Improvement of Power Quality by Simulation of Large Hybrid Wind Integrated Power Generation using STATCOM

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Abstract— Injection of the hybrid wind power into an electric power grid affects the power quality in power system. The influence of the wind turbine(WT) in the electrical power grid system concerning the power quality measurements are-the active power(P), reactive power(Q), variation of voltage sag & flicker, voltage dip, harmonics, distortion and electrical behavior of switching operation and greater flexibility to optimized for loss evolution criteria since convertor can be generated & absorb reactive power (Q). The power quality problem mainly due to installation of wind turbine (WT) with the electrical power grid. In this proposed scheme SVC (STATCOM) is coupled at a point of common connected with a battery energy storage system (BESS) to mitigation the power quality issues. The battery energy storage (BESS) is integrated to sustain the real power (P) source under changing hybrid wind power system. The STATCOM control scheme for the grid coupled hybrid wind energy generation system for power quality improvement is simulation using MATLAB SIMULATED in electrical power system block set. The effectiveness of the proposed scheme relives the main power supply source from the reactive power (Q) demand of the load and the Static var generator. The development of the power grid current transmission system incorporated power electronic based & other static controller to static to enhance controllability and increases power transfer capability.

Key words: Static Compesator (SVC), Power Quality, Wind Generating System (WGS), BESS

I. INTRODUCTION

Wind power is the conversion of wind energy into useful form such as electricity, using wind turbines. Wind energy is directly used to crush grain or water pump .Wind energy is plentiful, renewable, widely distributed, cleans, and reduces greenhouse gas emissions when it displaces fossil-fuel-derived electricity. Today, modern energy industry faces a growing awareness regarding the impact of conventional power generation on the environment. Issues such as limited fossil fuel reserves, climate change due to $CO2$ emissions, bring to attention alternative technologies to generate electricity in a more sustainable manner The wind power has increased in the past few years, hence it has become necessary to address problems associated with maintaining a stable electric power system that contains different sources of energy including hydro, thermal, coal, nuclear, wind, and solar. In the past, the total installed hybrid wind power capacity was a small fraction of the power system and continuous connection of the wind farm to the grid was not a major concern. The wind farm capacity is being continuously increased through the installation of more and larger (WT) wind turbines. Voltage dip, voltage sag & voltage stability and an efficient fault ride through capability are the basic requirements for higher penetration. Flexible AC Transmission Systems (FACTS) such as the Static Synchronous Compensator (STATCOM) are used in power systems because of their ability to provide flexible power flow control. The main aim for choosing STATCOM in wind farms is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power(Q) into the system The STATCOM generator operated as a shunt connected static VAR compensator whose capacitive & inductive output current can be controlled in depended of system voltage. The methods used to develop an equivalence of a collector system in a large wind power plant are described in [5]. The requirements, assumptions and structure of an aggregate model of a wind park with constant speed turbine and variable speed turbines are discussed in [6].

II. PROBLEM IDENTIFICATION

Wind power is the conversion of hybrid wind integrated power into a useful form of non-conventional energy, such as using wind turbine to make electrical power generation & distribution. Hybrid Wind power is very consistent from few year but it has significant variation over shorter time scales. As the proportion of hybrid wind power generation in a region increases, a need to upgrade the power grid and a lowered ability to supplant conventional generation can occur. The power electronic switching devices such as Flexible AC Transmission System (FACTS) have been developed; introduction of customs power devices and the technology of emerging branch provide a modern control capability of power system. This project work describes how the WT installation creates power quality problem in power grid system. In the proposed system in order to solve the power quality issues a BESS coupled by STATIC COMPENSATOR (STATCOM) at a common point coupling. The real power (P) source under fluctuating hybrid wind power is sustained by the integrated battery energy storage.

III. METHODOLOGY

A. Basics of Wind Generation

Wind turbine utilizes the energy stored in air currents flowing close to earth's surface. The air currents create a torque on the rotor blades of the wind turbine and transfers wind's kinetic energy. The blades convert this energy into mechanical (rotational) form. A generator takes this mechanical energy as input and outputs electrical energy. Fig.4.1.1 shows an overview of the energy conversion process of a typical wind turbine. Each of these steps has its own efficiency factor. The efficiency of the overall process is the efficiency of the wind turbine.

