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Grid Power Quality Improvement and Battery Energy Storage in Wind Energy System by PI and Fuzzy Based STATCOM Controller

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Abstract: ***Wind power is one of the optimistic sources of energy generation among all the renewable energy sources. Hence for exploiting wind energy sources it must be connected to electric grid. Wind power inculation into grid affects power quality because of its fluctuating nature. This paper recommends a control scheme based on instantaneous SRF (Synchronous Reference Frame) theory for compensating the reactive power requirement of a three phase grid connected wind energy generating system along with the mitigation of harmonics produced by non linear load connected at PCC using STATCOM. In this proposed scheme a STATCOM (static synchronous compensator) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality problems is simulated using MATLAB/SIMULINK in simpower system block set.. Fuzzy based controller is designed to improve the profile of source current in STATCOM.***

Keywords: Fuzzy Logic Controller (FLC), International Electro-technical Commission (IEC), Wind Energy Generating System (WEGS)

1. Introduction

In the deregulated power market, adherence to Power Quality (PQ) standards has emerged as a figure-of-merit for the competing power distribution utilities. Wind power is among the utilities considered to be potential sources for bad power quality. To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc in sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant. The integration of wind energy into existing power system presents a technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer- focused measure and is greatly affected by the operation of a distribution and transmission network.

In this paper, a Static Synchronous Compensator (STATCOM) with energy storage system for wind power application has been treated. This device was proposed as a mean to improve voltage stability and power transmission by offering reactive as well as active power compensation. This paper focuses on the converter topology of the STATCOM part and the control system. The operation of wind turbines has an impact on the power quality of the connected grid. If the wind turbine is operating at fixed-speed, the tower shadow and wind speed gradients will result in fluctuating power. Many power quality problems usually occur in the distribution system. The nonlinear loads draw harmonic and reactive power components of current from AC mains in addition to fundamental active power current components. The injected harmonics unbalance and excessive neutral currents, reactive power burden, causes low system efficiency, and poor power factor. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc. However the wind generator introduces disturbances into the distribution network. One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. However; induction generators require reactive power for magnetization. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production .In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine. A STATCOM-based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines.

2. Power Quality of Wind Turbine

Apart from uneven power production, other factors contribute to the power quality of wind turbines. IEC 61400-21specifies the quantities characterizing the power quality of a wind turbine. Measurement procedures for quantifying the characteristics are given, wind turbine requirements with respect to power quality are determined and methods for assessing wind turbine impact on power quality are suggested. Perfect power quality means that the voltage is continuous and virtually purely sinusoidal, with a constant amplitude and frequency. The power quality, which depends on the interaction between the grid and the wind turbine, can be expressed in terms of physical characteristics and properties of the electricity. It is most often described in terms of voltage stability, frequency stability and phase balance. Moreover, a procedure for determining the characteristics of the power output of a wind turbine, with respect to the impact on the voltage quality in a power system, is specified. The voltage drop is mainly caused by reactive power consumption during magnetization of the generator. Grid-connected wind turbines do affect power quality. The power quality depends on the interaction between the grid and the wind turbine. The frequency of large power systems is normally very stable and therefore no problem. A wind turbine normally will not cause any interruptions on a high-voltage grid.

2.1 Voltage Variations

Voltage variations on the grid are mainly caused by variations in load and power production units. When wind power is introduced, voltage variations also emanate from the power produced by the turbine. The power production from wind turbines may vary widely and not only due to variations in the wind. It may also momentarily go from full to zero power production in the event of an emergency stop or vice versa at a start under high wind conditions.

2.2 Flicker

Flicker emission is mainly caused by variations in the produced power due to the wind gradient and the tower shadow effect. Flicker from wind turbines originates in two different modes of operation; continuous operation and switching operations. Flicker produced during continuous operation is caused by power fluctuations. Power fluctuations mainly emanate from variations in the wind speed, the tower shadow effect and mechanical properties of the wind turbine. Switching operations will also produce flicker. Typical switching operations are the start and shut down of wind turbines. Start, stop and switching between generators or generator windings will cause a change in the power production.

