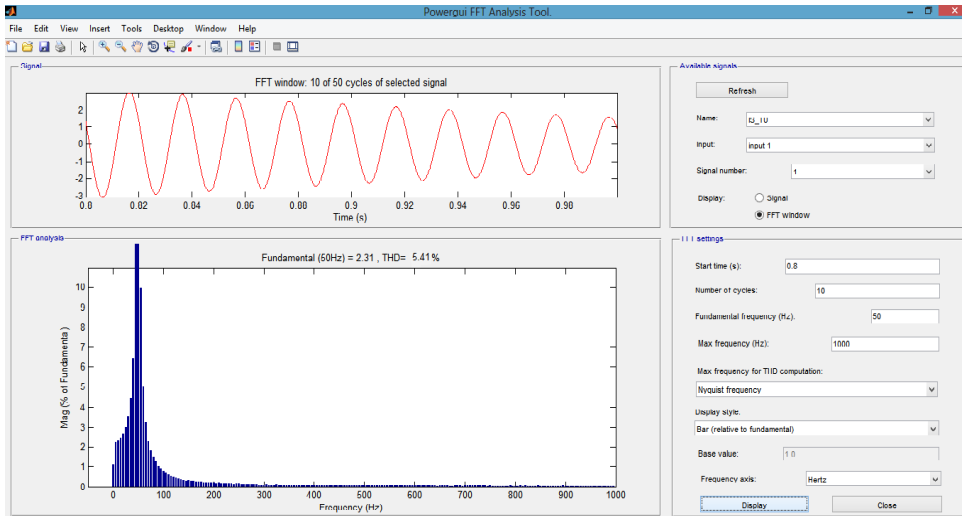


Figure 14- FFT analysis with THD 5.41%

The results of all the three cases are summarized as below.

Table 2 THD values of PCC current

Description	Values
With non-linear load	23.20
With Harmonic Compensation	5.41

Conclusion

This paper shows the effectiveness STATCOM in increasing the system stability during fault condition and the suppression of harmonic content introduced by nonlinear loads. The DFIG based WECS is modeled for performing both the fault and harmonic analysis. A Distributed Generation system consisting of DFIG based WECS connected to grid is considered as a test system. For fault analysis, a single phase to ground fault is created at the 25 kV feeder and the STATCOM provides the required compensation and increases the system stability. The harmonic content is introduced by adding a nonlinear load along with the existing load.

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