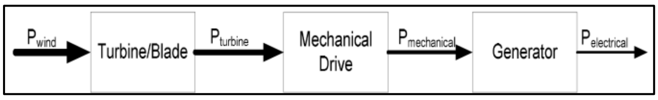
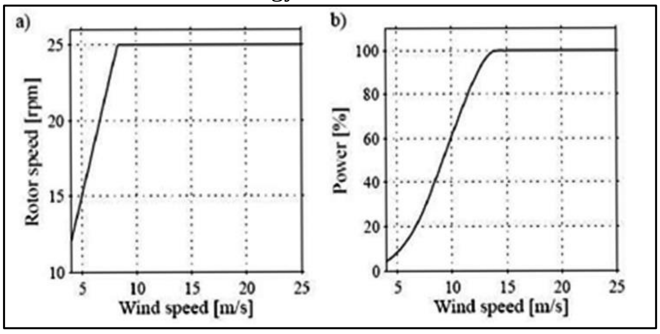


Fig. 3.1: Energy Conversion Process of a Wind Turbine (WT)

B. Energy from wind

The energy content of wind depends on its density, intercepting area and speed of impact on that area. For a wind turbine, the intercepting area is the area of the circle created by the rotation of the rotors. The following formula can be used to calculate the energy stored in wind.



$$P_{Wind} = \frac{1}{2}\rho A V^{3}_{Wind}$$

Where,

P=*wind* power stored in wind [W]

ρ =air density [kg/m^3]

A= intercepting area (area of the wind rotor) [m^2]

V=wind speed [m/s]

A wind turbine cannot extract all the power stored in the wind. If all the kinetic energy were transferred to the rotor blades, the air mass would stop completely near the wind turbine and any future energy conversion would be impossible. According to Betz' theorem, the theoretical maximum for energy conversion using wind turbines is limited to 59% of energy stored in the wind flowing through the turbine..

C. Wind Turbine System

Wind turbines can operate with either fixed speed or variable speed. For fixed-speed wind turbines, the generator (induction generator) is directly coupled to the power grid. Since the speed is almost fixed to the power grid frequency and most certainly not controllable, it is not possible to store the turbulence of the hybrid wind in form of rotational energy.

1) AC/DC Power Flow Equations

When the DC-link is included in the power flow equations, only the mismatch equations at the converter terminal AC buses have to be modified.

$$\Delta P_{tr} = P_{tr}^{spec} - P_{tr}^{ac}(\delta, v) - P_{dr}(V_{tr}, V_{ti}, x_{dc})$$

1) Rotor speed as a function of wind speed
2) Mechanical power as a function of wind speed

Fig 3.2 characteristics for a variable –speed wind turbine

D. Wind Turbine Components

Horizontal turbine components include:

– A tower that supports the rotor and drive train
– A drive train, usually including a gearbox and a generator;
– Blade or rotor, which converts the energy in the wind to rotational shaft energy;
– And other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.
– Wind turbines are often grouped together into a single wind power plant, also known as a wind farm, and generate bulk electrical power system. Electricity from these turbines is fed into a utility power grid and distributed to consumer as with conventional power plants.

E. Types of Wind Turbine

There are two types of wind turbine:

1) Fixed speed generator.
2) Variable speed generators.

1) Fixed and Variable Speed

Fixed speed generators are induction generators with capacitor bank for self-excitation or two-pole pairs or those which use rotor resistance control. Fixed Speed Wind Turbine is a concept that uses a Squirrel Cage Induction Generator (SCIG) directly connected to grid. Therefore the speed of this Wind turbine is fixed by the power grid frequency. In case of a power grid various fault there is a large amount of fault current contribution, thus the wind turbines need to relay on protection devices (over & under current, over- and under voltage, over and under frequencies). As a result FSWTs cannot connected grid code demands without any form of external support such as FACTS (STATCOM) devices.

