Long Term Dynamic Stability of Power System Connected with Wind Farms Equipped with DFIG and Facts Controllers

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Abstract— Wind is a vast worldwide available renewable energy source. Grid integration of a wind farm is an important issue in recent days. Due to the recent addition of huge amounts of wind power connected grids are promising in increasing system reliability. The effect of wind turbines during fault is investigated. FACTS device was designed to stabilize both wind energy conversion and Grid. The dynamic behaviour of the wind turbine is analysed in various wind speeds.

I. INTRODUCTION

The worldwide increase in the demand and consumption of energy since last years may be attributed to the rise of world population and the rapid pace of industrial development nations such as China, India and Brazil. Renewable energy sources are concerned in recent years due to reduction of carbon emission and due to climatic changes. Renewable energy sources such as photovoltaic, tidal power, wind power, bio gas and piezo electric power are used to generate power. Wind energy becomes main stream in power generation and main globally used power generation due to its widely abundant, free of cost and high power generation than other renewable energy resources.

The variable speed wind turbine (VSWT) has recently become more popular than fixed speed WTGS. Doubly Fed Induction Generator (DFIG), Wound Field Synchronous Generators (WFSG) and Permanent Magnet Synchronous Generator (PMSG) are currently used as variable speed wind turbine. DFIG is taken as VSWT for this paper. Power System stability is analysed in 5 bus system with fault and including DFIG in the system with fault for various wind speeds. During grid fault in power system causes voltage dip in wind turbine connection. Increase in stator current in DFIG due to voltage dip in grid which results in flow of current through rotor and power electronic converters and destruction. Sudden disconnection of wind turbines from grid integration will cause voltage instability in the grid. Hence the turbines should be connected with grid during fault conditions. The modern variable-speed drive uses power electronics to convert variable voltage, variable frequency output of the generator into the fixed voltage, fixed frequency output.

II. MODELLING OF DFIG

Wind turbines use the kinetic energy of the wind into mechanical power that drives an electric generator Appropriate tapering of the rotor blades is selected to maximize the kinetic energy of the wind. The power and torque equations for the wind turbine are as follows. A Doubly Fed Induction Generator has several advantages over a conventional induction machine in wind power applications.

DFIG allows the machine to support the grid during severe voltage disturbances (low voltage ride through). Control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid while the wind turbine speed varies. The wind power varies linearly with the air density sweeping the blades.

III. SPEED AND POWER RELATIONS

The kinetic energy in air of mass “m” moving with speed V is given by the following in SI units:

$$\text{Kinetic Energy} = \frac{1}{2} m v^2 \quad \rightarrow (1)$$

The power in moving air is the flow rate of kinetic energy per second.

$$\text{Power} = \frac{1}{2} \text{(mass flow rate per second)}\ v^2$$

the mass flow rate of the air in kilograms per second is =ρAV

therefore:

$$p_o = \frac{1}{2} (\rho AV) V^2 = \frac{1}{2} (\rho AV^3) \text{ watts} \quad \rightarrow (2)$$

III. POWER EXTRACTED FROM THE WIND

The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers are given as

$$p_o = \frac{1}{2} \text{ mass flow rate per second } (v^2 - v^2{}_0) \quad \rightarrow (3)$$

The mass flow rate of air through the rotating blades is, derived by multiplying the density with the average velocity is given as

$$\text{Mass rate flow} = \rho A \frac{v + v_0}{2} \quad \rightarrow (4)$$

On substituting in equation (4), we get

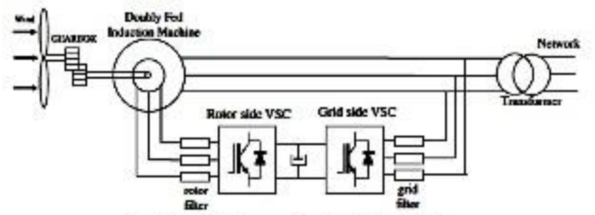
$$p_o = \frac{1}{2} (\rho A V^3) c_p \quad \rightarrow (5)$$

$$\text{Where } c_p = \frac{(1 + \frac{v_0}{v})[1 - (\frac{v_0}{v})^2]}{2} \quad \rightarrow (6)$$

c_p depends on the ratio of the downstream to the upstream wind speeds, that is (V_0/V). The maximum value of 0.59 when the (V_0/V)) is one-third under this condition the equation becomes

$$P_{\max} = \frac{1}{2} \rho A V^3 0.59 \quad \rightarrow (7)$$

The theoretical maximum value of C_p is 0.59. If we take 0.5 as the practical maximum rotor efficiency, the maximum power output of the wind turbine becomes a simple.