2.3 Harmonics

Voltage harmonics are virtually always present on the utility grid. Non-linear loads, power electronic loads, rectifiers and inverters in motor drives etc., are some sources which produce harmonics. The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. To ensure the harmonic voltage within limit, each source of harmonic current can allow only a limited contribution, as per the IEC-61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current com-pared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

2.4 Transients

Transients seem to occur mainly during the start and shut down of fixed-speed wind turbines. The start-up sequence of a fixed-speed wind turbine is performed in two steps. First, the generator is switched. To avoid a large inrush current a soft starter is used. As the soft starter begins operating and the generator is connected to the grid the shunt capacitor banks is switched. The shunt capacitor banks are switched directly to the grid without any soft switching devices.

3. Topology for Power Quality Improvement

The STATCOM with capacitance at DC side is a three phase voltage source inverter. The basic principle of STATCOM installed in power system is to generate controllable ac voltage source by a VSI connected to dc capacitor. Here the shunt connected STATCOM is operated in current control mode and is connected with wind turbine induction generator and non-linear load at the point of common coupling (PCC) in the grid system. The current controlled voltage source inverter based STATCOM injects the current into the grid in such a way that the source current (grid current) are harmonic free and they are in phase-angle with respect to source voltage. The injected current will cancel out there active part and harmonic part of the induction generator current and load current, thus it improves the system power quality.

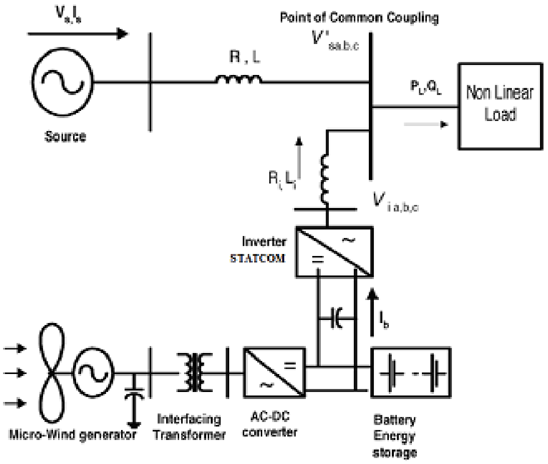

Figure 1: Grid Connected Wind Turbine With non linear load & STATCOM for PQ improvement

To achieve these goals, the grid voltages are sensed by sensors and are synchronized for generating the current. The proposed grid connected system with battery energy storage system with STATCOM and wind energy generation system is implemented for power quality improvement at the point of common coupling (PCC) is shown in Fig.1. The grid integrated system in Fig.1, includes wind energy generation system with non linear load connected and battery energy storage system with STATCOM.

3.1 Wind Energy Generating System

In this configuration, wind generations are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it can accept constant and variable loads, and has natural protection against short circuit. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. Pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds In order to generate power the induction generator speed must be slightly above the synchronous speed. But the speed variation is typically so small that the WTIG (wind turbine induction generator) is considered to be a fixed-speed wind generator. The reactive power absorbed by the induction generator is provided by the grid or by some devices like capacitor banks, STATCOM. The wind energy is not a constant energy source. Its output is varies according to variation of wind, the electricity is produced by using the power of wind to rotate the induction generator. The wind generating system (WEGS) consists of turbine, induction generator, interfacing transformer, and rectifier to get dc bus voltage.