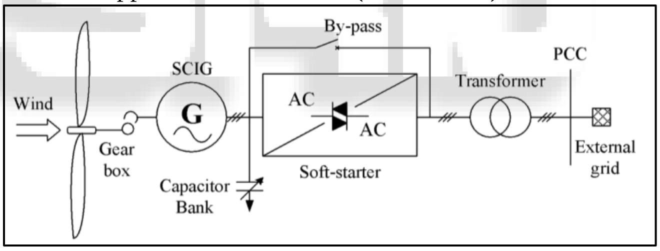


Fig. 3.5.1: Fixed-speed wind turbine with an induction generator.

2) Variable Speed Generators

Variable speed generators are either DFIG (which is a round rotor machine) or full power converters such as squirrel cage induction generators, permanent magnet synchronous generators, or externally magnetized synchronous generators. Variable speed wind turbines are coupled to the grid using power electronic technology and maximize effective turbine speed control. Second type of wind turbine is the Partial Variable Speed Wind Turbine with a variable rotor resistance.

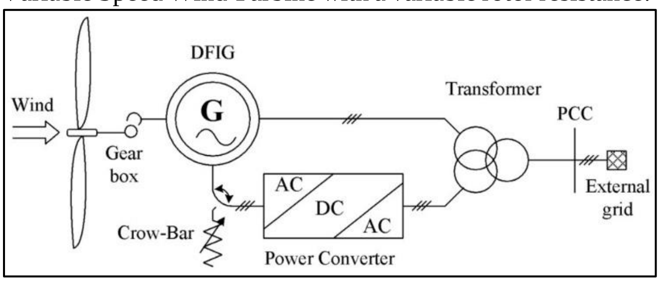


Fig. 3.5.2: Variable-speed wind turbine with a doubly-fed induction generator (DFIG)

IV. DISTRIBUTED GENERATION SYSTEM

In today's open energy market, distributed energy systems have an increasingly important role [17]. Distribution generated is an electric power source coupled directly to the distribution network or on the consumer side of the meter. A distributed energy system is a integrated system comprising of a number of energy suppliers and consumers, district heating pipelines, heat storage facilities and power transmission lines in a region. DG should not be exclusively confused with renewable energy generation.

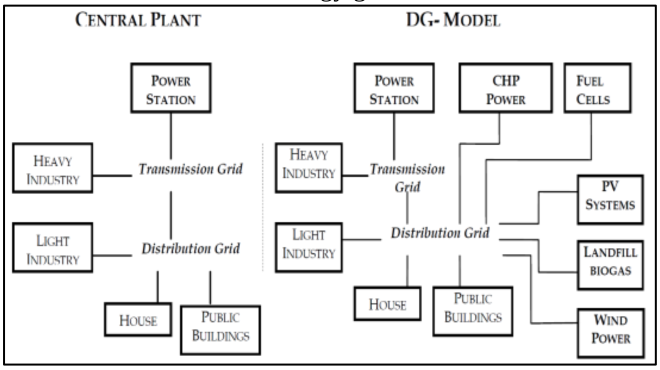


Fig. 4.0.1: Schematic diagram of traditionally central-plant model and DG-model

A. Flexibility in Needs Power Quality

Apart from large voltage drops to near zero (reliability problems), one can also have smaller voltage deviations. The latter deviations are aspects of power quality. Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage and current waveform, with current and voltage in balance. Thus, strictly speaking, power quality encompasses reliability. Insufficient power quality can be caused by failures and switching operations in the network (voltage dips and transients) and by network disturbances from loads (flickers, harmonics and phase imbalance).

B. Impacts on Power Quality

DG units are likely to affect the system frequency. As they are often not equipped with a load-frequency control, they will free ride on the efforts of the transmission grid operator or the regulatory body to maintain system frequency. Therefore, connecting a large number of DG units to the grid should be carefully evaluated and planned. The installation and connection of distributed generation units can positively affect the power quality.

C. Facts Devices & Capabilities

FACTS devices can be used in hybrid integrated wind power systems to improve the transient and dynamic stability of the overall power system. The STATCOM is from the family of FACTS devices that can be used effectively in hybrid wind farms to provide transient voltage support to prevent system collapse. In other words a STATCOM is an electronic generator of reactive power compensation.

The main difference between those two categories is that Voltage source convertor technology is much faster and has a bigger range of control [23].

