IMPROVEMENT OF POWER QUALITY IN WIND ENERGY SYSTEM USING STATCOM

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Abstract- This paper presents improvement of power quality in wind energy system using STATCOM (Static compensator). The project study demonstrates the power quality problem due to installation of wind turbine with the grid. The power quality measurements are- the active power, reactive power, variation of voltage(sag, swell), flicker, harmonics and electrical behavior of switching operation. In this proposed scheme static compensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The main functional requirements of the STATCOM in this paper are to provide shunt compensation, operating in capacitive mode only, in terms of the following; voltage stability control in a power system, as to compensate the loss voltage along transmission. Here two control schemes for STATCOM are compared: Bang-Bang current controller and Fuzzy logic controller. In this paper its operation and its simulation diagram is discussed. The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system bock set.

Keywords- STATCOM, power quality, wind energy system, BESS, Bang-Bang current controller, Fuzzy logic controller.

I. INTRODUCTION

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. 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. The issue of power quality is of great importance to the wind turbine. 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.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

A static synchronous compensator (STATCOM), also known as a static synchronous condenser (STATCON), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage source converter and can act as either a source or sink of reactive AC power to an electricity network. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. If connected to a source of power it can also provide active AC power.

It is a member of the FACTS family of devices. There is a similar device to STATCOM they are SVC (static VAR compensator) can also be used for voltage stability. The response time of a STATCOM is shorter than that of static VAR compensator (SVC), mainly due to the fast switching
times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage. However, a STATCOM has better characteristics than SVC.

Fig 1: STATCOM (static compensator)

III. OPERATING PRINCIPLES OF STATCOM

To understand the working principle of STATCOM, we will first have a look at the reactive power transfer equation. Let us consider two sources V1 and V2 are connected through an impedance Z = Ra + jX as shown in figure below.

Assuming Ra is zero,
The flow of reactive power is given as
Q = (V2/X)[V1cosδ - V2]

In the above reactive power flow equation, angle δ is the angle between V1 and V2. Thus if we maintain angle δ = 0 then Reactive power flow will become
Q = (V2/X)[V1 - V2]
and active power flow will become
P = V1V2Sinδ / X = 0

To summarize, we can say that if the angle between V1 and V2 is zero, the flow of active power becomes zero and the flow of reactive power depends on (V1 – V2). Thus for flow of reactive power there are two possibilities.
1) If the magnitude of V1 is more than V2, the reactive power will flow from source V1 to V2.
2) If the magnitude of V2 is more than V1, reactive power will flow from source V2 to V1.
This principle is used in STATCOM for reactive power control. Now we will discuss about the design of STATCOM for better correlation of working principle and design.

Design of STATCOM:
STATCOM has the following components:
1) A Voltage Source Converter, VSC
The voltage-source converter is used to convert the DC input voltage to an AC output voltage. Two of the common VSC types are as below.
a) Square-wave Inverters using Gate Turn-Off Thyristors
b) PWM Inverters using Insulated Gate Bipolar Transistors (IGBT)
2) DC Capacitor
DC Capacitor is used to supply constant DC voltage to the voltage source converter, VSC.
3) Inductive Reactance A Transformer is connected between the output of VSC and Power System. Transformer basically acts as a coupling medium. In addition, Transformer neutralize harmonics contained in the square waves produced by VSC.
IV. POWER QUALITY IMPROVEMENT

Power Quality is a measure of how well a system supports reliable operation of its loads. A power disturbance or event can involve voltage, current or frequency variations. Power disturbances can originate in consumer power systems, consumer loads, or the utility because of non-linear loads, adjustable speed drives, traction drives, start of large motor loads, arc furnace, lightning etc. Typical power quality disturbances are voltage variation (voltage swelling, voltage sag) frequency variation & waveform distortion.

In this proposed scheme Static Compensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC). The grid connected system in Fig.2, consists of wind energy generation system and battery energy storage system with STATCOM.

A. 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 does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented.

Where \( \rho \) (kg/m) is the air density and \( A \) (m²) is the area swept out by turbine blade, \( V_{\text{wind}} \) is the wind speed in mtr/s. It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient \( C_p \) of the wind turbine.

