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Increasing the Power Quality for Grid Connected Wind Energy System Using Facts

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Abstract:- Power quality is affected by injection of the wind power into an electric grid. Generated power from wind energy system is always fluctuating due to the fluctuations in the wind. To mitigate the power quality issues STATic COMpensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) is proposed here. Under fluctuating wind power the battery energy storage is integrated to sustain the real power source. The system is simulated using MATLAB/SIMULINK in power system block set.

Keywords:- Power Quality, Wind Generating System (WGS), STATCOM, BESS

I. INTRODUCTION

The demand of electricity increased dramatically nowadays, to satisfy this electrical demand, it is needed to utilize the renewable energy resources like wind, biomass, hydro, co-generation, etc, The renewable energy like wind need to integrate with power system to reduce the impact on environment. 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 serious issue in wind turbine is power quality. The rapid change in wind makes the behavior of wind generator quite different from conventional generator. In recent years there has been extensive growth and quick development in the exploitation of wind energy. The individual units can be of large capacity up to 2 MW, feeding into distribution network, particularly with customers connected in close proximity [8].

Large voltage fluctuations occur when all the fluctuations in the wind speed are transmitted as fluctuations in the mechanical torque in the fixed-speed wind turbine operation. During normal operation continuous variable output power was produced by wind turbine. The effect of turbulence, wind shear, and tower-shadow and control system in the power system causes the variations in power. Such fluctuations are needed to be managed by the network. 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. Induction generator which is connected directly to the grid system is the simple method of running a wind generating system. Cost effectiveness and robustness are the advantages of induction generator.

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. Power quality can be improved by the STATCOM-based control technology. Objectives are proposed by STATCOM control scheme for grid connected wind energy generation for power quality improvement are, unity power factor at the source side, reactive power support only from STATCOM to wind Generator and Load, simple bang-bang controller for STATCOM to achieve fast dynamic response. At the Point of Common Coupling (PCC) high performance steady state and transient voltage control have been achieved by the Shunt Flexible AC Transmission System (FACTS) devices, such as the Static Var Compensator (SVC) and the Static Synchronous Compensator (STATCOM) [8]. In [9] applications of SVC or a STATCOM to fixed-speed wind turbines equipped with induction generators have been reported for steady state voltage regulation, and in [1] for short-term transient voltage stability. The remaining of this paper has been organized as: Section II introduces the wind turbine model. Section III introduces STATCOM controller section IV describes Grid coordination rules. Section V gives overall system design. Control Scheme is described in section VI. Simulation results are presented in Section VII. Finally the work is concluded with future enhancement.

II. WIND TURBINE MODEL

The aerodynamic model of a wind turbine can be characterized by the well-known CP-λ-β curves. CP is called power coefficient, which is a function of both tip-speed-ratio λ and the blade pitch angle β. The tip-speed-ratio λ is defined by $\Lambda= \omega t\ R/vw$ (1)

Where R is the blade length in m, ωt is the wind turbine rotor speed in rad/s, and vw is the wind speed in m/s. The CP-λ-β curves depend on the blade design and are given by the wind turbine manufacturer. Given the power coefficient CP, the mechanical power extracted by the turbine from the wind, is calculated by

$$P_m = ½ \rho A_r V_w^3 C_p(\lambda,\beta) \qquad (2)$$

Where ρ is the air density in kg/m^3; Ar = πR2 is the area in m2 swept by the rotor blades. At a specific wind speed, there is a unique value of ωt, to achieve the maximum power coefficient C_P and thereby extract the maximum mechanical (wind) power. If the wind speed is below the rated (maximum) value, the wind turbine operates in the variable speed mode, and the rotational speed is adjusted such that the maximum value of CP is achieved. In this operating mode, the wind turbine pitch control is deactivated and the pitch angle β is fixed at 0○. If the wind speed is above the rated value, the rotor speed can no longer be controlled within the limits by increasing the generated power, as this would lead to overloading of the generator and/or the converter. In this situation, the pitch control is activated to increase the wind turbine pitch angle to reduce the mechanical power extracted from wind[1].