Doubly fed induction machine based wind turbine.

P_o = Output power of the turbine (W)

T_m= mechanical torque (N.m.)

ω = Rotor speed of wind turbine (rad/s)

ρ = Density of air (kg/m^3)

A = Swept area of the blade (m^2)

C_p = power coefficient of the rotor or the rotor efficiency

V= wind speed (m/s)

v= upstream velocity at entrance of the rotor blades

v_0= downstream velocity at exit of the rotor blades

R = gas constant.

T = temperature of the absolute scale

IV. TORSIONAL RESONANCE:

Modelling of DFIG is chosen with d-q reference frame. The modelling of this machine is based on "parks transformation" .

Where,

T_t = Mechanical torque referred to generator side in Nm

T_e = Electromagnetic torque in Nm

J_t = Equivalent turbine –blade inertia referred to the generator side (kg m^2)

ω_t = Turbine rotational speed(rad/s)

ω_g = Generator rotational speed(rad/s)

K_s = Shaft stiffness (Nm/rad)

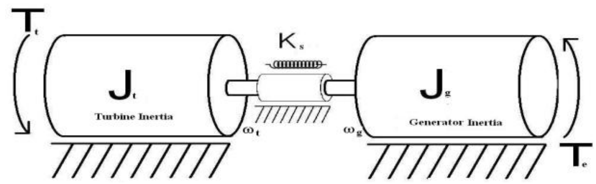
θ_s = Angular displacement between the ends of the shaft(rad)

If shaft, turbine and generator damping are neglected, the two mass model is described by the following equations

Tt = Jt(dωt/dt) + Ks θs

Te = Jg(dωt /dt)- Ks θs

dθ/dt = ωt – ωg



V. DFIG:

DFIG consist of two three-phase winding sets: one placed in the stator and the other in the rotor. These two three-phase windings need to be supplied independently and also both windings can be bidirectional energy supplied. The rotor three-phase windings can be connected in a star or delta configuration and they are supplied thanks to the brushes and the slip ring assembly. The stator is composed of three windings 120_ spatially shifted and p pairs of poles. When these three stator windings are supplied by a balanced three phase voltage of frequency fs, the stator flux is induced. This stator flux rotates at constant speed. The synchronous speed (ns) is given by the expression

$$n_s = \frac{60 f_s}{p} \text{ (rev / min)} \quad \rightarrow (8)$$

According to fardays law $e_{ind} = (v \times B)L$

e_{ind} = induced emf in one conductor of the rotor

v=speed of the conductor in relation to the stator flux rotation

B=stator flux density vector

L=length of the conductor

according to Laplace's law, creates an induced force in the rotor of the machine:

F= i . (L x B) → (9)

VI. SLIP CONCEPT

The induced voltage in the rotor depends on the relation between the stator flux rotational speed and the rotational speed of the rotor. the angular frequency of the induced rotor voltages and currents is given by the relation

$$\omega_r = \omega_s - \omega_m \quad \rightarrow (10)$$

ω_r = angular frequency of the voltages and currents of the rotor windings (rad/s)

ω_s = angular frequency of the voltages and currents of the stator windings (rad/s)

ωm = angular frequency of the rotor (rad/s) the rotor angular frequency is the slip, s

$$s = \frac{\omega_s - \omega_m}{\omega_s} \quad \rightarrow (11)$$

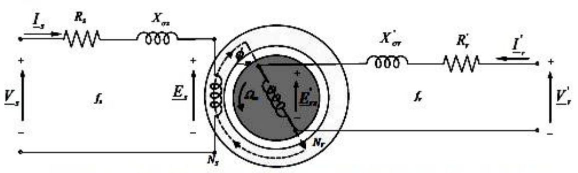
The relation between the frequencies at stator and rotor is

$$f_r = sf_s \quad \rightarrow (12)$$

VII. EQUIVALENT CIRCUIT

The steady state equivalent circuit of Doubly Fed Induction Generator is designed with few assumptions an diagram is shown below

- Stator and Rotor is designed for star type configuration
- Supply from stator to grid is supplied at constant voltage and frequency.
- Rotor is supplied at constant voltage and frequency with back to back voltage source converter.



One phase steady state equivalent electric circuit of the DFIM with different stator and rotor frequencies.

