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# Design of Power Converters for Harmonics Elimination in Integrated Power Plants Using Closed Loop Power Compensators

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**Abstract:** To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy sources like wind, hydro, co-generation etc. The need to integrate the Non-renewable energy and wind energy into power system is to make it possible to minimize the environmental impact on conventional plant. The integration of renewable energy into existing power system presents a technical challenges and that requires consideration of voltage regulation, stability, power quality problems. In this proposed scheme the Static compensator (STATCOM) is connected at a point of common coupling to mitigate the power quality issues in wind energy system. The project also presents a novel control strategy for achieving maximum benefits from the grid-interfacing inverter when installed in 3-phase distribution systems. The effectiveness of STATCOM scheme relives the main supply source from the reactive power demand of the load and the induction generator.

**Keywords:** Statcom, Total Harmonic Distortion, Matlab, UPFC & Simulink.

## I. INTRODUCTION

Stability of power system has been a major concern in system operation. This arises from the fact that in steady state, the angular speed of all the generators must remain the same anywhere in the system.. The stability of a system determines whether the system can settle down to the original or close to the steady state after the transients disappear. In general, power system stability is the ability to respond to a disturbance from its normal operation by returning to a condition where the operation is again normal. Power system stability may be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance.
Stability of a power system is divided into three broad classes namely

- Steady state stability
- Transient stability
- Dynamic stability

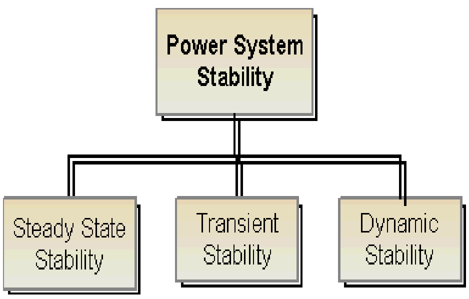


Figure 1: Power system Stability diagram

## II.PREVIOUS RESEARCH

**2.1 Power Flow Control Scheme for Wind Energy Conversion System using FACTS Controller**. R. Billinton and Y. Gao, IEEE Trans. on E. Conv., vol. 23, no. 1, pp. 163–169.

Injection of wind power into an electric grid affects the power quality. The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In the fixed speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. 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. In this proposed scheme STATIC COMPENSATOR (STATCOM) is connected at a point of common coupling to mitigate the power quality issues. The Conventional STATCOM comprises of Voltage Source Converter, DC link Capacitor and a Coupling Transformer is being connected to the Point of Common Coupling (PCC) to the grid. The STATCOM based Voltage Source Converter injects the current into the grid in such a way that the source current are harmonic free and their phase angle with respect to source voltage has a desired value.

**2.2 Impact of Optimal Location of Statcom to Improve Stability of Wind Farms in Weak Power System Network**. C. Han, A. Q. Huang, M. Baran, S. Bhattacharya, and W. Litzenbergr IEEE Trans. Energy

Conv., vol. 23, no. 1, pp. 226–232.
Today Wind Farms (WF), both in size and in number are growing to meet the load demand. The integration of large-scale wind farms in to healthy power network causes many problems related to power quality. A Static Synchronous Compensator is proposed as a novel solution to improve the stability of the system. This paper describes the methodology to conduct an impact study of a STATCOM on the integration of a large WF into a weak loop power system.
The main objective of STATCOM is to reduce the voltage fluctuations and provides reactive power compensation. Compact structure, fast response, power quality enhancement, and easy modularity are the merits of STATCOM. In addition to the performance enhancement, the optimal location of STATCOM for best results was also going to be investigated. A 12-bus system with two conventional source stations and two wind farms is analysed. For this system PV, QV and voltage fluctuations during faults were analysed.
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**2.3 K. S. Hook, Y. Liu, and S. Atcitty (2006) "Mitigation of the wind generation integration related power quality issues by energy storage**," EPQU J.,vol. XII, no. 2
The need to integrate the renewable energy like wind energy into power system is to minimize the environmental impact on conventional plant. The power quality measurements are-the active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behaviour of switching operation and these are measured according to national/international guidelines. The paper clearly shows the existence of power quality problem due to installation of wind turbine with the grid. In this STATCOM is used with energy storage system (BESS) to reduce the power quality problems. The STATCOM based current control voltage source inverter injects the current into the grid will cancel out the reactive part and harmonic part of the load and induction generator

**2.4 STATCOM Impact Study on the Integration of a Large Wind Farm into a Weak Loop Power System**. Chong Han, Member, IEEE, Alex Q. Huang, Fellow, IEEE Anders L. Johnson, Member, IEEE, and Abdel-Aty Edris, Senior Member, IEEE.