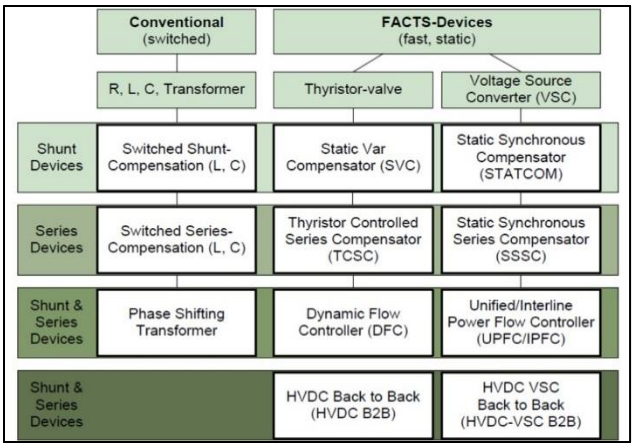


Fig. 4.3.1: FACTS Device

The FACTS controllers are mainly used for the following applications:

- Power flow control,
- Reactive power(Q) compensation,
- Power quality improvement,
- Voltage dip and sag control,
- Increase of transmission steady state stability capacity,
- Dynamic Stability improvement,
- Frequency collapse,
- Flicker mitigation,

In general, FACTS controllers can be divided into four categories:

- Series Controllers
- Shun Controllers
- Combined series-series Controllers
- Combined series-shunt Controllers

D. Electric Power Quality

Power Quality is a term that refers to maintaining the near sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency. Thus PQ is often used to express voltage quality, current quality, reliability of service, quality of power supply, etc. PQ has captured increasing attention in power engineering in recent years. In the study of PQ, different branches are being formed. They deal with different issues related to power quality. Power quality may be divided into following stages [26-28]:

1) Fundamental concepts
2) Sources
3) Effects
4) Modeling and Analysis
5) Instrumentation
6) Solutions

V. IMPLEMENTATION IN MATLAB (SIMULATION)

A. Modeling Of Power Quality Improvement

The STATCOM based(1) current control (2)voltage source inverter injects the current into the power 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. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality in power system.

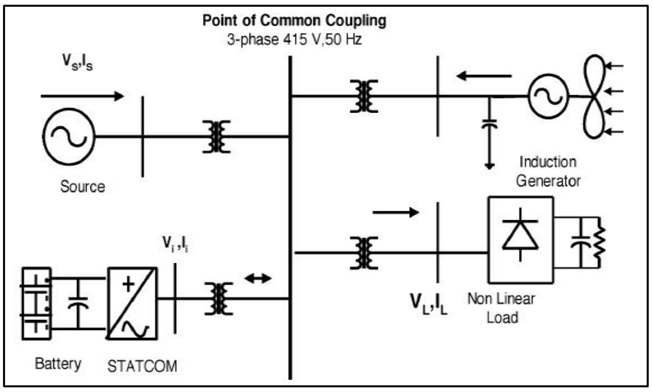


Fig. 5.1.1: Grid connected integrated wind energy system for power quality improvement

B. System Operation

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the power grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM compensator in the power system. A single STATCOM using IGBT is proposed to have a reactive power (Q) support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational power grid connected hybrid wind energy integrated system for power quality improvement.

