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Hysteresis Current Control Technique for STATCOM to Operate and Mitigate the Power Quality Issues for Grid Interfaced with Wind Power System

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ABSTRACT

Power quality can be considered by the appropriate supply voltage and an effective and reliable process for electrical energy delivery to consumers. Owing to increased sensitivity of applied receivers and power controls processes, many customers may experience severe electrical and technical consequences of poor power quality. Low power factor, harmonic pollution, load imbalance, fast voltage variations are some common issues that are caused due to insufficient power supply. Capacitor banks, FACTS devices, harmonic filters, Static Voltage Compensators, STATCOM (Static Synchronous Compensator) are the solutions to achieve enhanced power quality. The proposed scheme mainly focuses on injecting wind power into an electric grid as a method running a wind generating system. This paper proposes STATCOM - Control scheme connected to PCC (Point of Common Coupling) with BESS (Battery Energy Storage System). This model's simulation is conducted in MATLAB/ Simulink. The simulation results disclose enhanced power quality, improvement in voltage profile and less distortion in harmonic waveform.

Keywords— *Power Quality, Renewable Energy, PCC (Power of Common Coupling), STATCOM (Static Synchronous Compensator), BESS (Battery Energy Storage System)*

1. INTRODUCTION

TO have sustainable growth and further progress in technology, it is necessary to meet the energy need by utilizing renewable energy resources like wind, biomass, hydro, etc. Energy conservation and the use of renewable source are the key paradigms in the sustainable energy system. The need for renewable energy integration like wind energy into power system is to make it possible to decrease the environmental impact on the conventional plant. The wind energy integration into the existing power system confers technical challenges, requiring inspection of voltage regulation, stability, power quality problems. The power quality is an essential customer-oriented measure and is greatly affected by a distribution and transmission network operation. The power quality issue is of great priority to the wind turbine. There has been substantial growth and rapid development in the utilization of wind energy in recent years. The individual units can be of a large capacity up to 2 MW, feeding into the distribution network, particularly with customers connected in the vicinity. Today, more than 28,000 wind generating turbine are successfully employed all over the world. In the fixed-speed wind turbine operation, all the wind speed fluctuations are transferred as fluctuations in the mechanical torque, electrical power on the grid and causes large voltage fluctuations. During normal operation, wind turbine produces continuous and variable output power. In the power system, these power variations are mainly caused by turbulence, wind shear, and tower-shadow and control system. Thus, the network needs to control such fluctuations. The power quality issues can be optimized to the wind generation, transmission and distribution network, such as voltage sag, voltage swells, flicker effects, increased harmonics etc. However, the wind generator introduces disruptions into the distribution network. One of the uncomplicated methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has intrinsic advantages of being cost effective and durability. However, induction generators require reactive power for magnetization. When an induction generator's generated active power is assorted due to wind, absorbed reactive power and the terminal voltage of an induction generator can be remarkably affected.

An appropriate control scheme in a wind energy generation system is essential under the normal operating condition to allow the proper control over the active power production. Subjected to increasing grid disturbance, a Battery Energy Storage System for a wind energy generating system is generally required to recompense the fluctuation generated by a wind turbine. A STATCOM –Control technology has been advanced and proposed to improve power quality, which can technically control the power level linked with the commercial wind turbines. The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has the following objectives:

• Maintain the Unity power factor at the source side.
• Reactive power assistance only from STATCOM to wind Generator and Load.
• Simple bang-bang controller for STATCOM to achieve a fast and effective response.

The paper is assembled as follows. Section II presents the standards of power quality, issues and its consequences of a wind turbine. Section III presents the grid coordination rule for grid quality limits. Section IV represents the topology for power quality improvement. Sections V, VI, VII outlines the Control scheme, system performance and conclusion, respectively.

2. POWER QUALITY STANDARDS AND PROBLEMS

2.1 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:

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

2.2 Voltage Variations

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.

2.3 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.

2.4 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.

