Enhancement of low voltage ride through capability of wind farm using super conducting magnetic energy storage

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Abstract— **This paper proposes a novel method for improving a low voltage ride-through of a wind farm. The main objective of this paper is to enhance a low voltage ride-through (LVRT) capability of individual wind turbine generator during grid fault conditions. The LVRT is tested for a wind farm with three units of doubly fed induction generator (DFIG). with SMES built in LVRT characteristics as per LVRT requirements and its grid code . Assessing the low voltage ride through (LVRT) capability of individual wind turbine generators and enhancing its LVRT capability with the help of Doubly Fed Induction Generator (DFIG) controllers (Grid Side Controller (GSC) and Rotor Side Controller (RSC)) through control algorithm.**

Keywords- **DFIG, Crowbar Protection , SMES(Superconducting Magnetic Energy Systems), 9 Bus System**

I. INTRODUCTION

Renewable energy is one of the most important resources which is not depleted even after use such as wind , sunlight, rain, tides and geothermal heat. Renewable energy provides energy in important areas such as electricity generation , air and water heating/cooling and rural (off grid) energy services. Wind power has realized the fastest growth in all renewable energy sources with a 20% annual growth since the past few years [1]Wind energy is clean ,sustainable and economically the least cost option among other renewable sources when adding new capacity to electrical grid .As a result the wind power penetration increases into the grid and electrical operators demanding more requirements from wind power plant through grid codes.Wind farms are now required to meet its requirements such as reactive power support , transient stability of a system and voltage/frequency regulation which constitutes the main challenges for wind generation. One of the major changes is the ride through capability of the wind turbines which implies that it must stay connected to the grid during grid disturbance or voltage dip and they should continuously feed the reactive power in addition to limited active power.One of the important requirements of grid code is Low voltage ride through capability (LVRT) which means ability of turbine to remain connected to the grid during fault conditions [2]. Doubly Fed Induction generators has been widely used for wind turbines operating more than 1 MW. However wind turbines based on the DFIG are very sensitive in a state of transient instability such as during grid disturbances and voltage dips. Drops in the grid voltage cause excessive voltage and current in the rotor circuit . Low Voltage Ride Through (LVRT) and various control methods are used to remove this problem in DFIG based wind farms[3].Thus to analyse the effect of wind energy on to the power system in a simpler way, the entire wind farm with huge number of wind turbine generating (WTG) units is represented as a single equivalent. A simple aggregation techniques are used where two or more than one wind turbines are simplified into equivalent model and a LVRT strategy has been proposed to enhance transient stability in grid disturbances for a large wind farms where there is a risk of voltage collapse

II. LITERATURE REVIEW

Enhancement a Fault ride through (FRT) capability of DFIG employed wind farm is attempted by Kennan **[4]** . In this the performance of demagnetizing current controller is compared against the crowbar protection technique. .Superconducting Fault limiter (SFCL) is applied at the stator side of DFIG to limit the current level during the fault condition **[5.]** The resistance of FCL improves terminal voltage of DFIG during disturbances. In **[6]** LVRT is improved for a hybrid generation plant with superconducting magnetic energy storage (SMES).The control strategy enhanced the grid code of the hybrid generation plant during disturbances. Coordinated operation of SFCL and SMES are applied to PCC of the wind farm with DFIG **[7.]** The mathematical modelling of a DFIG was initiated and the transient response of DFIG system is obtained with or without crowbar protection during grid fault**[8]** Fault current of DFIG with crowbar protection during voltage dip due to severe disturbance and **[9]** The protection scheme is utilized in the connection of DFIG to the grid in case of grid faults, so that it can inject the power supply after the clearance of faults with the help of resistors and capacitor connected in series. **[10]** A coordinated control strategy for the rotor crowbar protection implemented in **[11]** , the back to back converters of DFIG system is proposed to ride through the fault. A decisive control algorithm has been optimized to deliver more active power during voltage dip for PMSG based wind farms is discussed in **[12]**.The wind turbines must stay connected to the grid during fault conditions using DVR, a distribution side FACTS controllers **[13]** .Enhancement of low voltage ride through (LVRT) and fault ride through capabilities were provided by means of STATCOM & PI controller for a DFIG is studied **[14]**. The DFIG is equipped with an active crowbar protection consisting of a rectifier and IGBT with a help of coordinated control **[15]**.The DFIG is safely reconnected to the grid and recover its synchronisation rapidly after the fault by using the machine safe operation so that characteristics of turbine and LVRT capability is improved**[16]** .

III. MODEL OF WIND TURBINE

A wind turbine converts kinetic energy to mechanical energy through gearbox and then it converts mechanical energy to electrical energy through generator. The wind power captures the wind energy through blades and gives mechanical power to the shaft.