In this paper, the effectiveness of a STATCOM in facilitating the integration of a large WF into a weak power system is presented. Firstly, an actual weak power system with two nearby large WFs is introduced. Based on the field supervisory control and data acquisition (SCADA) data analysis, the issues are highlighted, and steady state and dynamic voltage controls are needed to solve these issues.
A STATCOM is proposed for dynamic voltage control, particularly to suppress the short-term (seconds to minutes) voltage fluctuations. A model of the system, WF and STATCOM for steady state and dynamic impact study is developed in the PSCAD/EMTDC simulation environment. The developed model is validated by using the field data. Moreover, based on the real power–voltage (PV) and voltage–reactive power (VQ) curves obtained from the simulation, the system voltage control and stability issues are analysed, and the size and location of STATCOM are assessed.

**2.5 Analysis and Modelling of Static Synchronous Compensator (STATCOM): A comparison of Power Injection and Current Injection Models in Power Flow Study**. Adepoju, G. A. 1, Komolafe, O.A. vol. 22, no. 1, pp. 229–236.
Flexible AC transmission system (FACTS) controllers are power electronics based controllers. Of all the VSC the most widely used is the STATCOM. It can provide bus voltage magnitude control. Computation and control of power flow for power systems embedded with STATCOM appear to be fundamental for power system analysis and planning purposes.
Power flow studies incorporating STATCOM requires accurate model in solution algorithms. There are mainly two models of STATCOM which have well tested in power systems. There are the Current Injection Model (CIM) and the Power Injection Model (PIM) . The CIM STATCOM has a current source connected in shunt the bus for voltage magnitude control.

**2.6 Use of FACTS Devices for Power Flow Control and Damping of Oscillations in Power Systems**. IEEE, Trans. vol. 23, no. 3, pp. 1581–1588
Due to the deregulation of the electrical market, difficulty in acquiring rights-of-way to build new transmission lines, and steady increase in power demand, maintaining power system stability becomes a difficult and very challenging problem. In large, interconnected power systems, power system damping is often modes of oscillations. Implementation of new equipment consisting high power electronics based technologies such as Flexible Alternating Current Transmission Systems (FACTS) and proper controller design become essential for improvement of operation and control of power systems. The aim of this dissertation is to examine the ability of FACTS devices, such as Thyristor Controlled Series Capacitor (TCSC),

**2.7 Operating modes and their regulations of voltage-sourced converter based facts controllers**. IEEE, Trans.
Voltage-sourced converter (VSC) based FACTS controllers are capable of providing fast voltage support and active power flow control to improve the power transfer capability over congested transmission paths. In most published literature, a shunt VSC such as a Static Synchronous Compensator (STATCOM) is set to control the bus voltage and a series VSC such as a Static Synchronous Series Compensator (SSSC) is set to control the line power flow. In practical operations, however, there are other control modes that are more appropriate,

such as fixed reactive power set point control for a shunt converter and fixed injected voltage control for a series converter.

## III. TRANSIENT STABILITY IMPROVEMENT CONTROLLER

The loss of transient stability in a power system is due to overloading of some of the lines (or due to severe line faults), as a consequence of tripping off of the other lines after faults or heavy loss of loads. By means of rapid and flexible control over the ac transmission parameters and network topology, FACTS technology can facilitate power control, enhance the power transfer capacity, decrease the line losses, increase power system damping and improve the stability and security of the power system.
Flexible AC Transmission Systems (FACTS) is alternating current transmission systems incorporating power electronics based and other static controllers with an aim to build flexibility in the system in order to enhance controllability and increase power transfer capability.
By providing added flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating. FACTS technology refers to device that enables flexible electrical power system operation i.e. controlled active and reactive power flow redirection in transmission paths. FACTS device offers continuous control of power flow or voltage, against daily load changes or even change in network topologies.

## IV. FACTS CONTROLLERS (STATCOM & UPFC)

FACTS Controller is a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters. The term FACTS controllers describes power electronic based circuit configuration applied in ac transmission systems. FACTS represent flexible ac transmission system, with the term 'flexible' implying the controllability of voltage and/or current.