III. STATCOM MODEL

Shunt connected FACTS device STATCOM also known as an advanced static VAR compensator. At the fundamental frequency, with rapidly controllable amplitude and phase angle it generates a set of balanced three-phase sinusoidal voltages. Voltage support is a typical application of STATCOM. STATCOM is used for voltage support. In this paper, the STATCOM is modeled as a IGBT PWM converter with a dc-link capacitor. The objective of the STATCOM is to regulate the voltage at the PCC rapidly in the desired range and keep its dc-link voltage constant. It can enhance the capability of the wind turbine to ride through transient disturbances in the grid.

IV. GRID COORDINATION RULE

Grid code for the inter-connection of the wind plants to the utility system was adopted in the United States by the American Wind Energy Association (AWEA). Distribution level was first focused in grid code, after the blackout in the United State in August 2003. The rules for realization of grid operation of wind generating system at the distribution net-work 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.

1. 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 [2], given in (3)

$$\Delta u = \frac{smax\ (Rcos\Phi - Xsin\Phi)}{u^2} \qquad (3)$$

where, Δu -voltage rise, smax —max. apparent power, Φ—phase difference, U—nominal voltage of grid.
The Limiting voltage rise value is <2 %

2) 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 (4).

$$D = Ku\ sn/sk \qquad (4)$$

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

3) 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 in (5)

$$P\mathbf{u} = c\ (\psi k)\ \ sn/sk \qquad (5)$$

Where P$\mathbf{u}$ - Long term flicker. c (ψk) - Flicker coefficient . The Limiting Value for flicker coefficient is about ≤ 0.4, for average time of 2 h [6].

4) 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)

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{Vn^2}{V_1}} 100 \qquad (6)$$

Where Vn is the nth harmonic voltage and V1 is the fundamental frequency (50) Hz.
The THD limit for 132 KV is < 3%. THD of current ITHD is given as in (7)

$$I_{THD} = \sqrt{\sum_{h=2}^{40} \frac{In^2}{I_1}}100 \qquad (7)$$

where In is the nth harmonic current and I1is the fundamental frequency (50) Hz. The THD of current and limit for 132 KV is <2.5%.

5) Grid Frequency: The grid frequency in India is specified in the range of 47.5–51.5 Hz, for wind farm connection.

V. GRID CONNECTED SYSTEM FOR POWER QUALITY IMPROVEMENT

The current is inject 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 by the STATCOM based current control voltage source inverter.

The reactive part and harmonic part of the load and induction generator current is cancelled out by injected current this lead to the power factor and the power quality improvement. The grid voltages are sensed and were synchronized in generating the current command for the inverter to accomplish above goals. Fig. 1. shows the proposed grid connected system and it is implemented for power quality improvement at the point of common coupling (PCC). Wind energy generation system and battery energy storage system with STATCOM were included in grid connected system.

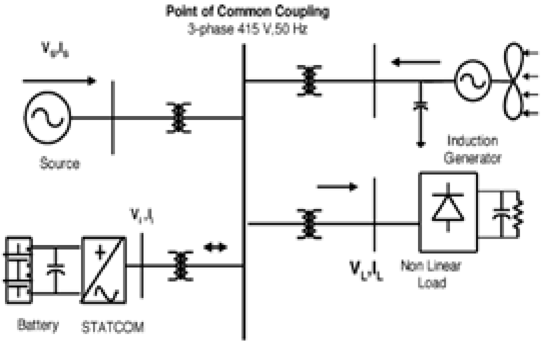

Fig. 1. Grid connected system for power quality improvement.

A.WIND ENERGY GENERATING SYSTEMS

Wind generations are based on constant speed topologies with pitch control turbine. Due to the simplicity of induction generator is used in the proposed scheme, a separate field circuit not needed, constant and variable loads can accepted, and has natural protection against short circuit. The available power of wind energy system is shown in (8)

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^3 \qquad (8)$$

Where ρ(kg/m) is the air density and A(m^2) is the area swept out by turbine blade, V_{wind} is the wind speed in mtr/s. It extract a fraction of power in wind because it impossible to extract all kinetic energy of wind, called power coefficient Cp of the wind turbine.

$$P_{mech} = C_p P_{wind} \qquad (9)$$

Where Cp is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be express as a function of tip speed ratio γ and θ pitch angle. The mechanical power produce by wind turbine is given in (10)

$$P_{wind} = \frac{1}{2}\rho \Pi R^2 V_{wind}^3 C_p \qquad (10)$$

Where R is the radius of the blade (m).