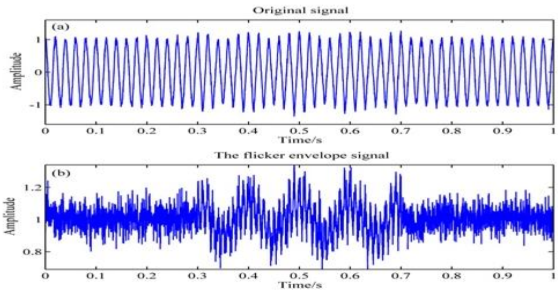

Figure 1. Voltage Flicker

2.5 IMPACT OF POWER QUALITY ISSUES

TABLE 1.1

Power Quality Issues	Causes	Effects
Voltage Fluctuations	Switching of Load	Over/ Under voltages, flickering of lighting
Voltage Sag	Fault in the system, excessive network loading, Source Voltage Variation, Inrush current, Inadequate wiring, starting of large loads,	Overloading problems. Intermittent Lockup, Grabbled data
Voltage Swell	Start/stop of heavy loads, Source Voltage Variation, Inrush current, Inadequate wiring	Data loss, Damage of equipment's, Intermittent Lockup, Grabbled data
Long Time Voltage Interruption	Failure of protecting Devices, insulation failure or control malfunction	Malfunction of equipment for data processing
Noise	Electromagnetic interference, improper grounding	Disturbances in the sensitivity of the equipment, data loss
Waveform Distortion	Noise in the system	Overheating and saturation of the transformers
Power Frequency Variations	Heavy load	Mainly affects the motors and sensitive devices
Harmonics	If a sinusoidal voltage is applied across the nonlinear load	Losses in electrical equipment, Overheated transformers or motors, Lock-up, Grabbled data
Voltage Spike	start/stop of heavy loads, bad dimensions of power sources/ badly regulated transformers	Data loss, flickering of lighting and screens, sensitive equipment gets damaged or stoppage happens
Transient	PE commutation, RLC snubber circuits, Lightning	Disturbance in electrical equipment
Flicker	Fluctuation of supply voltage	Damage the equipment at the load side

3. 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 expect 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.

3.1. 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 decrease as given in the equation (1)

$$D= K_u \,.\, S_n / S_k \quad (1)$$

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.

3.2. 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).

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

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

3.3. 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)

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

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

3.4. 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):

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad (4)$$

Where V_n is the n^{th} harmonic voltage and V_1 is the fundamental frequency (50) Hz. THD of current I_{THD} is given as in (5)

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

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

4. SYSTEM CONFIGURATION AND OPERATION PRINCIPLE

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. The STATCOM based on current controlled voltage source inverter inserts the current into the grid in such a manner that the source current is 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.

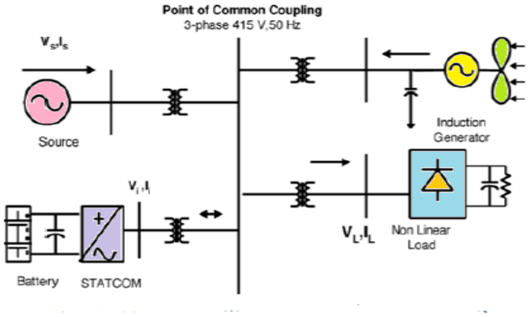

Figure 2. System operational scheme in grid system

4.1. 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:

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

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).

4.2 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.

4.3 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 2 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.

4.4 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.

4.5 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.

4.6 Bang – Bang Current Controller

The proposed control system scheme of STATCOM-BESS is bang-bang controller is shown in the figure (3). The reference current is generated and actual current is detected by current sensors. Then both the current is 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:

$$\vec{I_{sa}} < (i^*_{sa} - HB) \qquad S_A = 0 \quad (7)$$

$$\vec{I_{sa}} > (i^*_{sa} - HB) \qquad S_A = 1 \quad (8)$$

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

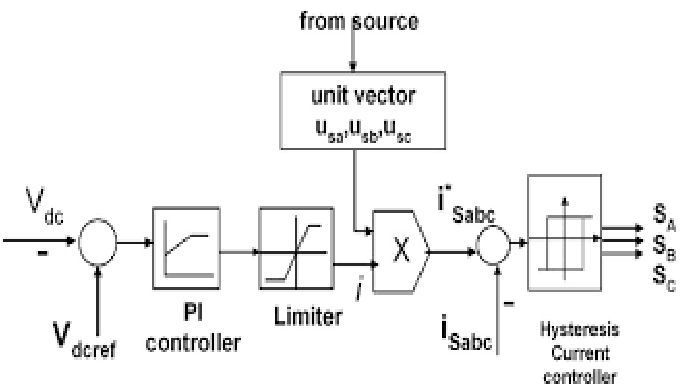

Figure 3. Control System scheme of STATCOM-BESS

5. SYSTEM PERFORMANCE PARAMETERS

The table 2 shows the system parameters:

Parameters	Ratings
Grid Voltage	3-Phase, 415V, 50Hz
Induction Motor/Generator	3.35kVA, 415V, 50Hz, P=4, Speed=1440rpm, Rs=0.01Ω, Rr=0.015Ω, Ls=0.06, Lr=0.06H
Line Series Inductance	0.05mH
Inverter Parameters	DC Link Voltage=800V, DC Link Capacitance= 100µF, Switching Frequency=2kHz
IGBT Ratings	Collector Voltage=1200V, Forward Current=50A, Gate Voltage= 20V, Power Dissipation=310W
Load Parameter	Non-Linear Load 25kW

6. SIMULATIONS AND RESULTS

SIMULINK model of the proposed STATCOM- BESS model is shown in Fig (4) while the Control System Design in MATLAB Model is displayed in Figure (5). Operating voltage and the interfacing transformer impedance decides the choice of hysteresis current band. Inverter provides the compensated current for the non-linear load and demanded reactive power. The real power transfer from the batteries is also supported by the Controller of inverter.