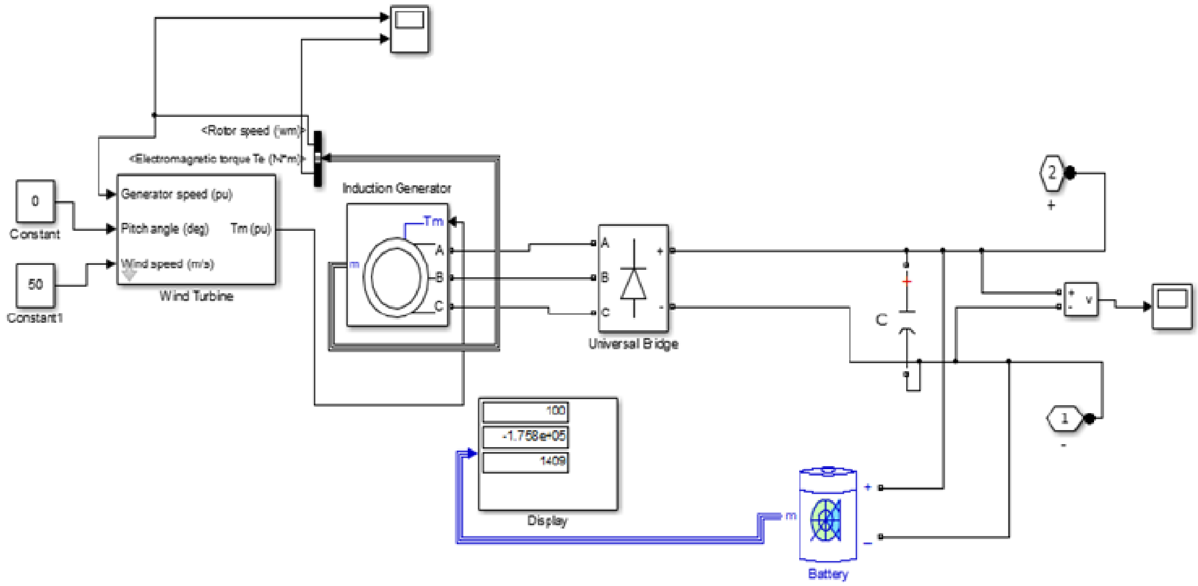

Figure 2: Simulink Modeling of Wind Energy Connected System

3.2 BESS System

Battery energy storage system (BESS) in conjunction with STATCOM have recently emerged as one of the most promising near-term storage technologies for power applications. By the addition of an energy storage system to the STATCOM it has been possible to control the active power flow between the STATCOM and the point of common coupling (PCC).

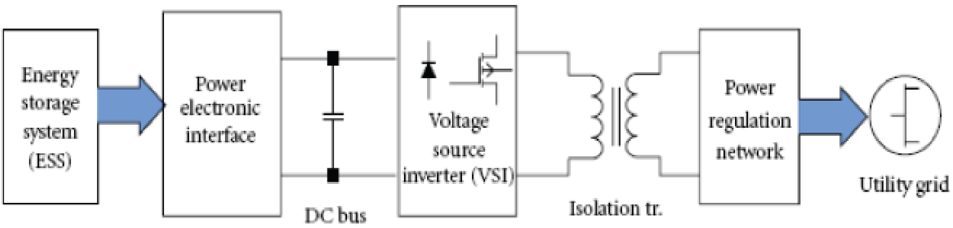

Figure 3: STATCOM + ESS connected to power utility system

The ability to independently control both active and reactive powers in STATCOM + BESS makes them ideal controllers for various types of power regulation system applications, including voltage fluctuation mitigation and oscillation damping. Among them, the most important use of the STATCOM + BESS is to stabilize any disturbances occurring in the power system.

3.3 STATCOM Current Controlled Device

Another way to enhance a Wind Power Plant with ability to deliver or absorb reactive power from the grid is to use Static Synchronous Compensation. STATCOM can be treated as a solid state synchronous condenser connected in shunt with the AC system. STATCOM is a new breed of reactive power compensators based on VSC. A STATCOM is a voltage source converter (VSC), with the voltage source behind a reactor.

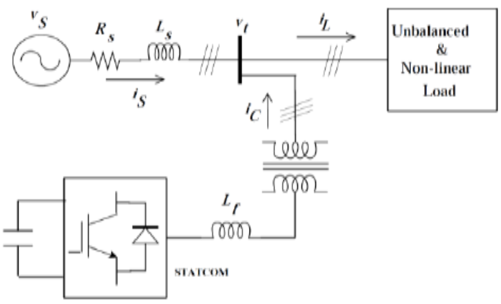

Figure 4: Shunt connected static compensator in grid

The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power storage. However, its active power capacity can be increased if a suitable energy storage device is connected across the DC capacitor. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive).

4. Control Scheme of System

The control scheme with battery storage and micro-wind generating system utilizes the dc link to extract the energy from the wind.

4.1 PI Voltage Regulator

The voltage regulator is of proportional plus integral type. The integral term in a PI controller causes the steady state error to zero.

