Voltage Stability Analysis of Doubly Fed Induction Generator for Wind Power Plant Using STATCOM

[1] Mr. Ravi H Patel, [2] Assistant Prof. Samir Chauhan,

[1]P.G Student, [2]Assistant Prof. at Sigma Institute of Engineering, Vadodara
[1]Electrical Engineering
[1]Sigma Institute of Engineering, Vadodara, India

***Abstract* - Electricity generation from wind has grown sharply and its growth potential is still significant. Unlike conventional sources, wind does not provide reactive power, which is necessary to maintain acceptable voltage conditions on the network. This paper deals with the implementation of FACTS controller called static synchronous compensator STATCOM to improve the performance of the grid connected wind farms. The control scheme of the DFIG rotor-side converter, grid-side converter and the STATCOM are suitably designed and coordinated. The essential feature of the STATCOM is that it has the ability to absorb or inject fast the reactive power with power grid. Therefore the voltage regulation of the power grid with STATCOM FACTS device is achieved. Moreover restoring the system stability after severe disturbance is achieved by using the STATCOM.**

***Keywords* - FACTS; Voltage Stability; STATCOM**

I. INTRODUCTION

The increased share of wind in electricity generation makes more and more complex integration in the system of electricity transmission Wind energy a significant proportion of non pollutant energy generation. If a large wind farm which electrically is far away from its connection point to power system, is not fed by adequate reactive power, it present major instability problem. In order to address the power quality issues that arise due to the integration of wind turbine with the grid, the grid operators have imposed stringent regulations requiring the wind turbines and wind Farms to full fill power plant properties. This necessitates the use of highly sophisticates and FACTS. They are able to provide rapid active and reactive power compensations to power systems, and therefore can be used to provide voltage support and power flow control, increase transient stability and improve power oscillation damping.

II. VOLTAGE STABILITY

The ability of a power system to maintain steady state voltages at all the buses after being subjected to a disturbance is known as voltage stability. There are many reasons leading to voltage instability causing system voltage collapse i.e., a phenomenon which makes the grid voltage to decrease to a level that is unacceptable and is unable to recover leading to interruption of the power supply in the system. Slow variations in the power system eventually lead to voltage collapse which can be analyzed in the steady state voltage study. This can be seen from the "PV" curve or "nose" curve which is the plot of the power with the voltage at the bus. Fig.1. is a typical P-V curve plot obtained from the equation 1 shown.

$$V = \{\left(\frac{E^2}{2}\right) - QX \pm \sqrt{[\left(\frac{E^4}{4}\right) - P^2X - E^2QX]}\} \quad (1)$$

Where V is the bus voltage, E is the terminal voltage, Q is the reactive power, P is the active power and X is the reactance.\

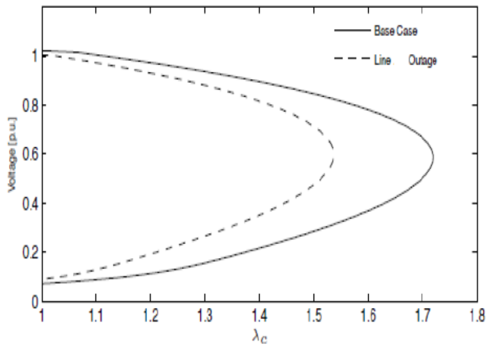

Fig.1. P-V Curve

In Fig.1.λc (loading parameter in p. u.) is marked along the X axis and V (bus voltages in p. u.) is marked along the Y axis. It can be seen from the figure that as the power transfer increases, the voltage at the receiving end decreases, eventually reaching a nose point where any further increase in the power transfer leads to a rapid decrease in voltage magnitude. The region above the nose point is referred to as the stable region and region below is the unstable region.

III. WIND ELECTRIC GENERATOR

The kinetic energy of moving air molecules are converted into rotational energy by the rotor of wind turbine. This rotational energy in turn is converted into electrical energy by wind electric generator. The mathematical relation for the mechanical power extraction from the wind can be expressed as follows:

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$$P_t = \frac{1}{2}.\sigma.\pi.\ R^2.\ v^3.c_p(\lambda, ß) \quad (2)$$

Where,

P = power contained in the wind (W)

p = air density (kg/m3)

R is the blade radius [m]

A = rotor area (m2)

V=wind velocity before rotor interference (m/s)

Cp= Power coefficient.

In this operating mode, the wind turbine pitch control is deactivated and the pitch angle Beta (ß) 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 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 the wind. The Cp- λ curves are shown in Figure (2) for different values of Beta (ß).

