Electrical Power Quality Enhancement of Grid Interfaced with Wind Power System Using STATCOM - Control Scheme

Prof. Rahatullah Khan
Theem College Of Engineering, Boisar, India
E-mail: rahatullah.khan@theemcoe.org

Mamta Rathod
Theem College Of Engineering, Boisar, India
Email: mamtar96654@gmail.com

Krupesh Vedpathak
Theem College Of Engineering, Boisar, India
E-mail: krupesh.vedpathak@gmail.com

Abstract - Infusion of the wind power into an electric grid influences the power quality. The exhibition of the wind turbine in this way power quality are resolved based on guidelines and the standards followed by the rule indicated in International Electro-technical Commission standard, IEC-61400. The impact of the wind turbine in the grid connected wind energy generation system are the active power, reactive power, voltage variations, harmonic distortion, flicker. The paper study exhibits the power quality issues due to establishment of wind turbine with the grid. In this proposed paper, STATCOM (Static Synchronous Compensator) is connected at point of common coupling (PCC) with a battery energy storage system (BESS) to reduce the power quality issues. The STATCOM control scheme for the grid associated wind energy generation system for power quality improvement is simulated utilizing MATLAB/SIMULINK. The viability of the proposed control scheme reduces reactive power from the load and induction generator. The advancement of the grid coordination rule and the plan for development in power quality standards as per IEC-standard on the grid has been introduced.

INDEX TERMS- Power Quality, Renewable Energy, PCC (Power of Common Coupling), STATCOM (Static Synchronous Compensator), BESS (Battery Energy Storage System).

I. INTRODUCTION

Since the past decade, there has been an immense concern between certain countries on the sustainable power source for control time. The market progression and government's forces have also revived the sustainable power source segment advancement. As of late, wind energy has gotten quite possibly the most significant and promising sources of renewable energy, which requests extra transmission limit and better methods for looking after system reliability. To have practical development and social advancement, it is important to meet the energy need by using the renewable energy assets like wind. The need to integrate the renewable energy like wind energy into power system is to make it conceivable to limit the ecological effects. Wind energy conversion systems are the quickest developing renewable source of electrical energy having huge natural, social, and financial advantages.

Power Quality is characterized as power that makes equipment to work appropriately. A power quality issue can be characterized as any deviation of magnitude, frequency, or purity from the ideal sinusoidal voltage waveform. Great power quality is advantage to the activity of electrical gear; however poor power quality will create extraordinary damage to the power system. In any case, the created power from wind energy conversion system is continually fluctuating because of the fluctuation nature of the wind. Consequently infusion of the wind power into an electric grid influences the power quality. The significant components to be considered in power quality estimation are the active power, reactive power, voltage variation, flicker, harmonics, and electrical conduct of switching operation.

STATCOM-based control technique for power quality change in network is related with wind generation system and with the non-linear load. The power quality issues on the sender-end and electric utility are presented in this paper. Along these lines the proposed scheme in the network related system fulfills the power quality principles according to the IEC standard 61400-2l. The FACTS device based control technique for power quality change in system is related wind generating system and with non-linear load.
The compensator is expected to inject reactive power to beat control quality issues and besides for better grid operations. The connection of STATCOM into the system backings to keep up the dynamic power, responsive power and terminal voltage are steady.

In this proposed scheme Static Synchronous Compensator (STATCOM) is connected at a Point of Common Coupling with a Battery Energy Storage System (BESS) to relieve the power quality issues. Consequently, STATCOM gives Reactive Power backing to wind generator and load. The battery energy storage system is connected to support the real power source under fluctuating wind power. The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated utilizing MATLAB/SIMULINK.

In this paper there will be the analysis of elements which are liable for the power quality issues in the wind energy transformation system and execution of the proposed control scheme for power quality improvement in the wind energy generation system connected to the grid. The paper is coordinated as follows. The section II presents the power quality standards and problems. The section III presents the grid coordination rule for grid quality cut-off points. The section IV depicts the system configuration for power quality improvement. The section V depicts the control scheme. The section VI and VII depicts the simulation, control system performance and conclusion respectively.