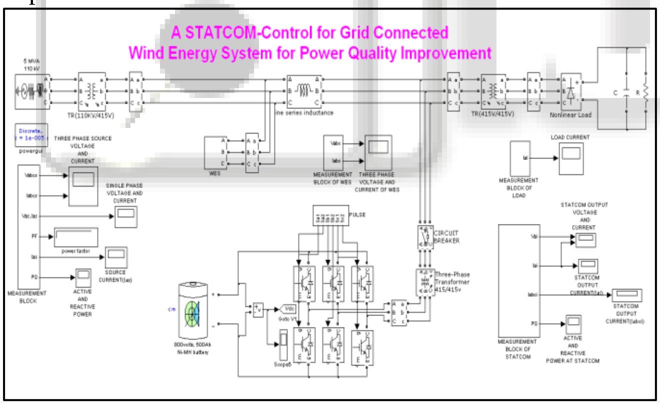


Fig. 5.2.2: Simulation model for STATCOM control

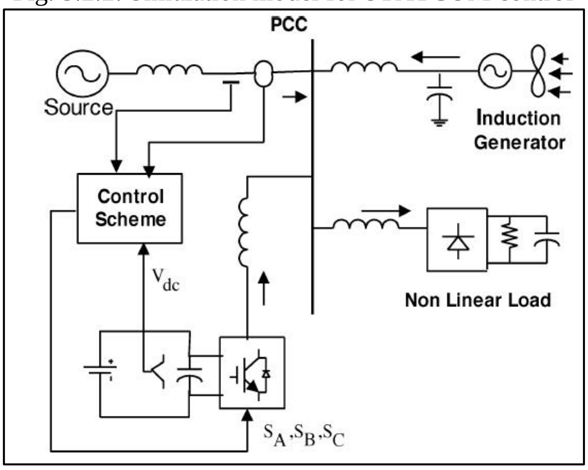


Fig. 5.2.3: control scheme with nonlinear load

C. Control system

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 Fig.4.6.10

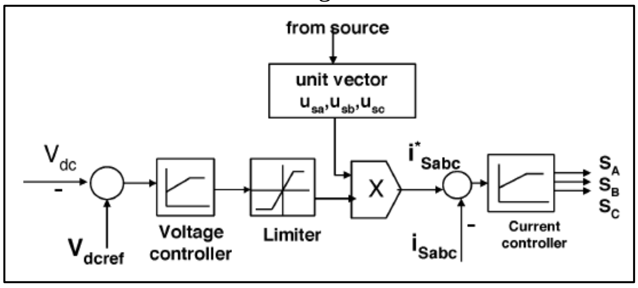


Fig. 5.3.1: hybrid Control system

VI. Modeling of Integrated Sub System

A. Hybrid Wind Energy System

Wind generation using wind turbine, pitch control, Induction Generator. Here we are using the induction generator as generating machine due to its advantages over other machines for its simplicity and economical factors. The pitch angle controller makes the angle of the turbine blade to adjust in such a way that the speed of rotation at every velocity of the wind is maintained constant. And the parallel capacitive bank is to supply the reactive power to the IM running as the generator. Here we considered the per unit values in the closed loop that can be seen from the fig 5.3.1. The rms values of the current and voltage generated is taken and the power is being measured

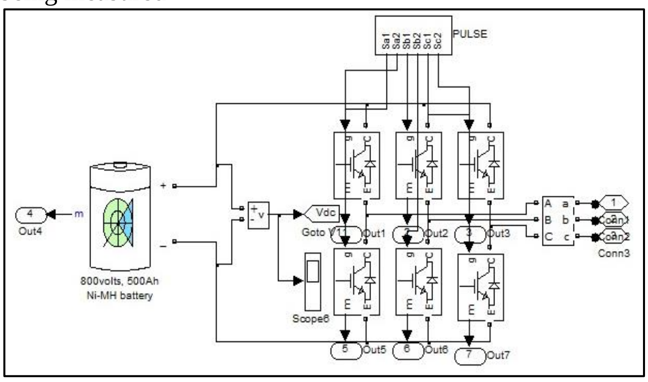


Fig. 6.1.1: Wind energy system

B. STATCOM (Voltage source invertor) with BESS and Controller

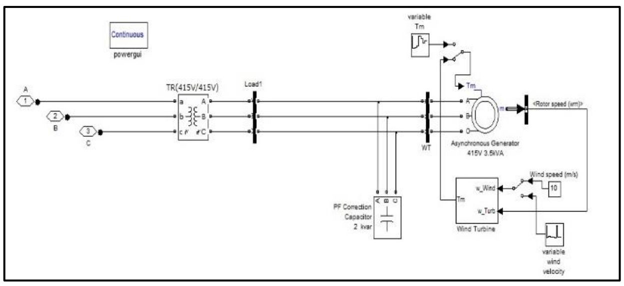


Fig. 6.2: Voltage source inverter with battery and

VII. RESULT & DISCUSSION

The wind energy generating system is connected with grid having the nonlinear load. The performance of the system is measured by switching the STATCOM at time s in the system and how the STATCOM responds to the step change command for increase in additional load at 0.22s is shown in the simulation. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to minimized for reactive power demand as well as harmonic current. The dynamic performance is also carried out by step change in a load, when applied at 0.21 s. This additional demand is fulfill by SVC. STATCOM can regulate the available real power(P) from source. The simulation results are shown in the various figures below.