Controllable Parameters for FACTS Controllers
There are few basic points that are to be considered regarding the possibilities of power flow control. These are:

- Control of the line impedance X can provide a powerful means of current control.
- When the angle is not large, which is often the case, control of X or the angle substantially provides the control of active power.
- Control of angle which in turns control the driving voltage, provides powerful means of controlling the current voltage and hence active power flow when the angle is not large.
- Injecting a voltage in series with line, and perpendicular to the current flow, can increase or decrease the magnitude of the current flow. Since the current flow lags the driving voltage by 90 degree, this means injection of reactive power in series, can provide a powerful means of controlling the line current, and hence the active power when the angle is not large.
- Injecting a voltage in series with line and with any phase angle with respect to the driving voltage can control the magnitude and the phase of the current. This means that injecting the voltage phasor with variable phase angle can provide powerful means of precisely controlling the active and reactive power flow; this requires the injection of both active and reactive power in series.
- When the angle is not large, controlling magnitude of one or the other line voltages can be a very cost effective means for the control of reactive power flow through the interconnection.

## V. STATIC SYNCHRONOUS COMPENSATOR (PHASOR TYPE)

The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. 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).

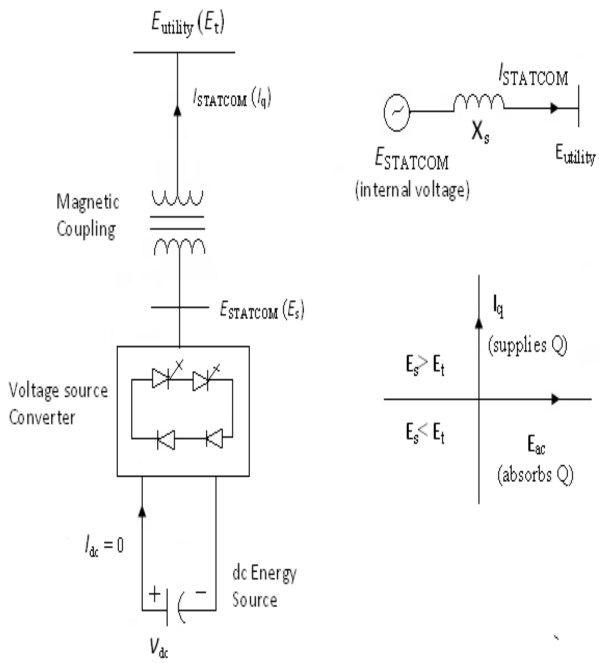


Figure 2: STATCOM Line Diagram

The variation of reactive power is performed by means of a Voltage-Sourced Converter (VSC) connected on the

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secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V2 from a DC voltage source.

The principle of operation of the STATCOM is explained on the figure 3.2 showing the active and reactive power transfer between a source V1 and a source V2. In this figure, V1 represents the system voltage to be controlled and V2 is the voltage generated by the VSC.

## VI. SYSTEM MODELLING AND SIMULATION

STATCOM & UPFC controller has been envisaged to be used for several power-system performance enhancements, namely, the improvement in the system stability, damping of power oscillations, prevention of voltage collapse, dynamic voltage control etc.