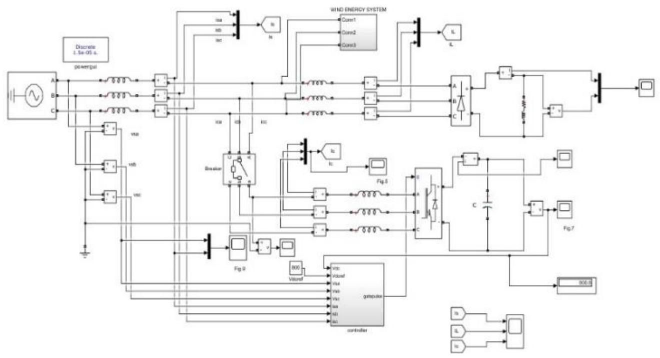

Figure 4. MATLAB model of the proposed scheme

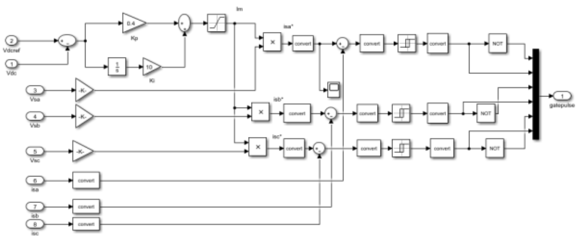

Figure 5: Control System of Proposed System

The performance of the system is measured by triggering the STATCOM at time t=0.5s within the system. Response of STATCOM towards the step modification command for increase in extra load at 1.0s is shown within the simulation. Once the STATCOM controller is ON, while not modification in the other load condition parameters, it starts to eliminate for reactive power furthermore as harmonic current. At time t=0.1 sec, dynamic performance is allotted by step modification in load. STATCOM compensator fulfills the extra demand. Thus, STATCOM regulates the offered real power from supply. The results of load current, supply current as shown in Fig. (6). Additionally the power factor Improvement and Reactive power Compensation is delineated in figure (7) whereas the results of supply currents, load currents and STATCOM injected currents is delineated in figure (8). The DC link voltage regulates the supply current within the grid connected wind energy generating system, that is the reason DC link voltage is maintained constant across the capacitor as shown in Fig. (9).