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM compensator in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational scheme is shown in fig

VIII. SIMULATION RESULT

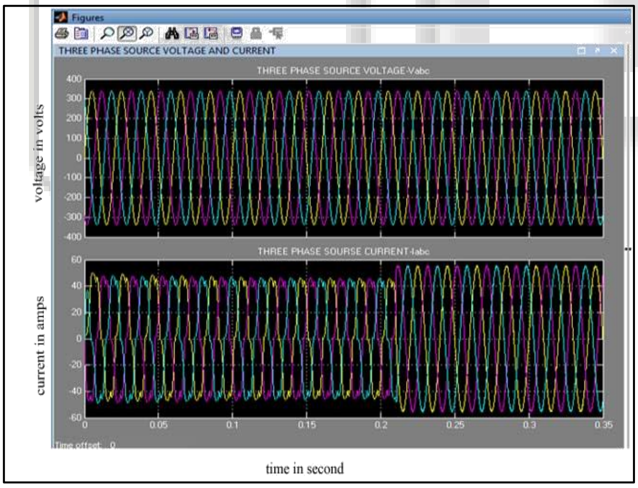


Fig. 7.1: Three phase source voltage and Current

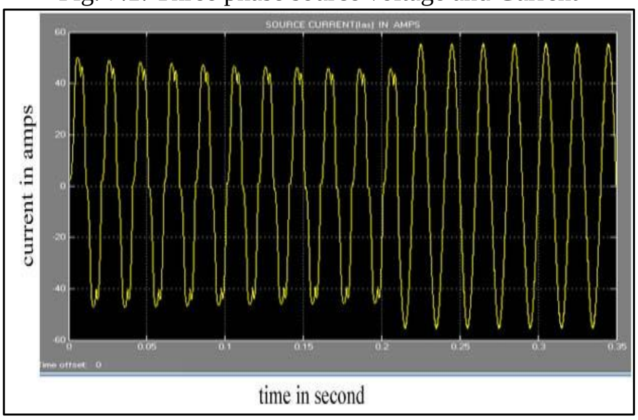


Fig.7.2: Source Current

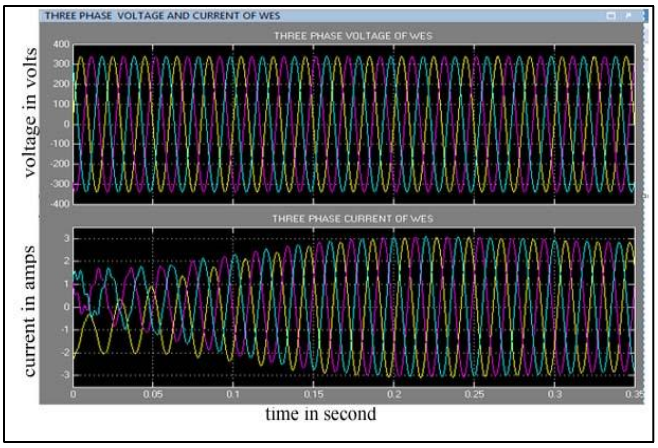


Fig. 7.3 3: phase Voltage and current of Wind Energy System

S.N.	Parameters	Ratings
1	Grid Voltage	3-Phase, 415V,50Hz
2	Induction Motor/Generator	3.35 KVA, 415V, 50Hz ,P=4, Speed=1440rpm, R_s=0.01Ω, R_r=0.015Ω, L_s=0.06H, L_r=0.06H
3	Line Series Inductance	0.05mH
4	Inverter Parameters	DC Link Voltage =800V DC Link capacitor=100μF Switching Frequency = 2 kHz
5	IGBT Rating	Collector Voltage =1200V, Forward Current =50A, Gate Voltage =20V, Power dissipation =310W
6	Load Parameter	Non-Linear Load =25kW