B. BESS- STATCOM

For voltage regulations the battery energy storage system (BSSS) is used as an energy storage element. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It quickly controls the distribution and transmission system. Power fluctuation leveled by BESS by charging and discharging operation when power fluctuation occurs in the system. The battery is connected in parallel to the dc capacitor of STATCOM [3]–[4]. The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.

C. 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. According to the controlled strategy the STATCOM compensator output is varied, so as the power quality norms maintained in the grid system. The control scheme that defines the functional operation of the STATCOM compensator in the power system included in the current control strategy. 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. Fig.2. shows system operational scheme.

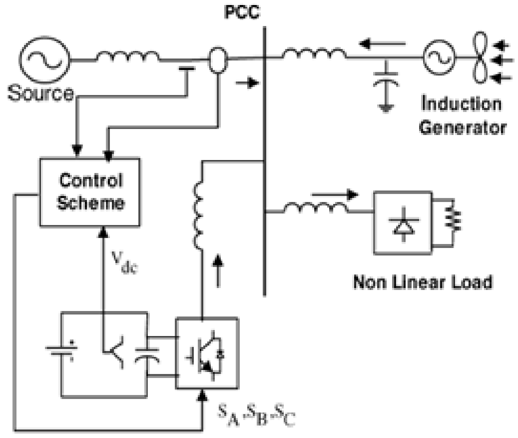

Fig. 2. System operational scheme in grid system.

VI. CONTROL SCHEME

Bang-Bang controller used to inject the current in to grid in the control scheme approach. The controller uses a hysteresis current controlled technique. The control system variable is kept between boundaries of hysteresis area and gives correct switching signals for STATCOM operation using this technique. The control system scheme for generating the switching signals to the STATCOM is shown in Fig. 3.The measurements of several variables needed for control algorithm, such as three-phase source current, DC voltage, inverter current with the help of sensor. An input of reference current is received by current control block, and to activate the operation of STATCOM in current control mode actual current are subtracted [5] [7]. In three-phase balance system, at the sampling frequency from the source phase voltage (Vsa, Vsb, Vsc), the RMS voltage source amplitude is calculated and is expressed, as sample template, sampled peak voltage, as in (11)

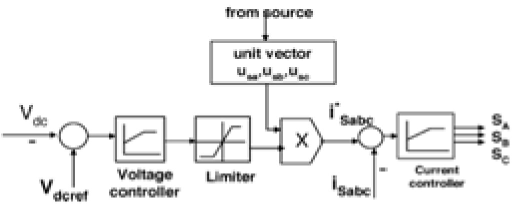

Fig. 3. Control system scheme

$$V_{sm} = \left\{\frac{1}{2}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)\right\}^{1/2} \qquad (11)$$

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector (Usa, Usb, Usc) as shown in bellow (12)

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, \quad U_{sb} = \frac{V_{sb}}{V_{sm}}, \quad U_{sc} = \frac{V_{sc}}{V_{sm}}, \qquad (12)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as bellow (13)

$$i^*_{Sa} = I. U_{Sa}\ , \quad i^*_{Sb} = I. U_{Sb}\ , \quad i^*_{Sc} = I. U_{Sc} \qquad (13)$$

Where I= is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal. In the current control scheme the Bang-Bang current controller implemented. The reference current is generated and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBT of STATCOM are derived from hysteresis controller. The switching function SA for phase ‘a’ is expressed as bellow

$$i_{sa} < (i^*_{sa} - HB) \rightarrow S_A = 0 \qquad (14)$$

$$i_{sa} > (i^*_{sa} - HB) \rightarrow S_A = 1 \qquad (15)$$

Where HB is a hysteresis current-band, similarly the switching function S_b, Sc can be derived for phases “b” and ”c”.

VII. SIMULATION RESULTS

The proposed control scheme is simulated using SIMULINK in power system block set. Fig 4 shows the simulation model of the conventional system.