II. POWER QUALITY STANDARDS AND PROBLEMS

A. INTERNATIONAL ELECTRO- TECHNICAL COMMISSION GUIDELINES

The guidelines and norms are provided for measurement of wind turbine's power quality. The International standards are developed by the working group of Technical Committee-88 of the International Electro-technical Commission (IEC), IEC Standard 61400-21 describes the procedure for determining the power quality characteristics of the wind turbine.

The standard norms are specified:

1) **IEC 61400-21:** Wind turbine generating system, part-21. Assessment and Measurement of power quality characteristic of grid connected wind turbine.
2) **IEC 61400-13:** Wind Turbine—measuring procedure in determining the power behavior.
3) **IEC 61400-3-7:** Assessment of emission limit for fluctuating load
4) **IEC 61400-12:** Wind Turbine performance.

The data sheet with electrical characteristics provides the base for the utility assessment regarding a grid connection with electrical network.

B. VOLTAGE VARIATION

Voltage variations are a power quality problem caused due to wind velocity and to generator torque. The voltage variation is distinguished under the following categories –

- Voltage sag
- Voltage Swell
- Long Time
- Voltage Interruptions
- Voltage spike
- Voltage Transients

The voltage flicker problem is caused by wind generators within the network. So the power fluctuation from wind turbine causes problems during the entire process throughout. Grid strength, phase angle and resistance in a network define the magnitude of fluctuations. Employment of ineffective methods of reactive power management causes voltage swells/ voltage sag. Voltage transients are caused due to fault in the power system network or sometimes due to capacitor switching. STATCOM responds well to voltage transients. Power disturbances can be classified as following shown in figure (1)

Figure 1. Power Disturbances

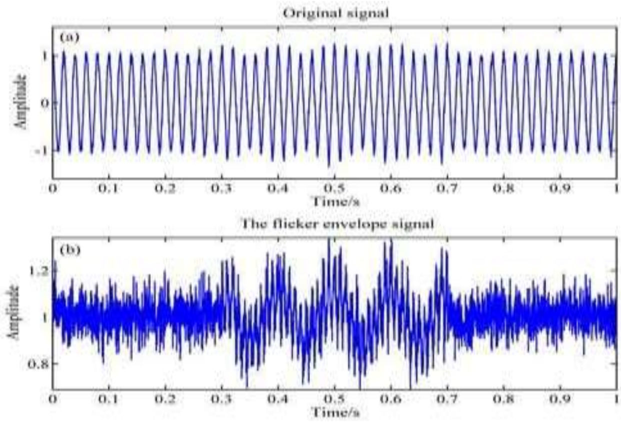
C. HARMONICS

Harmonics are being caused because of operation of power converters. The harmonic voltage and current should be accepted to a limit at the point of wind turbine connection to the network. According to the IEC-61400-36 guideline, limited contribution is allowed by individual sources of harmonic current to ensure harmonic voltage is within limits.

D. FLICKER

Electric power is required to run equipment and appliances in domestic and industries. Power distribution system connected to appliances and equipment should be measured through acceptable quality which is electrical power. The IEC 610002-1 standard distinguishes low frequency conducted disturbances in the subsequent 5 groups out of which flicker is one of them. Flicker is a voltage fluctuation generated inside the illumination intensity of light source. Voltage fluctuations are cyclic variations in voltage with amplitude below 100% of the face value. Flickers is illustrated in figure (2).