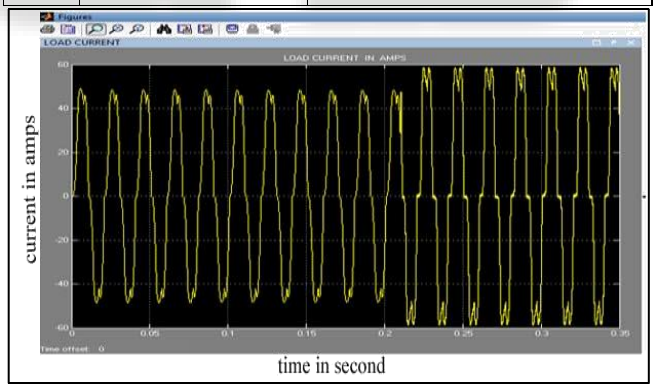


Fig. 7.4: Load Current in Amperes

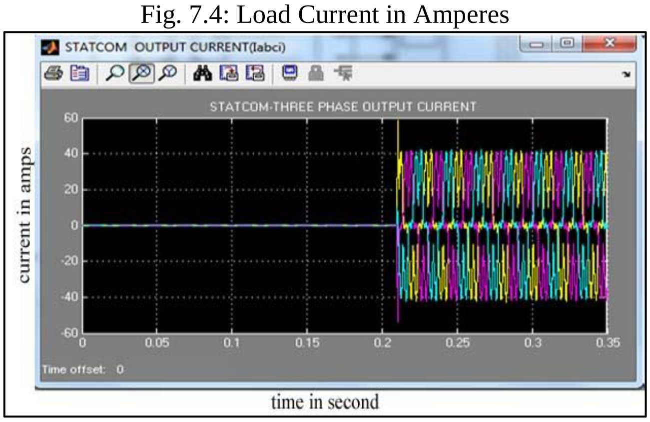


Fig. 7.5: Statcom Output Current

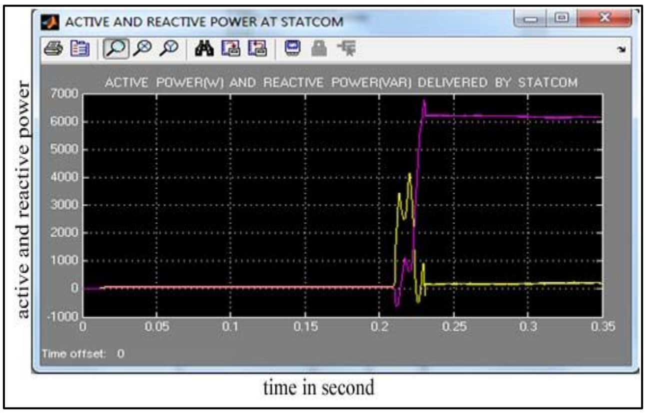


Fig. 7.6: Active (P) and Reactive Power (Q) in STATCOM

IX. Conclusion & Future Scope

A. Conclusion

In this paper we present the FACTS device (STATCOM) - based control scheme for power quality improvement in power grid coupled hybrid wind generating system and with nonlinear load. The power quality issues and its consequences on the consumer and electric utility are presented. The operation of the control system developed for the STATCOM in MATLAB/SIMULINK for maintaining the power quality is to be simulation. It has a capability to neutralize out the harmonic parts of the load current. It maintains the source voltage and current in-phase and support the reactive power (Q) demand for the hybrid wind generator and load at Power quality control in the grid system, thus it gives an opportunity to enhance the utilization factor of transmission line in power system.

Integrated hybrid wind generation and FACTS device with BESS have shown the outstanding performance in maintaining the voltage profile as per requirement. Thus the proposed scheme in the power grid coupled system fulfils the power quality improvement requirements and maintains the grid voltage free from harmonic distortion.

X. Future Scope

– STATCOM can be replaced with UPFC for better power quality control in power system.
– Change the Induction Generator with Doubly fed Induction generator is preferred for better results power quality.
– In future the off-shore wind turbines (WT) will be well modification due to its advantages of Generating high power.

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