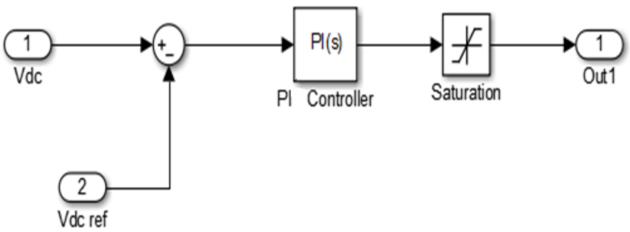

Figure 5: Matlab/Simulink Model of STATCOM model with PI- Voltage Regulator

A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. The weighted sum of these two actions is used to adjust the process of the plant. By "tuning" the two constants in the PI controller algorithm, the PI controller can provide control action designed for specific process requirements.

4.2 FLC Voltage Regulator

FLC voltage regulator is fed with two inputs one of them is voltage error and another one is change in voltage error. This gives the appropriate reactive source current, which is required to the system to improve the function of control system.

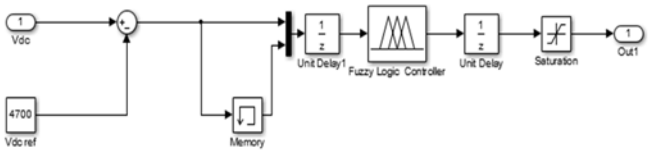

Figure 6: Matlab/Simulink Model of STATCOM model with FLC Voltage Regulator

5. Fuzzification and Membership functions

Fuzzy logic is a convenient way to map an input space to an output space. Mapping input to output is the starting point for everything.

5.1. Fuzzy Inference Method

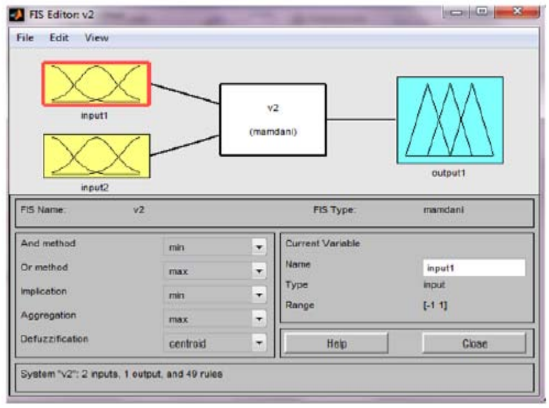

Figure 7: Mamdani Interface Method

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. Mamdani-type inference, as defined for the toolbox, expects the output membership functions to be fuzzy sets.