The power extracted from the wind

$$P_m = \frac{1}{2}\rho A v_w^3 c_p(\lambda\,,\theta)$$

The power coefficient c_p is a function ofλ (tip speed ratio) and θ (pitch angle)

The generator function of c_p is

$$c_p(\lambda\,,\theta) = c_1(\frac{c_2}{\lambda} - c_3\theta - c_4\theta^x - c_5)e^{-\frac{c_6}{\lambda}}$$

$$\frac{1}{\lambda} = \frac{1}{\lambda + 0.08\theta} - \frac{0.035}{1-\theta^3}$$

c_1 toc_6 and x are constants

The tip speed ratio is given by

$$\lambda = \frac{\omega_r R}{v_w}$$

Model of Doubly Fed Induction Generator

A DFIG is a slip ring induction generator where the stator and rotor circuits are energised. Three phase stator and rotor is referred to synchronously rotating reference frame with quadrature axis (q axis) leading direct axis (d axis) by 90 degree.

The stator and voltage equations are

$$\frac{1}{\omega_s}\frac{d\psi_{qs}}{dt} = V_{qs} + R_s I_{qs} - \psi_{ds}$$

$$\frac{1}{\omega_s}\frac{d\psi_{ds}}{dt} = V_{ds} + R_s I_{ds} + \psi_{qs}$$

$$\frac{1}{\omega_s}\frac{d\psi_{qr}}{dt} = V_{qr} - R_r I_{qr} - (\frac{\omega_s - \omega_r}{\omega_s})\psi_{dr}$$

$$\frac{1}{\omega_s}\frac{d\psi_{dr}}{dt} = V_{qr} - R_r I_{dr} - (\frac{\omega_s - \omega_r}{\omega_s})\psi_{qr}$$

The stator and rotor flux linkage equations are

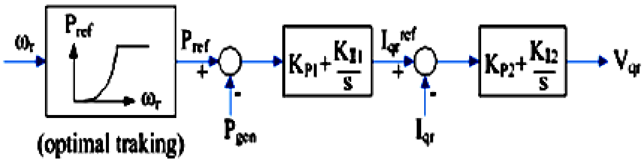
$$\psi_{qs} = -X_s I_{qs} + X_m I_{qs}$$

$$\psi_{ds} = -X_s I_{ds} + X_m I_{dr}$$

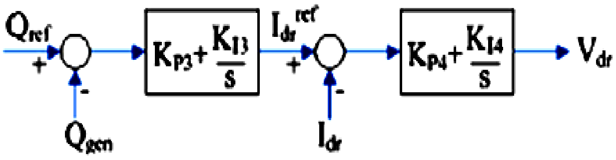
$$\psi_{qr} = -X_m I_{qs} + X_r I_{qr}$$

$$\psi_{dr} = -X_m I_{ds} + X_r I_{dr}$$

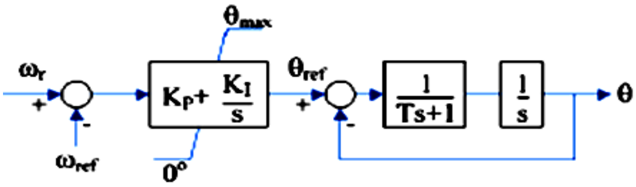
Rotor Side Controller (RSC)



Grid Side Controller (GSC)



Pitch Angle Controller



$$\frac{dE'_{qd}}{dt}=\frac{-1}{T'}(E'_{qd}+(X_s-X'_s)I_{ds}+\left(\omega_s\frac{X_m}{X_r}V_{dr}-(\omega_s-\omega_r)E'_{dD}\right))$$

$$\frac{dE'_{dd}}{dt}=\frac{-1}{T'}(E'_{dd}-(X_s-X'_s)I_{qs}-\left(\omega_s\frac{X_m}{X_r}V_{qr}-(\omega_s-\omega_r)E'_{qD}\right))$$