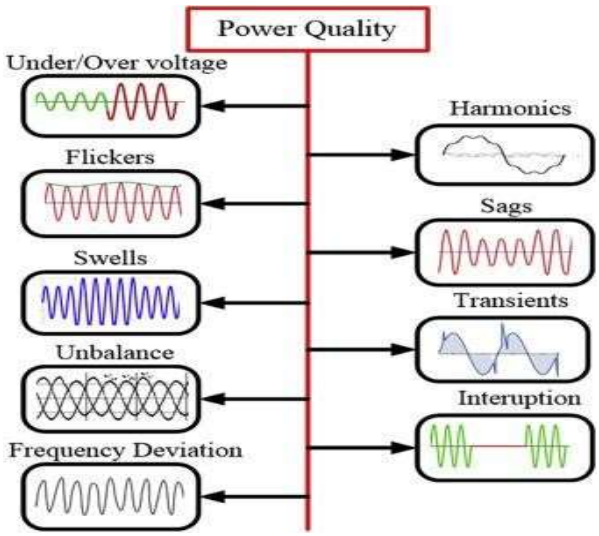
Figure 2. Voltage Flicker



E. IMPACT OF POWER QUALITY ISSUES

Power quality can be basically characterized as represented in the exhibited graph in figure (3).

Figure 3. Impact of Power Quality Issues



III. RULE FOR GRID COORDINATION

IEC-61400-21 defines the rules for grid coordination in a wind generator system at the grid connected electrical network. The customer and the utility grid expects grid quality limits and characteristics for references. The operator of the transmission grid is responsible for the organization and for interconnected systems as per Energy- Economic Law.

1. Voltage dips (d): As the wind turbine starts, there are voltage dips and it causes reduction of voltage suddenly. Switching operation of wind turbine causes relative % voltage change. The voltage changes nominally decreases as given in the equation (1)

$$D = K_u \cdot S_n / S_k \qquad (1)$$

Where d is relative voltage change, S_n is rated apparent power, S_k is short circuit apparent power, and K_u sudden voltage reduction factor.

2. Voltage rise (u): At the point of common coupling, there is a voltage rise. It can be calculated as a function of maximum apparent power S_{max} of the turbine, the grid impedances R and X at the point of common coupling and the phase angle ϕ. It's given in the equation (2).

$$\Delta u = S_{max} (R \cos\phi - X \sin\phi) \qquad (2)$$

Where U is the nominal voltage of grid, Δu-voltage rise, S_{max} – maximum apparent power, ϕ- phase difference.

3. Flicker: The measurements are done for the maximum number of specified switching operation of the wind turbine with 2h period and 10 min period. It's been specified in equation (3)

$$P_{lt} = C(\Psi K) \, S_n / S_k \qquad (3)$$

Where P_{lt} -Long term flicker, C(ΨK)-Flicker coefficient calculated from the wind speed of Rayleigh distribution.

4. Grid Frequency: Frequency change in the grid connected network is known as grid frequency. In India, grid frequency is between the range of 47.5–51.5 Hz for wind generator networks.

5. Harmonics

At PCC (Point of Common Coupling), the harmonic distortion is assessed for variable speed turbine with an electronic power converter.

The total harmonic voltage distortion is given as in (4):

$$V_{THD} = \sqrt{\sum \frac{I_n}{I_1}} \, 100 \qquad (4)$$

Where Vn is the nth harmonic voltage and V1 is the fundamental frequency (50) Hz.

THD of current is given as in (5)

$$I_{THD} = \sqrt{\sum \frac{I_n}{I_1}} \, 100 \qquad (5)$$

Where In is the nth harmonic current and is the fundamental frequency (50) Hz.

IV. SYSTEM CONFIGURATION AND OPERATION PRINCIPLE:

A. STATCOM PRINCIPLE:

The Static Synchronous Compensator (STATCOM) could be a shunt device of the adaptable AC Transmission Systems (FACTS) family utilizing power gadgets to control power flow and improve transient stability on power grids as displayed in figure 4. The STATCOM is directing voltage at its terminal by controlling the measure of reactive power infused into or ingested from the power system. When system voltage is low, the STATCOM produces reactive power (STATCOM capacitive). Once system voltage is high, it retains reactive power (STATCOM inductive). In synchronization with the interest to balance out the voltage of the facility network.