V_s = supplied stator voltage

V_r^I = supplied rotor voltage

I_s = induced stator current

I_r^I = induced rotor current

E_s = induced emf in the stator

E_{rs}^I = induced emf in the rotor

R_s = stator resistance

R_r^I = rotor resistance

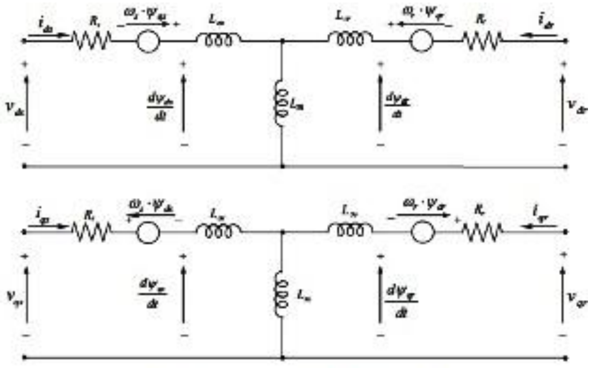
$X_{\sigma s}$ = stator leakage impedance

X_{sr}^I = rotor leakage impedance

N_s = stator winding's number of turns per phase

N_r = rotor winding's number of turns per phase

The voltage and currents of the stator and the rotor circuits have different frequencies. The stator frequency (f_s) is fixed if the stator is connected directly to the grid, while the frequency of the rotor voltages and currents is variable (f_r) and depends on the speed of the machine according to expression (12)



dq Model of the DFIM in synchronous coordinates.

VIII. FLUX LINKAGE EQUATION:

If d- axis of synchronous frame is fixed to stator voltage then Vsd = 0

- Stator Flux

$$\psi_s = L_s I_s + L_m I_r$$

- Rotor Flux

$$\psi_s = L_m I_s + L_r I_r$$

Were

$$L_s = L_m + L_{\sigma s} \; L_r = L_m + L_{\sigma r} \quad \rightarrow (13)$$

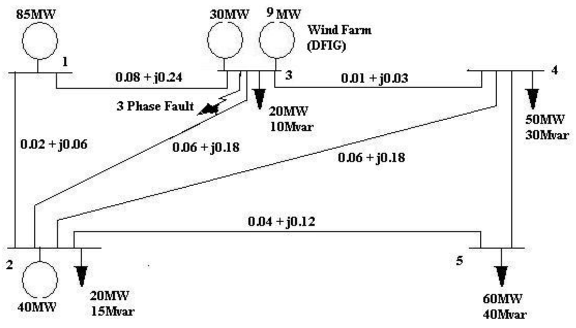
TORQUE EQUATION:

$$T_e = \psi_{rq} I_{rd} - \psi_{rd} i_{rq} \quad \rightarrow (14)$$

Variable-Speed Using Power Electronics

The modern variable-speed drive uses power electronics to convert variable voltage, variable frequency output of the generator into the fixed voltage, fixed frequency output. The energy yield of the variable-speed system is higher. The cost and benefit trade is generally positive for large machines. Using power electronic devices fine-tuning for superior grid connection, making it better suited for meeting the demand of weak grids.

IX. LONG TERM DYNAMIC SIMULATION



The single line diagram of the test system with wind turbine (DFIG) is shown. The test system consists of 5 bus system with 3 synchronous generators at 155Mw and 4 loads at different location with 150Mw. Bus 1 is taken as slack bus with reference of Generator 1, rotor angle of Generator 3 is measured. Speed of Generator 1 and 3 are measured. The dynamic performance of the FACTS controllers with wind turbines is investigated following the disturbance sequence mentioned below.

1. At t=0.1 seconds a three-phase fault on bus 3.

2. At t= 0.25 seconds the three-phase fault is cleared.

3. At t = 7 seconds the wind speed increases from 8m/sec to 14m/sec.

4. At t = 15 seconds the load at bus 3 is decreased to 15

The doubly fed induction generator is modelled as two active power injections at nodes stator and rotor. The FACTS controllers SVC and STATCOM are modelled as power injections or current injections in the load flow program.

The dynamics simulation results will be presented in the following sequence.

a) Rotor angle deviation of Synchronous generator 1_3 without and with FACTS controllers (SVC & STATCOM)

X. FACTS DEVICES.

Flexible AC transmission systems or FACTS are devices which allow the flexible and dynamic control of power systems. FACTS devices enhance controllability and increase power transfer capability. FACTS allow to mitigate the problems associated with the unreliable of supply issues of renewable energy sources. SVCs and STATCOM devices are well suited to provide ancillary services (such as voltage control) to the grid and fault rid through capabilities which standard wind farms cannot provide, FACTS reduce oscillations in the grid.