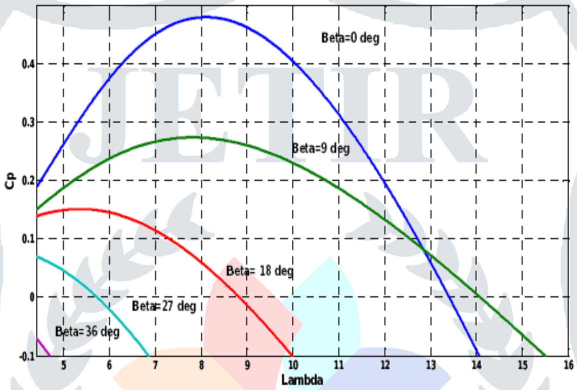


Fig.2 CP- λ curves for different pitch angles

IV. MODELING OF DFIG

The DFIG is used to produce electrical power at constant frequency whatever wind and shaft speed conditions. We used the classical d–q magnetization of the induction generator in the Park reference frame. The equations for a DFIG are identical with a squirrel-cage induction generator, except that the rotor voltages are not zeros. The basic grid connected DFIG WT with a back-to-back converter is shown in fig.3.

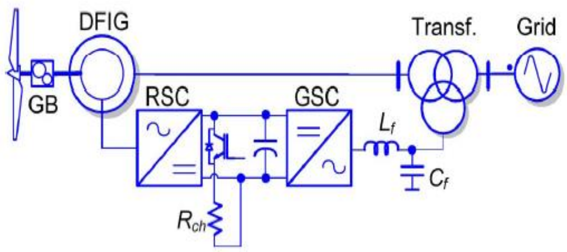


Fig.3 Grid-connected DFIG WT with a back-to-back converter

$$V_{ds} = R_s I_{ds} + \frac{d}{dt}\emptyset_{ds} - w_s\emptyset_{qs} \quad (3)$$

$$V_{qs} = R_s I_{qs} + \frac{d}{dt}\emptyset_{qs} + w_s\emptyset_{ds} \quad (4)$$

$$V_{dr} = R_r I_{dr} + \frac{d}{dt}\emptyset_{dr} - w_r\emptyset_{qr} \quad (5)$$

$$V_{qr} = R_r I_{qr} + \frac{d}{dt}\emptyset_{qr} + w_r\emptyset_{dr} \quad (6)$$

Where,

$$\emptyset_{ds} = L_s I_{ds} + L_m I_{dr} \quad (7)$$

$$\emptyset_{qs} = L_s I_{qs} + L_m I_{qr} \quad (8)$$

$$\emptyset_{dr} = L_r I_{dr} + L_m I_{ds} \quad (9)$$

$$\emptyset_{qr} = L_r I_{qr} + L_m I_{qs} \quad (10)$$

The mechanical equation is:

$$T_e = T_1 + fw + j\frac{dw}{dt} \quad (11)$$

V_{ds} , V_{qs} are the stator direct and quadrature voltages referred to synchronously rotating co-ordinate (V)
V_{dr} , V_{qr} rotor direct and quadrature voltages referred to synchronously rotating coordinate (V)
Ids, Iqs stator direct and quadrature currents referred to synchronously rotating coordinate (A)
I_{dr} , I_{qr} Rotor direct and quadrature currents referred to synchronously rotating coordinate (A)
L_s , L_r Per phase stator and rotor self inductance respectively (H)
P number of poles pairs of the machine
Te, electromagnetic torque (N m)
J moment of inertia of the machine (kg-m2)