Typically a STATCOM is introduced to help electrical networks that have a poor power issue and at times poor voltage guideline. The most widely recognized utilization of this device is for voltage stability. Basically it is a voltage source converter (VSC) based device, with the voltage source behind a reactor. The voltage source is framed from a DC capacitor and consequently the device has minimal active power capability. Notwithstanding, its active power capability might be expanded if a reasonable energy storage device is associated across the DC capacitor.

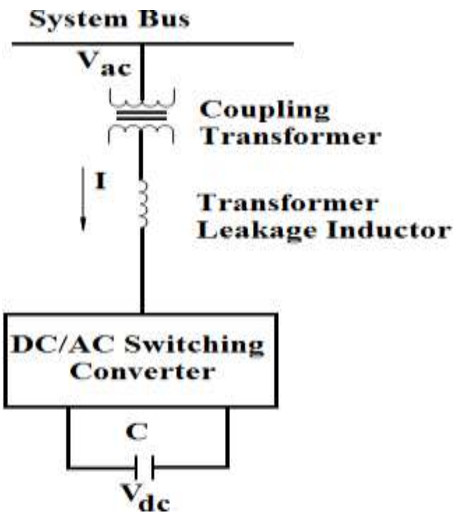


Fig (4). single line diagram of the STATCOM

B. SYSTEM OPERATION

The STATCOM interfaced with capacitance at DC side regulates as a three phase voltage source inverter (VSC). The basic principle of operation of STATCOM located in power system is to generate controllable ac voltage source by a Voltage Source Inverter connected to dc capacitor. Here the paralleled connected STATCOM is operated in current control manner and is connected with non-linear load and wind turbine induction generator at the

Point of Common Coupling (PCC) in the grid system as represented in figure 5. The STATCOM based on current controlled voltage source inverter inserts the current into the grid in such a manner that the source current are free from harmonic distortions leading to reduced Total Harmonic Distortions and they are accordance in phase-angle with regard to source voltage. The inserted current will terminate their active part and harmonic part of the induction load current and generator current, thus it upgrades the system power quality.

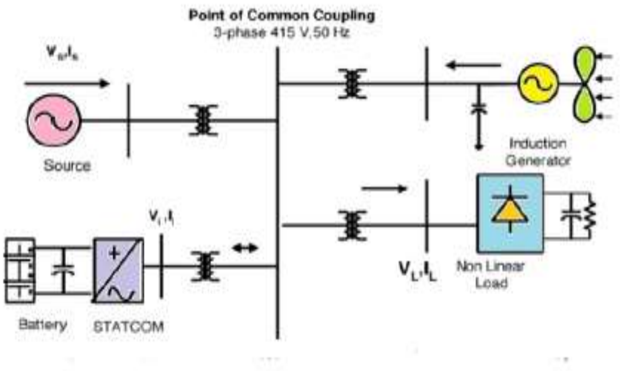


Figure 5. System operational scheme in grid system

IV.I. WIND GENERATING SYSTEM SPECIFICATIONS IN PROPOSED SCHEME

In the presented system induction generator is utilized since separate excitation field circuit in not required, it accepts constant values and variable load values. Induction generator and Battery Energy Storage System are interfaced at Point of Common Coupling. The shunt connected STATCOM in the proposed system is preferred. This system has natural shielding against sudden occurring short circuits. The wind power available is represented by:

$$P_{air} = 0.5pAV_{wind}^2 \quad (1)$$

Where P_{air} is represented as density (Kg/m^3), A represents the Area swept out by turbine blade (m), V_{wind} represents the wind speed in m/s.