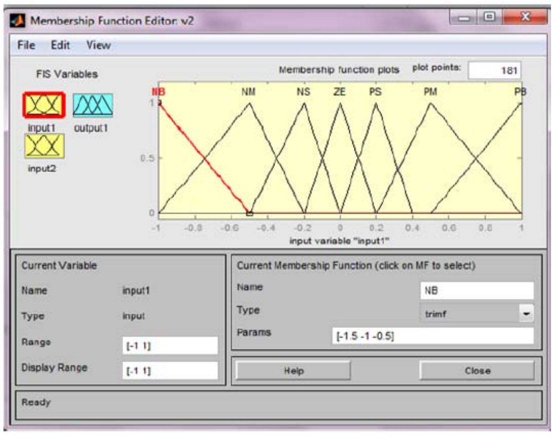

Figure 8: Membership function of Error

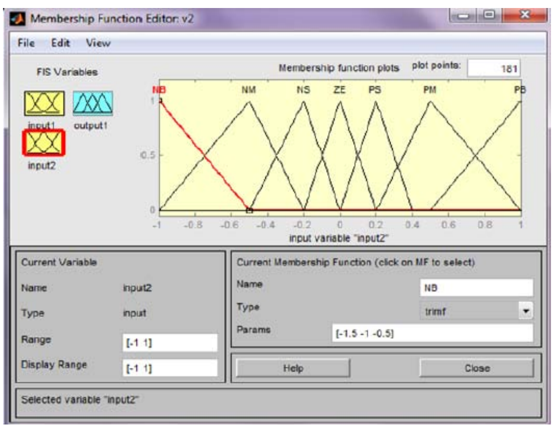

Figure 9: Membership function of Change in Error

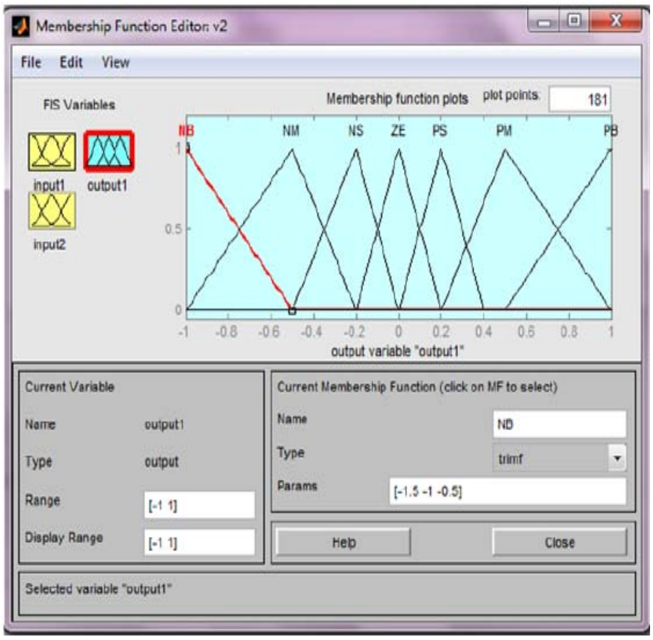

Figure 10: Membership function of Output

After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This type of output is sometimes known as a singleton output membership function, and it can be thought of as a predefuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function.

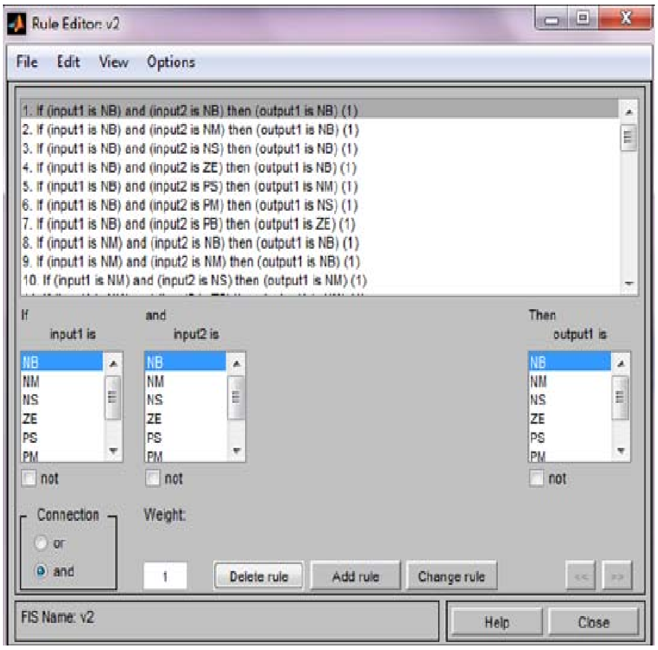

Figure 11: Rules for Fuzzy logic Controller

6. Simulation Model with STATCOM

Fig.12 shows the complete MATLAB model of STATCOM along with control circuit. The power circuit as well as control system are modeled using power system block set and simulink.

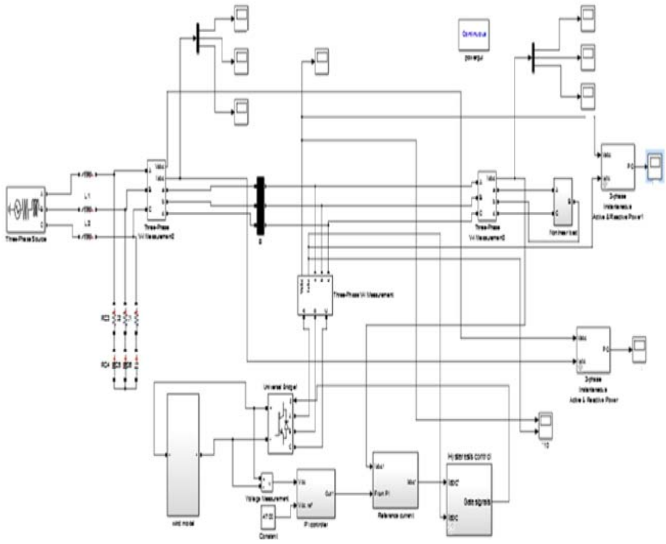

Figure 12: Simulink modeling of grid connected WECS with STATCOM Controller

The grid source is represented by three phase AC source. A STATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT based PWM inverter is implemented using universal bridge block from power electronics subset of power system block. The three phase AC source is connected to grid along with three phase nonlinear load induction generator wind turbine.