Rotor-Side Converter Control System

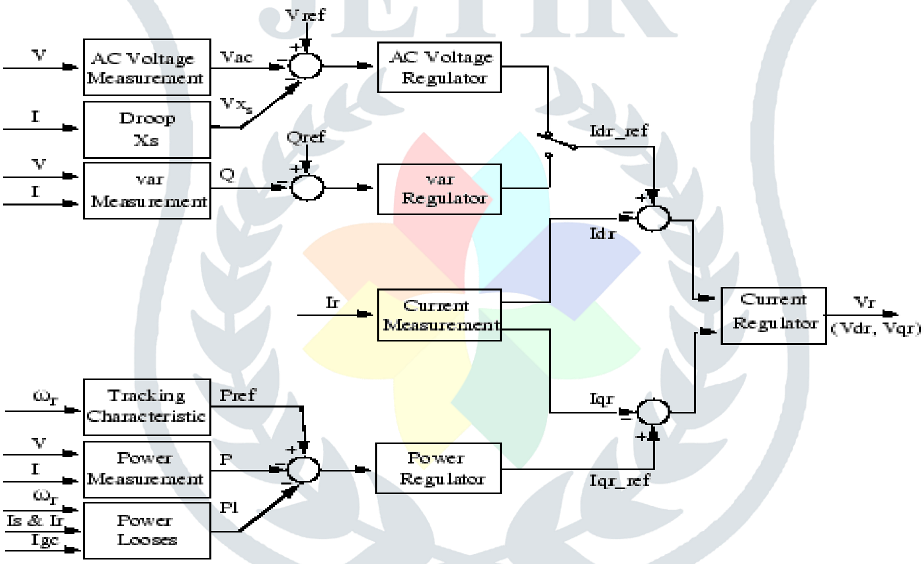
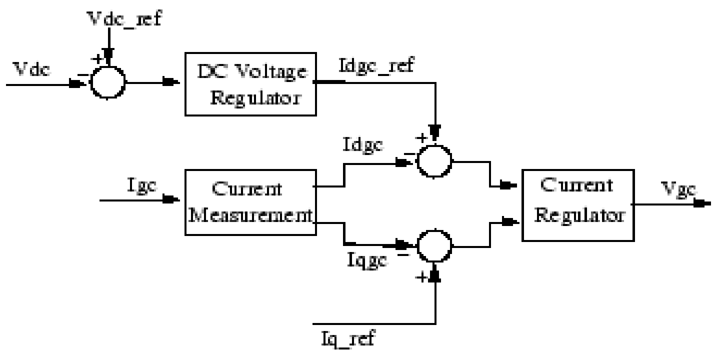


Fig.4. Voltage Control and Reactive Power Control

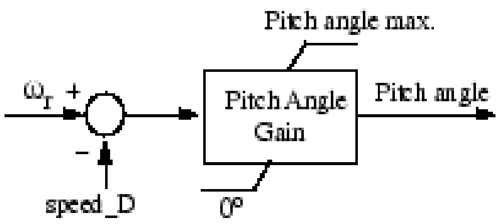
The voltage or the reactive power at grid terminals is controlled by the reactive current flowing in the converter C_{rotor}.

Grid-Side Converter Control System

The converter C_{grid} is used to regulate the voltage of the DC bus capacitor. In addition, this model allows using C_{grid} converter to generate or absorb reactive power.



Pitch Angle Control System



V. STATCOM

STATCOM is a FACTS device is a reactive shunt compensator with a DC capacitor used for shunt reactive power compensation. A STATCOM is a shunt-connected reactive power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. The operating principle of STATCOM is the reactive power compensation where the reactive power and voltage magnitude of the system can be adjusted such as shown in Fig.5. The main parts of a STATCOM are: shunt (coupling) transformer, voltage source converter (VSC), and capacitor. The convert supplies leading current to the AC system if the converter output voltage Vi is made to lead the corresponding AC system voltage VS. Then it supplies reactive power to the AC system by capacitive operation. In case of lagging current from the AC system; the converter output voltage V_i is made to lag the AC system voltage V_s then it absorbs reactive power to the AC system by inductive operation.

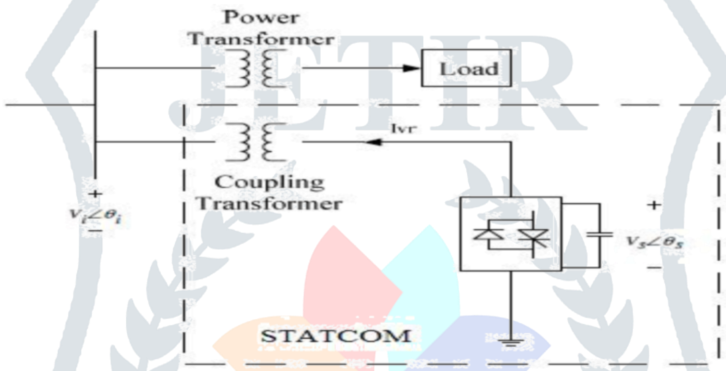


Fig.5. STATCOM connected to power system

If the output voltage is equal to the AC system voltage, the reactive power exchange STATCOM can be used to obtain desired reactive power compensation and regulate the bus voltage.