It is not practicable to draw out all kinetic energy of wind. Thus extraction of a fractional power is termed as Power Coefficient 'Cp' of the wind turbine which is given by:

$$P_{mech}=C_p\, P_{wind} \quad (2)$$

The mechanical power generated by wind turbine is given by:

$$P_{mech}= 1/2\pi R^2 V_{wind} C_p \quad (3)$$

Where R represents Radius of the Wind Turbine Blade (m).

IV.II. BESS INTEGRATION WITH STATCOM

The Battery Energy Storage System (BESS) is used as an energy repository element designed for the aim of better voltage regulation. The BESS will conventionally maintain dc capacitor voltage constant and is best acceptance in STATCOM since it rapidly inserts or absorbs reactive power to stabilize the grid system. When power fluctuation occurs in the system, the BESS is used to maintain the level of power fluctuation by charging and discharging operations. The battery is coupled in parallel to the dc capacitor of STATCOM.

IV.III. ARRANGEMENTS MADE IN PROPOSED SYSTEM

The shunt connection for STATCOM with Battery Energy Storage System is connected at the interconnection of the induction generator and non-linear load at the Point of Common Coupling. The Figure (5) presents the system operational scheme in grid system. The STATCOM output is deviated in consonance to the control strategy, so as to maintain the power quality norms in the grid system according to IEC Standards. The current control scheme for STATCOM practiced in the proposed paper is Bang-Bang controller which is derived from the Hysteresis Current Controller. A single STATCOM designed using Insulated Gate Bipolar Transistors (IGBT's) is practiced to have a reactive power support to the no-linear load and induction generator in the grid system.

IV.IV. CONTROL SCHEME

In this proposed control scheme, bang- bang current controller is being used to inject wind into a grid connected electrical network. A hysteresis current controlled derived technique is used. By utilizing this technique, the controller keeps the control system variable between correct switching signals and boundaries of hysteresis area for STATCOM operation. The current controller block accepts reference current and actual current as inputs and are subtracted so as to start-up the operation of STATCOM in current control mode.

IV.V. GRID SYNCHRONISATION

In the three-phase balance system, the RMS source voltage amplitude is calculated from the source phase voltages (V_{sa}, V_{sb}, V_{sc}) and is expressed as sampled peak voltage-V_{sm} :

$$V_{sm} =\sqrt{2/3(V_{sa}^2+V_{sb}^2+V_{sc}^2)} \quad (4)$$

In-phase unit vectors are calculated from source voltage in each of the phases and the RMS value of unit vector is shown below:

$$U_{sa} =V_{sa}/V_{sm}$$
$$U_{sb} =V_{sb}/V_{sm} \quad (5)$$
$$U_{sc} =V_{sc}/V_{sm}$$

The in-phase reference currents produced are acquired using in-phase unit voltage template as shown below:

$$i_{sa}^*=I^*\, U_{sa},\ I^*_{sb}=I^* U_{sb},\ i_{sc}^*= I^*\, U_{sc} \quad (6)$$

Where 'I' represents the proportionality magnitude of filtered source voltage for respective phases. This makes sure that the source current is controlled to be sinusoidal.

IV.VI. BANG – BANG CURRENT CONTROLLER

The proposed control system scheme of STATCOM-BESS is bang-bang controller is shown in the figure (6). The reference current is generated and actual current is detected by current sensors. Then both the current are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for Insulated Gate Bipolar Transistors of STATCOM are obtained from hysteresis controller.

The switching function S_a for phase 'a' is expressed as:

$I_{sa} < (i^*_{sa}\text{-HB}) \longrightarrow S_A = 0$ (7)

$I_{sa} > (i^*_{sa} - \text{HB}) \longrightarrow S_A = 1$ (8)

This is similar for phases 'b' and 'c.