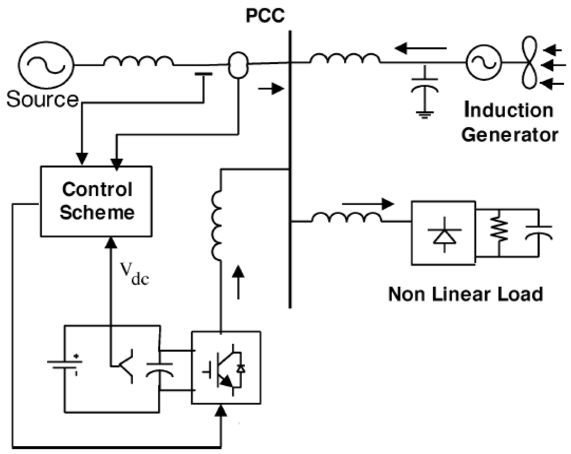


Figure 3: Model Diagram for Simulation

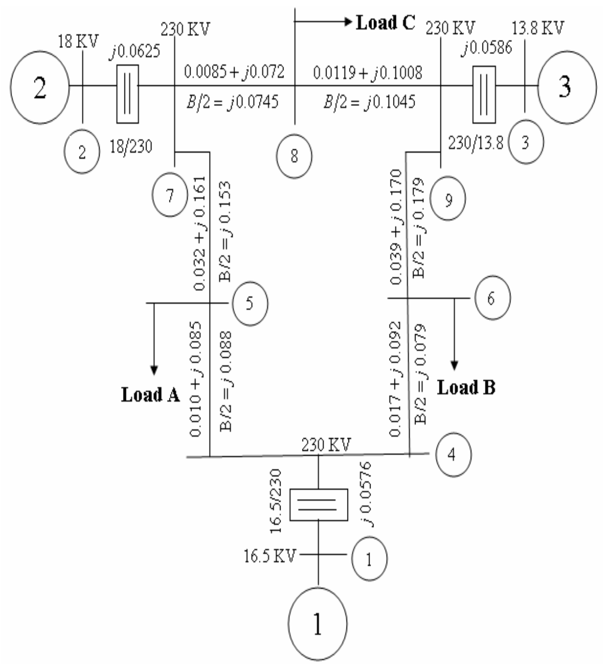


Figure 4: Shows multi-machine Model system.

Multi-Machine System modeling the popular Western System Coordinated Council (WSCC) 3-machines 9-bus practical power system with loads assumed to be represented by constant impedance model. WSCC system is widely used and found very frequently in the relevant literature as presently appearing in references

The base MVA of the system is 100, and system frequency is 50 Hz. The complete system been represented in terms of MATLAB/Simulink blocks. This model finds its utility for transient stability study the reason being power system configuration differs before fault and after fault. Multi-machine system with all the required components is modeled. The generator data is given in appendix A. All time constants are in seconds.

## VII. GRID COORDINATION RULE

The American Wind Energy Association (AWEA) led the effort in the united state for adoption of the grid code for the interconnection of the wind plants to the utility system. The United State wind energy industry took a stand in developing its own grid code for contributing to a stable grid operation. The rules for realization of grid operation of wind generating system at the distribution network are defined as-per IEC-61400-21. The grid quality characteristics and limits are given for references that the customer and the utility grid may expect. According to Energy-Economic Law, the operator of transmission grid is responsible for the organization and operation of interconnected system.

### A. VOLTAGE RISE (U)

The voltage rise at the point of common coupling can be approximated as a function of maximum apparent power of the turbine, the grid impedances R and X at the point of common coupling and the phase angle, given in.

$\Delta u = smax (R\cos\Phi - X\sin\Phi)/ U^2$

Where $\Delta u$ -voltage rise, smax -max. apparent power,$\Phi$-phase difference, U-is the nominal voltage of grid. The Limiting voltage rise value < 2 is %.

### B. VOLTAGE DIPS (D)

The voltage dips is due to start up of wind turbine and it causes a sudden reduction of voltage. It is the relative %voltage change due to switching operation of wind turbine. The decrease of nominal voltage change is given in.

D=Ku and Sn/Sk

Where D is relative voltage change, Sn rated apparent power, Sk short circuit apparent power, and Ku sudden voltage reduction factor. The acceptable voltage dips limiting value is <3%.

### C. FLICKER

The measurements are made for maximum number of specified switching operation of wind turbine with 10-min period and 2-h period are specified, as given


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$$P_u = c(\psi_k) S_n / S_k$$

Where $P_u$ —Long term flicker. c ($\psi_k$ )—Flicker coefficient calculated from Rayleigh distribution of the wind speed. The Limiting Value for flicker coefficient is about ≤0.4, for average time of 2 h.

D. HARMONICS

The harmonic distortion is assessed for variable speed turbine with a electronic power converter at the point of common connection. The total harmonic voltage distortion of voltage is given as in (6.3.4):

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad \ldots 6.1$$

Where is the nth harmonic voltage and is the fundamental frequency (50) Hz. The THD limit for 132 KV is <3 %. THD of current is given as in (6.3.5),

$$I_{THD} = \sqrt{\sum_{h=2}^{40} \frac{I_n}{I_1} 100} \quad \ldots\ldots 6.2$$

Where is the nth harmonic current and is the fundamental frequency (50) Hz. The THD of current and limit for 132 KV is <2.5 %.