6.1. Simulation Model without STATCOM

The STATCOM is connected in shunt at PCC and it consists of SRF theory with hysteresis control technique for pulse generation for IGBT and DC capacitor connected DC bus. The fluctuating power due to the variation of wind cannot be smoothened by reactive power control using a STATCOM, because it has no active power control ability.

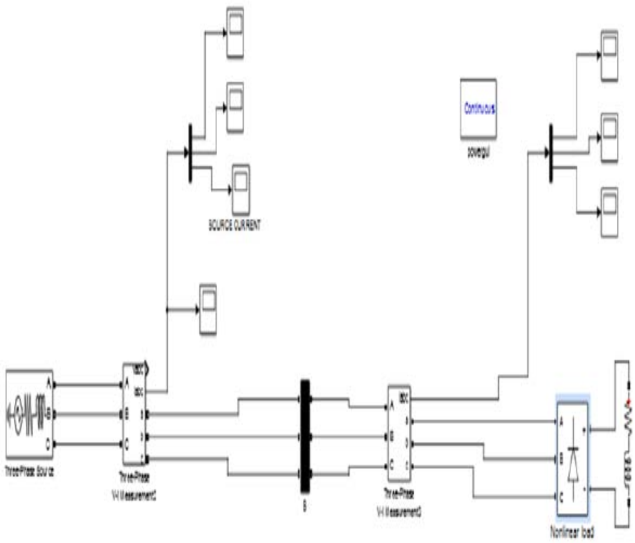

Figure 13: Simulink Modeling of Grid Connected System without STATCOM

7. Simulation Results

7.1. Source Current without STATCOM

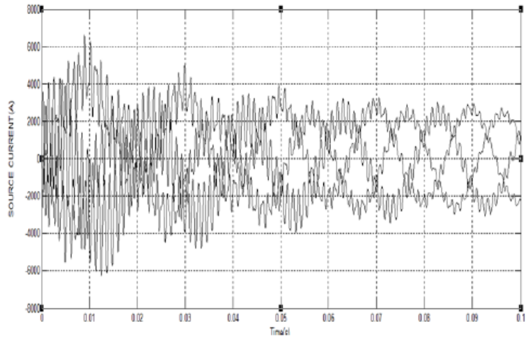

Figure 14: Simulation output of Source Current without STATCOM

From the Fig.14, it is observed that source current on the grid is affected due to the effect of nonlinear load and wind generator. Nonlinear load connected distorts the source current and increases the harmonics.

7.2. DC Link Voltage

The DC link voltage maintain the reactive power and active power also it regulates the source current in the grid system, because of that the DC link voltage is maintained constant across the capacitor as shown in Fig.15