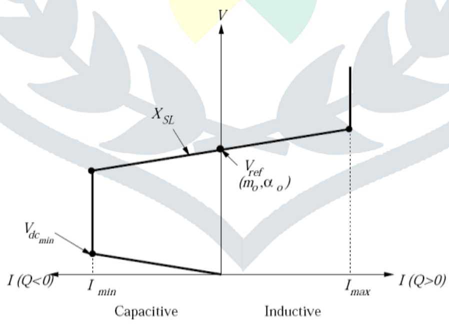


Fig.6.Characteristic of STATCOM

VI. PRINCIPLE OF OPERATION

The exchange of reactive power is done by regulating the output voltage of the inverter V STATCOM (VS), which is in phase with the mains voltage(V_k). The operation can be described as follows:

- If the voltage VS is below V_k, the current through the inductor is phase shifted in relation to the voltage V_k which provides an inductive current, then QS becomes positive and the STATCOM absorbs reactive power.
- If the voltage Vs exceeds V_k , the current through the inductor is phase shifted in relation to the voltage V_k which provides a capacitive current, then Qs becomes negative and the STATCOM generates reactive power.
- If the voltage Vs is equal to V_k, the current through the inductor is zero and therefore there is no exchange of energy.

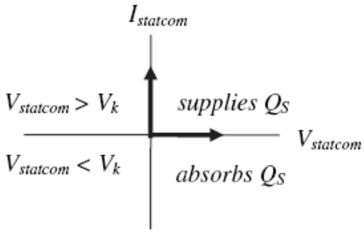


Fig.7.STATCOM operation

VII. MODELING OF STATCOM

The STATCOM is represented as voltage source for the full range of operation. The bus at which the STATCOM is connected is represented as a PV bus, which may change to a PQ bus in the event of limits being violated. In such a case, the generated or absorbed reactive power would correspond to the violated limit.

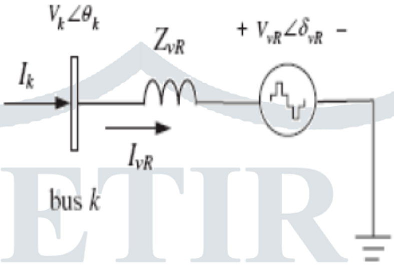


Fig.8.Equivalent Circuit of STATCOM

The power flow equations for the STATCOM are derived assuming the following voltage source representation:

$$E_{vR} = V_{vR}(Cos\delta_{vR} + jSin\delta_{vR}) \qquad (12)$$

The power from the STATCOM is:

$$S_{vR} = V_{vR}I_{vR}^* = V_{vR}Y_{vR}^*(V_{vR}^* - V_k^*) \qquad (13)$$

The STATCOM is a voltage-sourced-converter (VSC)-based shunt-connected device. By injecting a current of variable magnitude in quadrature with the line voltage, the STATCOM can inject reactive power into the power system .The STATCOM does not employ capacitor or reactor banks to produce reactive power as does the SVC, but instead uses a capacitor to maintain a constant dc voltage for the inverter operation .An equivalent circuit for the STATCOM is shown in Fig.9.

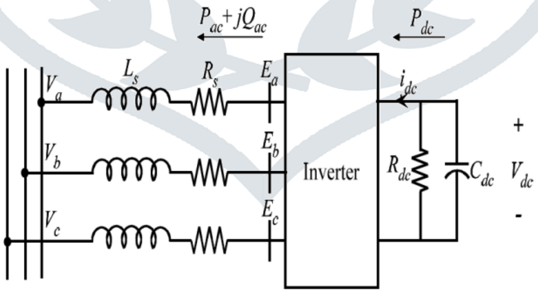


Fig.9.Equivalent circuit for the STATCOM

The loop equations for the circuit may be written in vector form as:

$$\frac{d}{dt}i_{abc} = -\frac{R_s}{L_s}i_{abc}\frac{1}{L_s}(E_{abc} - V_{abc}) \qquad (14)$$

Where, Rs and Ls represent the STATCOM transformer losses, E_{abc} are the inverter ac side phase voltages, V_{abc} are the system-side phase voltages, and i_{abc} are the phase currents. The output of the STATCOM is given by:

$$E_a = kV_{dc}Cos(wt+\alpha) \qquad (15)$$

Where V_{dc} is the voltage across the dc capacitor, k is the modulation gain, and α is the injected voltage phase angle.

VIII. CONCLUSION

In this review, the application of a STATCOM to a wind farm is studied. Several strategies for steady-state voltage and reactive power flow control of a wind farm equipped with a STATCOM were investigated. When a wind farm is connected to a weak power grid, it is necessary to provide efficient power control during normal operating conditions and thus enhanced support during and after faults. This paper explores the possibility of connecting a STATCOM to the wind power system in order to provide efficient control. The essential feature of the STATCOM is that it has the ability to absorb or inject fast the reactive power with power grid. Therefore the voltage regulation of the power grid with STATCOM FACTS device is achieved.

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