E. GRID FREQUENCY

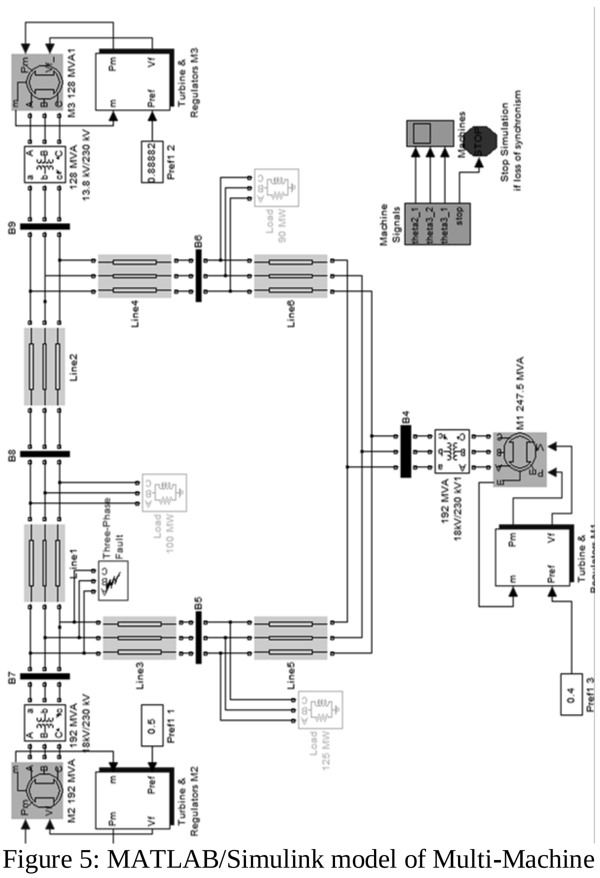

Figure 5: MATLAB/Simulink model of Multi-Machine System

The grid frequency in India is specified in the range of 47.5–51.5 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5 Hz/s.

## VIII. CONTROL SCHEME

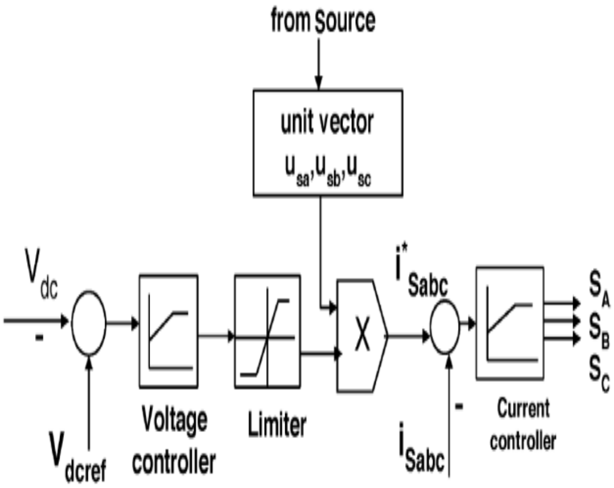


Figure 6: Control system scheme for STATCOM.

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller." The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation.

The control system scheme for generating the switching signals to the STATCOM is shown in Figure. The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode.

The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the nonlinear load and wind generator. The IGBT based three-phase inverter is connected to grid through the transformer. The generation of switching signals from reference current is simulated within hysteresis band of 0.08. The choice of narrow hysteresis band switching in the system improves the current quality. The control signal and switching frequency within its operating band can be choosing based on requirements.

The choice of the current band depends on the operating voltage and the interfacing transformer impedance. The compensated current for the nonlinear load and demanded reactive power is provided by the inverter. The real power transfer from the batteries is also supported by the controller of this inverter. The wind energy generating system is connected with grid having the nonlinear load

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## IX. PROPOSED SYSTEM SIMULINK