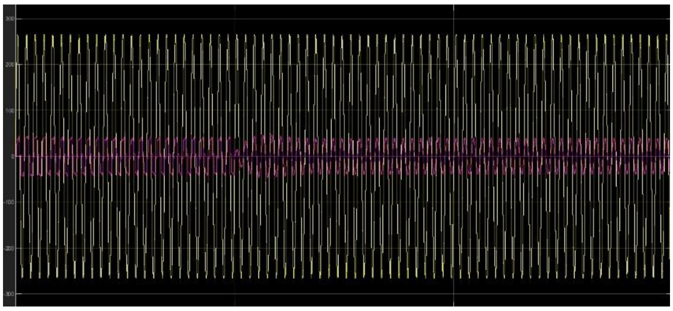

Figure 6. Load currents and Source Currents

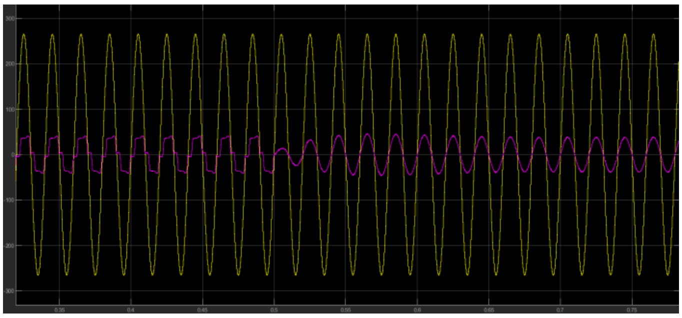

Figure 7. Power Factor Improvement and Reactive power Compensation

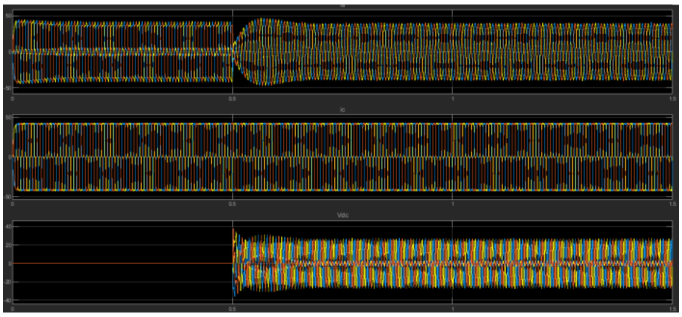

Figure 8. Supply currents, Load currents and STATCOM injected currents

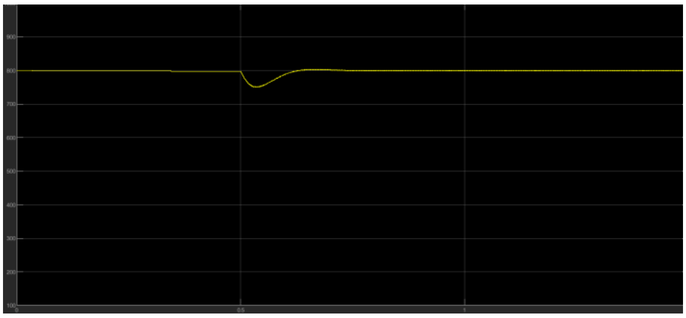

Figure 9: DC Link Voltage

When the controller is in ON mode, power quality is enhanced at point of common coupling. It is shown that the THD improved remarkably and within the norms of the IEC standard. The above tests with proposed scheme have power quality improvement feature also it has sustained capability to support the load with the battery energy storage system. The THD% without STATCOM is 24.82% and THD% with STATCOM is 2.54% hence proving that power quality has been improved which are displayed in figure (10) and (11) respectively.

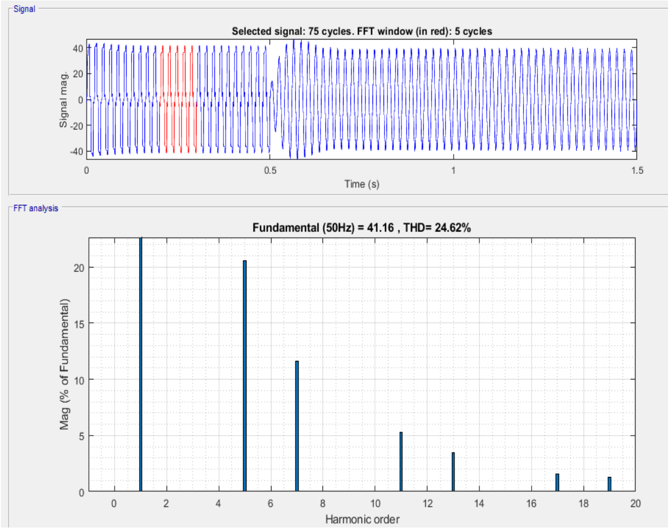

Figure 10. Total Harmonics Distortion without STATCOM

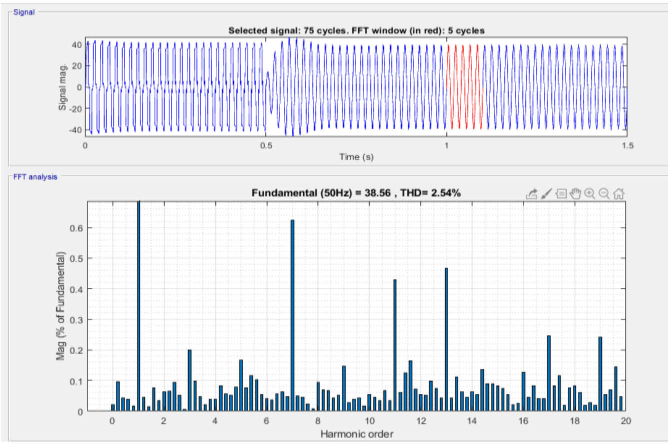

Figure 11. Total Harmonics Distortion with STATCOM

7. CONCLUSION

The paper analyses the factors which affects the power quality in the wind energy generation system. Also, this paper discusses the implementation of STATCOM-Control scheme for power quality enhancement in grid connected wind energy generation system. The simulation of the proposed control scheme for the grid connected Wind energy generation is simulated using MATLAB/SIMULINK. The control scheme has a capability to eliminate the harmonic parts of the load current and reactive power. It also helps to maintain the source voltage and current in-phase hence supporting the reactive power demand for the load at PCC and wind generator in the grid interfaced wind energy generation system. It gives a chance to enhance the utilization factor of transmission lines.

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