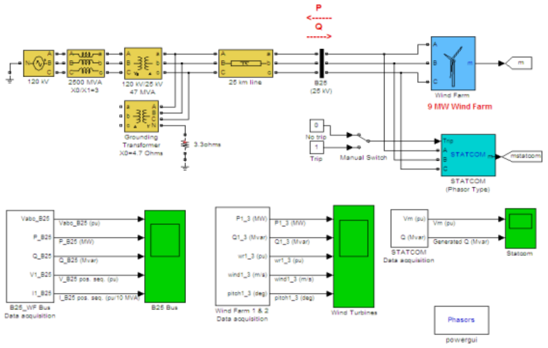

Fig. 4. The conventional based STATCOM model

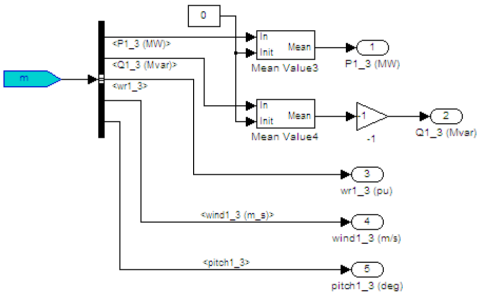

Fig. 5. Control model of wind turbine

Fig. 6 shows (in an extended view of the first 20 ms of the transient) the response obtained with different values of real power, reactive power, wind speed, wind turbine speed, pitch angle for the values of wind turbine.

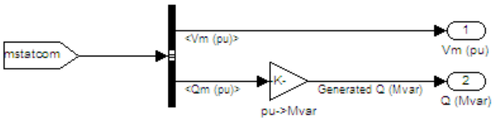

Fig. 6. Control model of STATCOM

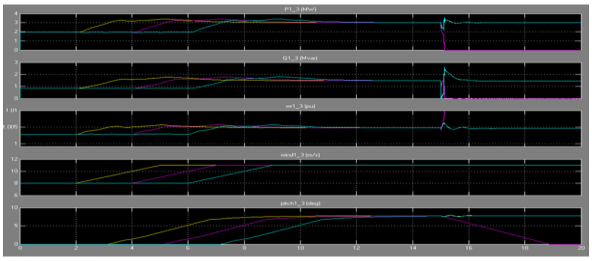

Fig. 7. Wave forms of real power, reactive power, wind speed, wind turbine speed, pitch angle for the systems of wind turbine.

The simulated results, as shown in Fig. 8, illustrate how the STATCOM shown in Fig. 6 responds to step change commands for increasing and decreasing its reactive power output and voltage changes, where the units 3 phase bus voltages, reactive current, ac voltage, ac output current, and reactive power output are kV, kA, p.u., p.u., and Mvar, respectively.

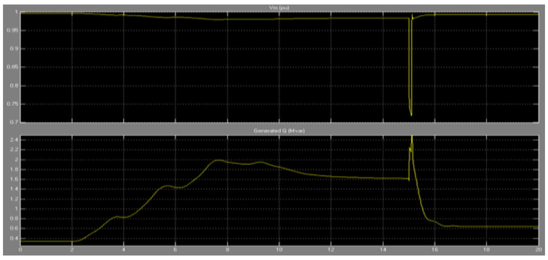

Fig. 8. Wave form of STATCOM voltage and reactive power

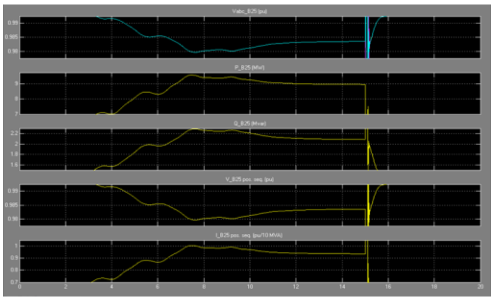

Fig. 9. Wave form of PCC or Grid parameters with STATCOM control

VIII. CONCLUSION

The power quality improvement in grid connected wind generating system and with nonlinear load was achieved with STATCOM-based control scheme. Wind turbine model, STATCOM model and Grid coordination rules were presented. The operation of the control system developed for the STATCOM-BESS in MATLAB/SIMULINK for maintaining the power quality is simulated. The STATCOM based controller not only control current from stator also improves stability, it can mitigate both current and voltage harmonics occurring in the system because of natural phenomenon or due to external sources.

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