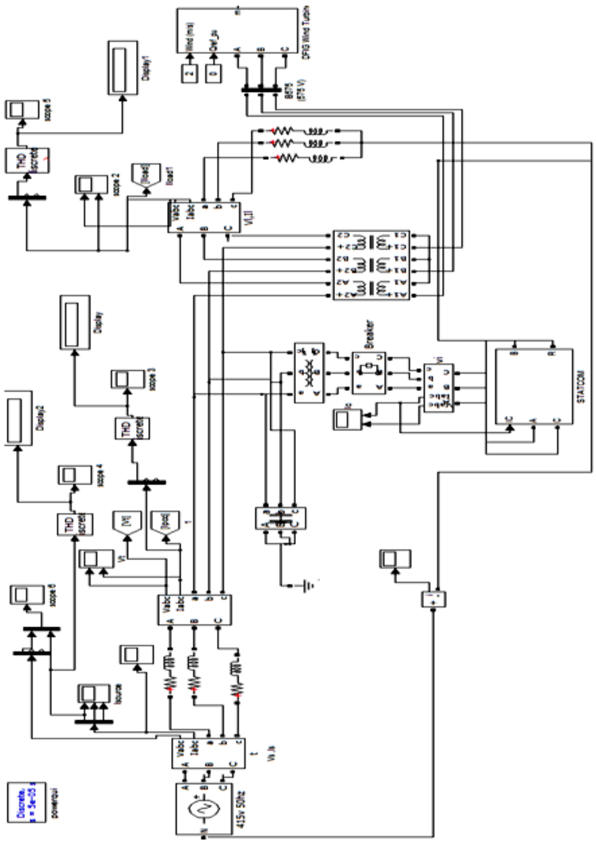

Figure 7 MATLAB/ Simulink Model Proposed System with STATCOM

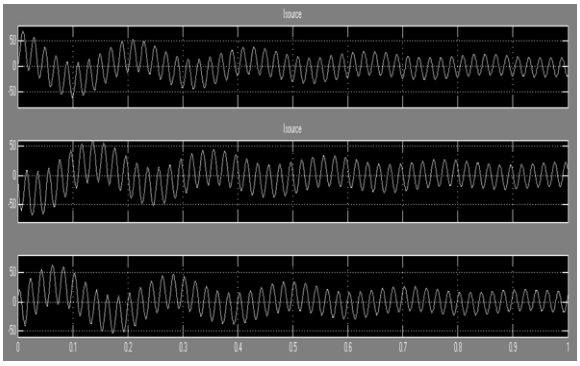

Figure 8:Three Phase Current Simulink

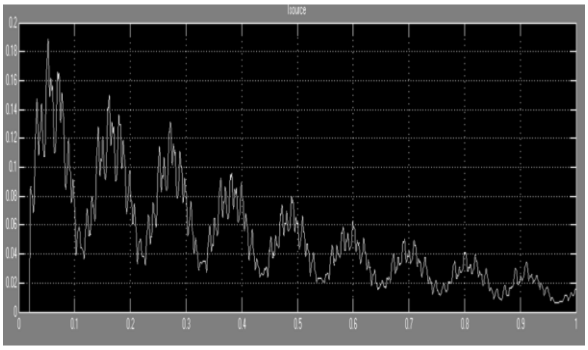

Figure 9: THD before Compensation Simulink

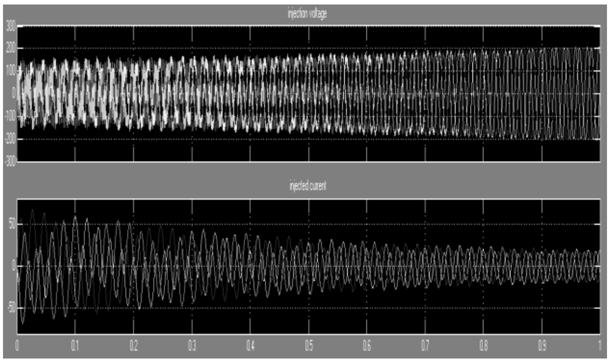

Figure 10: Figure Injection Voltage and Current

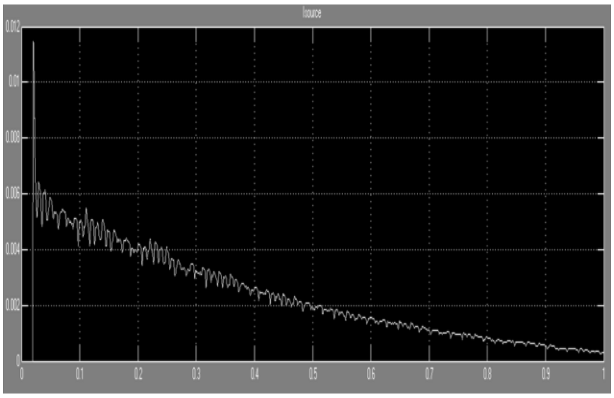

Figure 11: THD after Compensation

## X. RESULTS

The results of those graphs are given below with both devices STATCOM & UPFC:-

Table 1: Showing Result Values

| FACTS CONTROLLER | STATCOM TIME | STATCOM THD |
|---|---|---|
| Stability before Compensation (in sec) | 0.8 | 0.20 |
| Stability after Compensation | 0.1 | 0.08 |

## IX. CONCLUSION

The project presents the FACTS device (STATCOM) - based control scheme for power quality improvement in wind generating system on integration to the grid and with nonlinear load (3-phase 3-wire system). The operation of the control system developed for the STATCOM system in MATLAB/SIMULINK for maintaining the power quality is simulated. It has a capability to cancel out the harmonic parts of the load current. The system maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and load at PCC in the grid system, thus it gives an opportunity to enhance the utilization factor of transmission line. The integrated wind generation and STATCOM with wind energy have shown the outstanding performance

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