Where \( C_p \) 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 and pitch angle. The mechanical power produces by wind turbine.

\[
P_{\text{wind}} = \frac{1}{2} \rho A V_{\text{wind}}^3 \quad (1)
\]

Where \( \rho = \text{air density (kg/m}^3\) , \( A = \text{area swept out by turbine blade (m }) , \) \( V_{\text{wind}} = \text{wind speed (m/s})). \) It is not possible to extract all kinetic energy of wind. Thus extracts a fraction of the power called power coefficient \( C_p \) of the wind turbine, and is given by:-

\[
P_{\text{mech}} = C_p P_{\text{wind}} \quad (2)
\]

The mechanical power produced by wind turbine is given by:-

\[
P_{\text{mech}} = \frac{1}{2} \rho \Pi R^2 V_{\text{wind}}^3 \quad C_p \quad (3)
\]
Where, \( R = \text{Radius of the blade (m)} \).

**B. BESS-STATCOM**

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbs reactive power to stabilize the grid system. When power fluctuation occurs in the system, the BESS is used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM.

**C. System Operation**

The shunt connected STATCOM with battery energy storage is connected at the interface of the induction generator and non-linear load at the PCC. The Fig 2 represents the system operational scheme in grid system. The STATCOM output is varied according to the control strategy, so as to maintain the power quality norms in the grid system. The current control strategies for STATCOM are the Bang-Bang controller and fuzzy logic controller. A single STATCOM using insulated gate bipolar transistors is proposed to have a reactive power support to the induction generator and to the non-linear load in the grid system.

**D. Control Scheme**

The first control scheme approach is based on injecting the currents into the grid using “bang-bang controller”. The controller uses a hysteresis current controlled technique as shown in Fig 2. Using such a technique, the controller keeps the control system variable between the boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The current controller block receives reference current and actual current as inputs and are subtracted so as to activate the operation of STATCOM in current control mode. The second control scheme is fuzzy logic controller. The inputs to the controller ‘change in grid voltage (\( \Delta V \))’ and ‘change in grid current (\( \Delta I \))’ and is represented as membership functions of the controller .The output is correct switching signals for IGBTs of STATCOM (\( \Delta U \)).

**E. Bang-Bang Current Controller**

It is implemented in the current control scheme. The reference current is generated as in equation (6) 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 IGBTs of 125 STATCOM are derived from hysteresis controller. The switching function \( S_A \) for phase ‘a’ is expressed as:

\[
S_A = \begin{cases} 
1 & \text{if } i_{abc} > i_{sat} \\
0 & \text{if } i_{abc} < i_{sat} 
\end{cases}
\]

This is same for phases ‘b’ and ‘c’.

**F. Fuzzy Logic Controller**

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The objectives include excellent rejection of input supply variations both in utility and in wind generating system.
and load transients. Expert knowledge can also be participated with ease that is significant when the rules developed are intuitively inappropriate. The rule base developed is reliable since it is complete and generated sophisticatedly without using extrapolation. In this paper, fuzzy control is used to control the firing angle for the switches of the VSI of STATCOM. In this design, the fuzzy logic based STATCOM has two inputs ‘change in voltage(ΔV)’ and ‘change in current(ΔI)’ and one control output(ΔU). Firstly the input values will be converting to fuzzy variables. This is called Fuzzification. After this, fuzzy inputs enter to rule base or interface engine and the outputs are sent to defuzzification to calculate the final outputs. These processes are demonstrated in Fig 4. Here seven fuzzy subsets have been used for two inputs. These are: PB (positive big), PM (positive medium), PS (positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big).

**Fuzzification:** It is the process of representing the inputs as suitable linguistic variables. It is first block of controller and it converts each piece of input data to a degree of membership function. It matches the input data with conditions of rules and determines how well the particular input matches the conditions of each rule.

**Defuzzification:** It is the Process of converting fuzzified output into a crisp value. In the defuzzification operation a logical sum of the results from each of the rules performed. This logical sum is the fuzzy representation of the change in firing angle (output). A crisp value for the change in firing angle is calculated. Correspondingly the grid current changes and improves the power quality.

**IV. SYSTEM PERFORMANCE**

The proposed control scheme is simulated using MATLAB/SIMULINK in power system block set. 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 t=0.7s in the system and how the STATCOM responds to the step change command for increase in additional load at 1.0 s.
Fig 5. Simulink model of occurrence of sag and swell
Fig 6. Occurrence of sag without STATCOM

Fig 7. Load voltage with STATCOM

Fig 8. Occurrence of swell without STATCOM

Fig 9. Load voltage with STATCOM
V. CONCLUSION

The paper presents the STATCOM-based control scheme for power quality improvement in grid connected 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-BESS in MATLAB/SIMULINK for maintaining the power quality is simulated. It has a capability to cancel out the harmonic parts of the load current. It 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 BESS have shown the outstanding performance.

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