The following FACTS controllers are taken up for the analysis.

i) Static Var Compensator (SVC)

ii) Static Compensator (STATCOM)

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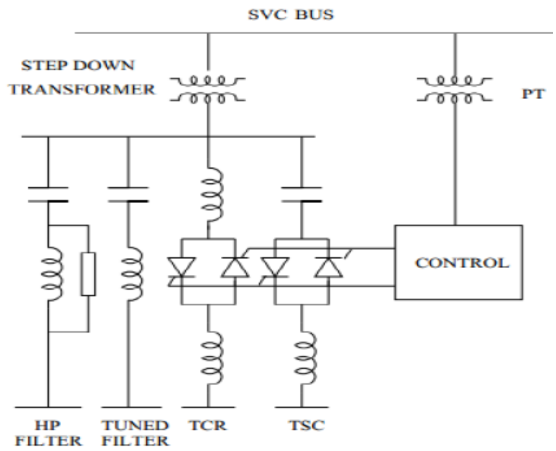


A Typical SVC (TSC-TCR) Configuration

There are two types of SVC's,

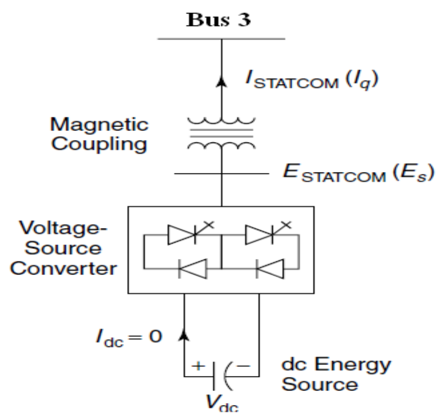
a) Fixed Capacitor-Thyristor Controlled Reactor

2. Thyristor Switched Capacitor - Thyristor Controlled Reactor (TSC-TCR).

Thyristor Switched Capacitor - Thyristor Controlled Reactor (TSC-TCR) is more flexible than the first one and it requires smaller rating of the reactor and consequently generates very less harmonics.

The TSC is switched in using two thyristor switches (connected back to back) at the instant in a cycle when the voltage across valve is minimum and positive, which results in minimum switching transients.

ii) STATCOM



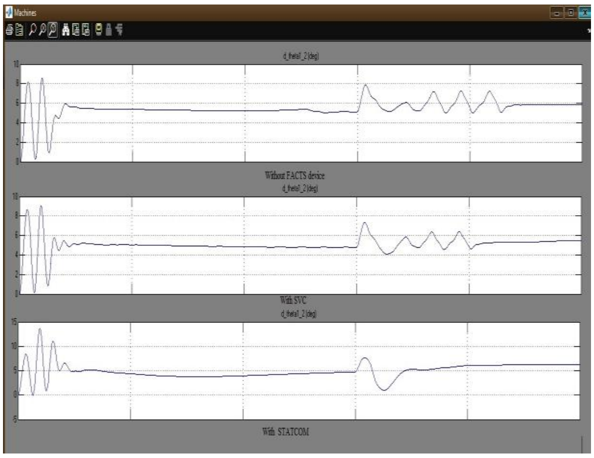
STATCOM principle diagram

Shunt connected static compensator was developed as an advanced static VAR compensator where a voltage source convertor (VSC) is used instead of the controllable reactors and switched capacitors.

It comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The exchange of reactive power between the converter and the ac system can be controlled by varying the amplitude of the 3-phase output voltage, Es, of the converter.

If the amplitude of the output voltage is increased above that of the bus voltage, B3, then current flows through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system. The converter can supply real power to the ac system from its dc energy storage if the converter-output voltage is made to lead the ac-system voltage.

XI. RESULT:



XII. CONCLUSIONS

From the result we conclude that among shunt connected FACTS controllers STATCOM provides better damping the oscillations compared to SVC. This done because STATCOM is voltage sourced converted based shunt controller and SVC is a shunt connected passive thyristor switched capacitor / reactor. From the result it states that STATCOM of suitable for stabilizing rotor speed oscillations associated with doubly fed induction generator following faults and wind speed changes.

This paper has described a comprehensive study of application of both shunt connected FACTS controllers SVC and STATCOM for enhancement of power system damping.

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