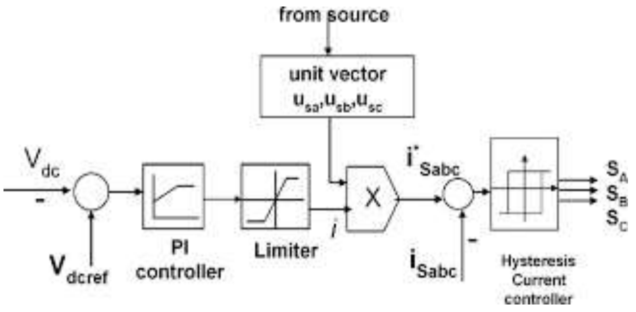


Figure 6. Control System scheme of STATCOM-BESS

V. SYSTEM PERFORMANCE AND ITS PARAMETERS

The proposed control scheme is simulated utilizing SIMULINK in power system block set. The system parameter for given system is given Table I. The system execution of proposed system under dynamic condition is additionally introduced.

Sr. No	Parameters	Ratings
1	Grid Voltage	3-Phase, 415V, 50Hz
2	Induction Motor/Generator	3.35kVA, 415V, 50Hz, P=4, Speed=1440rpm, Rs=0.01Ω, Rr=0.015Ω, Ls=0.06, 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 Ratings	Collector Voltage=1200V, Forward Current=50A, Gate Voltage= 20V, Power Dissipation=310W
6	Load Parameter	Non-Linear Load 25kW

Table 1. System Performance Parameters

A. VOLTAGE SOURCE CURRENT CONTROL—INVERTER OPERATION:

The three phase injected current into the grid from STATCOM will counterbalance the distortion brought about by the non-linear load and wind generator. The IGBT based three-phase inverter is coupled with grid through the transformer. The Generation of switching signals from reference current is simulated inside hysteresis band of 0.08. The decision of thin hysteresis band switching in the system improves the current quality and control signal of switching frequency inside its operating band.

B. STATCOM—PERFORMANCE UNDER LOAD VARIATIONS:

The wind energy generating system is associated with grid having the non-linear load. The execution of the system is estimated by exchanging the STATCOM at time t=0.5s in the system and how the STATCOM reacts to the progression change order for expansion in extra load at 1.0 s is appeared in the simulation.

At the point when STATCOM controller is made ON, without change in some other load condition boundaries, it begins to response for demanded harmonic current. This extra demanded harmonic current is satisfied by STATCOM compensator .The simulation model of proposed control scheme with STATCOM is appeared in Figure (7). The Control system used for STATCOM operation is appeared in Figure (8). The source current and load currents waveform in simulated model is examined and displayed in figure (9). Power Factor Improvement and Reactive power Compensation is illustrated in figure (10) while the Source currents, Load currents and STATCOM injected currents are displayed in figure (11). The DC link voltage controls the source current in the grid system, so the DC link voltage is kept up steady across the capacitor which is displayed in figure (12). Total Harmonics distortion with STATCOM and without STATCOM operation is displayed in Figure (13) and (14) respectively.

The above tests with proposed scheme have power quality improvement include as well as has support capability to help the load with the energy storage system through the batteries.

VI. SIMULATIONS AND RESULTS:

Figure 7. MATLAB model of the proposed scheme

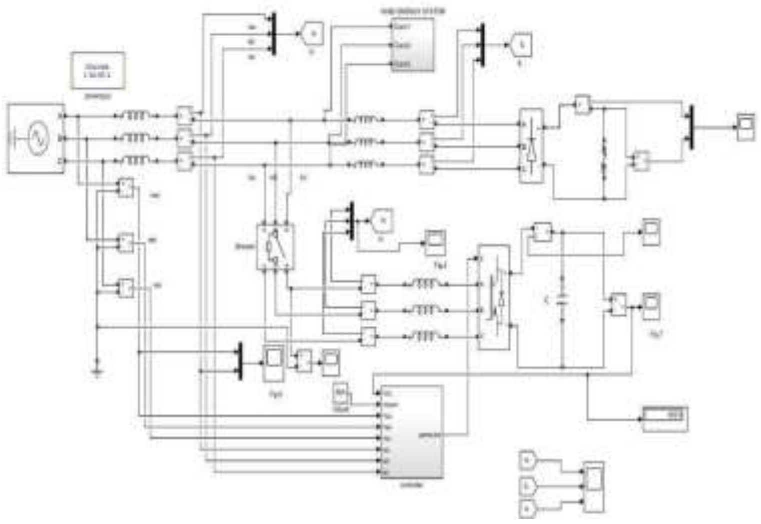


Figure 8. Control System Design in MATLAB Model.