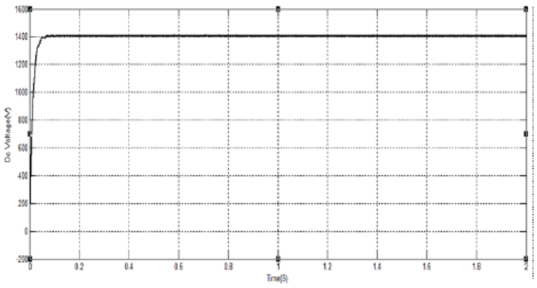

Figure 15: Simulation output of WECS DC Voltage

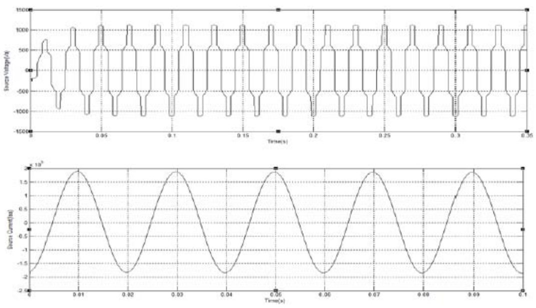

Figure 16: Simulation output of Source Voltage and Current with STATCOM

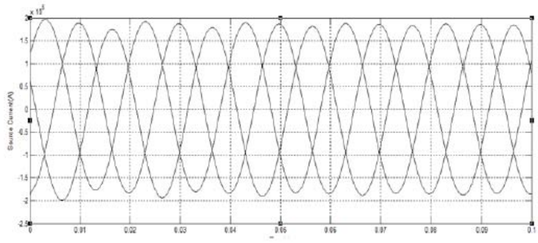

Figure 17: Simulation output of Three Phase Source Current

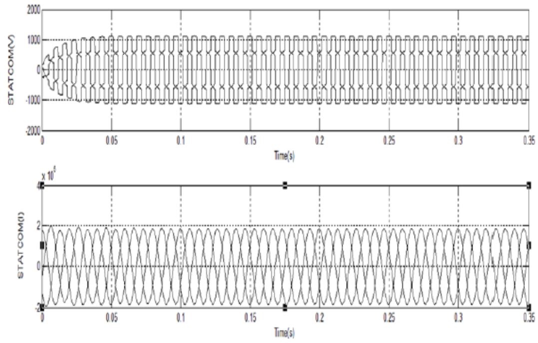

Figure 18: Output of Three Phase Source Voltage and Current with STATCOM

7.2. FFT Analysis

Fig.19 shows the fourier analysis of this waveform is expressed, it is observed that Total Harmonic Distortion (THD) of the source current waveform without controller is 15.76%.

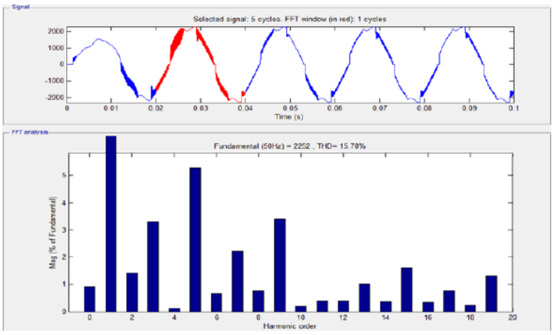

Figure 19: FFT Analysis without controller

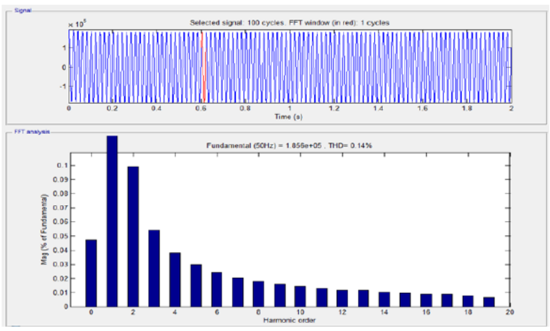

Figure 20: FFT Analysis with PI controller

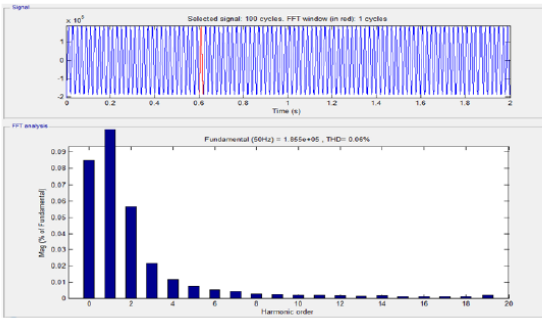

Figure 21: FFT Analysis with FUZZY Controller

It is observed from the simulation results that the THD in the source current is reduced from 0.14% to 0.06% after the connection of FUZZY.

8. Conclusion and Future Scope

The paper presents the STATCOM-based control scheme for power quality improvement in grid connected wind generating system and with non linear load. For better voltage regulation Fuzzy –PI control technique showed better performance than the conventional controller. The hysteresis current controller is used to generate switching signal for inverter in such a way that it will cancel the harmonic current in the system. The STATCOM based control scheme for improving the power quality is simulated in MATLAB/SIMULINK. From the investigation of the control system using fuzzy logic controller both for dc bus voltage and inverter output current control, the dc bus voltage during the transient response and the THDi index of the grid currents are obviously improved. The simulation results show that the performance of converter system has been found to be satisfactory for improving the power quality at the consumer premises. In future research STATCOM can be replaced with custom power device for better power factor control.

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