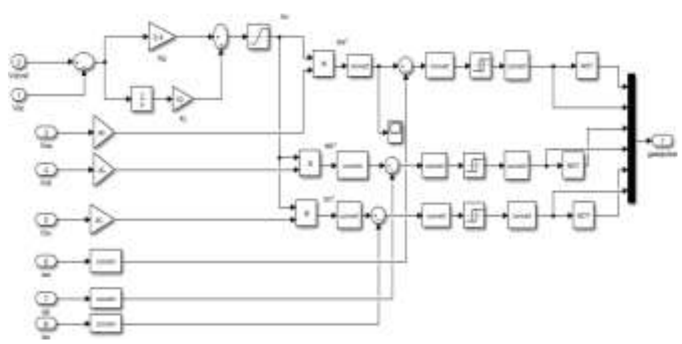


Figure 9. Load currents and Source Currents

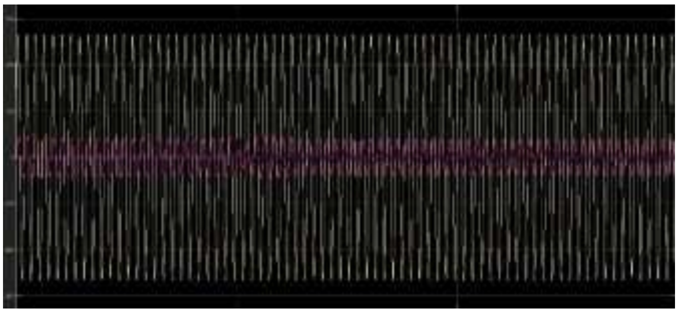


Figure 10. Power Factor Improvement and Reactive power Compensation

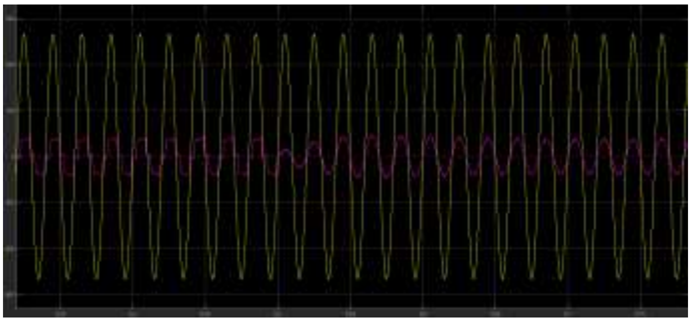


Figure 11. Source currents, Load currents and STATCOM injected currents

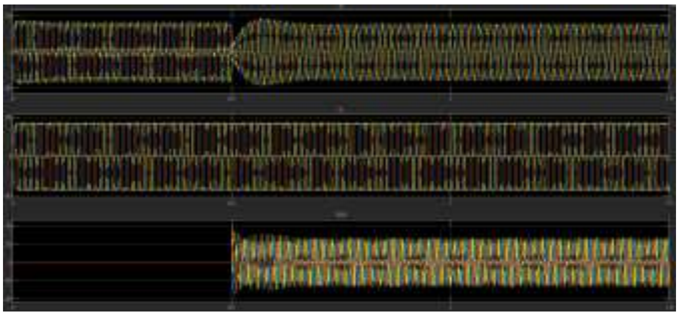


Figure 12. DC link Voltage

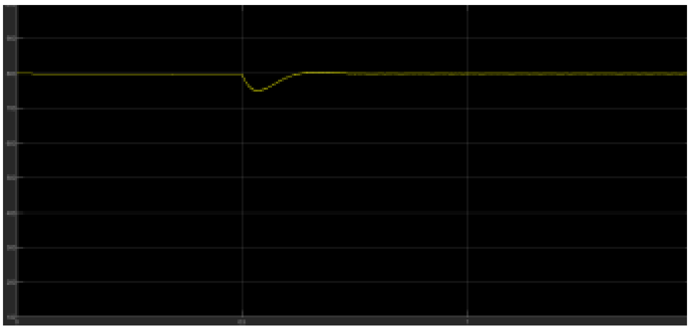


Figure 13. Total Harmonics Distortion without STATCOM

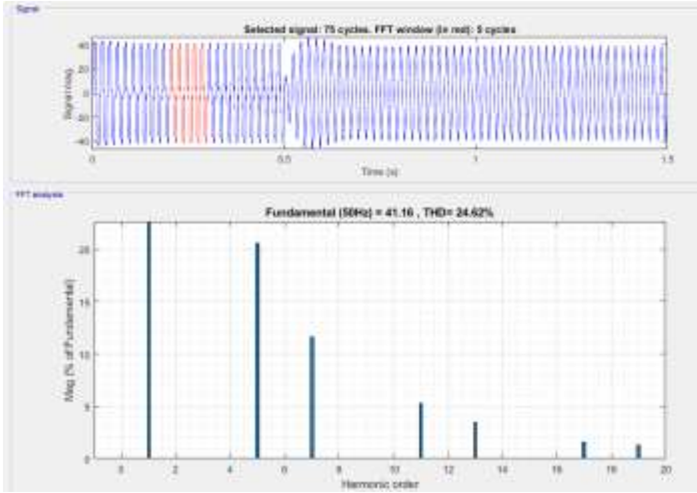
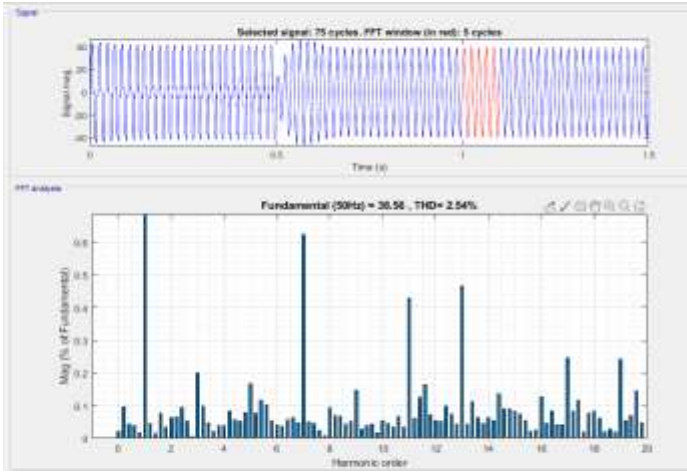


Figure 14. Total Harmonics Distortion with STATCOM



VI. CONCLUSION

The paper analyses the elements which influences the power quality in the wind energy generation system. Likewise this paper examines the execution of STATCOM-Control scheme for power quality improvement in grid associated wind energy generation system. The simulation of the proposed control scheme for the grid associated Wind energy generation is simulated utilizing MATLAB/SIMULINK. The control scheme has an ability to dispense with the harmonic parts of the load current and reactive power. Total Harmonic Distortion before the STATCOM connected was observed to be 24.62%, whereas, after STATCOM connection it was observed to be 2.54%. It additionally assists with keeping up the source voltage and current in-stage which makes maintaining power factor at source-end and thus supporting the demanding reactive power injection for the load at PCC and wind generator in the grid interfaced wind energy generation system. It allows an opportunity to upgrade the use factor of transmission lines.

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