$$\frac{d\omega_r}{dt}=\frac{\omega_s}{2H_D}[T_m-E'_{dD}I_{qs}-E'_{qd}I_{qs}]$$

$$\frac{dX_1}{dt}=K_{I1}(P_{ref}-P_{gen})$$

$$\frac{dX_2}{dt}=K_{I2}\left(K_{p1}P_{ref}-P_{gen}\right)+X_1-I_{qr})$$

$$\frac{dX_3}{dt}=K_{I3}(Q_{ref}-Q_{gen})$$

$$\frac{dX_4}{dt}=K_{I4}(K_{p3}\left(Q_{ref}-Q_{gen}\right)+X_3-I_{dr}$$

$$\frac{dX_5}{dt}=K_I(\omega_r-\omega_{ref})$$

$$\frac{dX_6}{dt}=X_5-X_6-\theta+K_p(\omega_r-\omega_{ref})$$

$$\frac{d\theta}{dt}=X_6$$

IV. STUDY SYSTEM DESCRIPTION

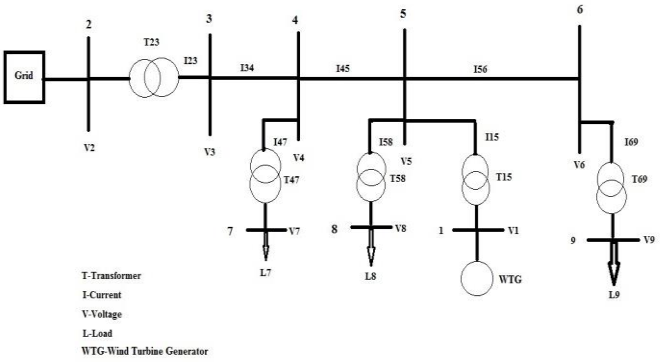


Fig.1 BLOCK DIAGRAM OF MODIFIED 9 BUS SYSTEM

This study case system consist of modified 9 bus with 5 transformer and 4 transmission line & wind farm is connected to a Point of common coupling (PCC) . The source voltage is 110kV

LOW VOLTAGE RIDE THROUGH CAPABILITY (LVRT)

During the fault occurence the active power supply to the grid through the wind farm is spontaneously reduced to a lower value than mechanical power available at the rotor, hence the speed of the rotor increases, therefore we need a LVRT capability , so that the wind generators must not be disconnected from the grid during fault contingencies, either due to excess speeding or over voltage . FRT has good advantage in which the wind generators s resume their power supply to the network without losing its stability. LVRT characteristics shown below is usually explained with the help of voltage v/s time graph, representing the minimum voltage.

LVRT requirement by wind turbine generator during the voltage dip or fault contingencies. Here LVRT behaviour is found through Indian grid code which maintains stability by reducing the risk of voltage collapse.

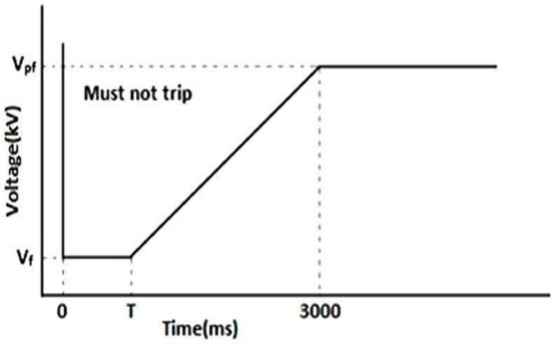


Fig.2 LVRT CHARACTERISTICS

Where,

Vf is 15% of nominal system voltage, Vpf is minimum voltage.

Whenever a fault occur , LVRT requirements demand the following conditions from power-generation plant:

- To remain connected to the grid, if line voltage is above the limit curve in Fig. above and
- To support the system during fault condition by injecting reactive power

Table1.Fault clearing time given to various system for nominal voltage levels [2]

Nominal System voltages(kV)	Fault Clearing Time T(ms)	Vpf(kV)	Vf(kV)
400	100	360	60
220	160	200	33
132	160	120	19.8
110	160	96.25	16.5
66	300	60	9.9

SMES (Superconducting Magnetic Energy Systems)

A SMES is a current controlled device that stores energy in the magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field. Depending on the control loop of its switching characteristics, the SMES system can respond very quickly (MWs/milliseconds). It injects/absorbs real or reactive power to increase the potency of the control, and enhance system reliability and availability. With compare to other storage technologies, the SMES technology has a unique advantage in two types of applications: transmission control and stability, and power quality improvement.

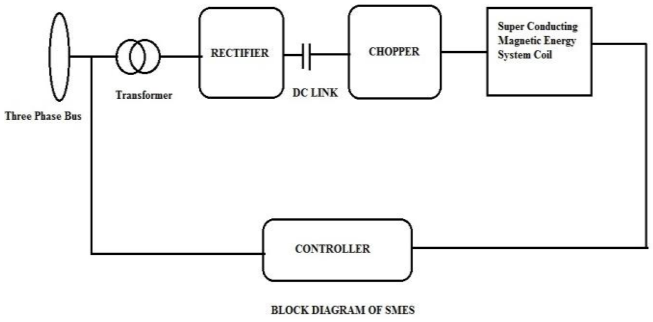


Fig.3 Block Diagram of SMES

It consists of three phase transformers, a voltage source converter (VSC), a DC chopper, and a superconducting magnet coil. To maintain a balance in a system , the reactive power compensation is used in the SMES system of over 1 MJ class is generally required to obtain both high power and speed control capabilityThe magnetic coil of inductance is determined by rated dc current and voltage for stored SMES energy. The voltage source converter works as a controllable switch device, which can control the active and reactive power transfer rapidly and independently and The DC chopper is used to regulate the voltage across the magnet to consent the required power transfer..

SMES CONTROLLER

The energy (E) stored in SMES is in Joule and the rated power (P) is in Watt units which are commonly accord in specifications for SMES devices and they can be expressed as follows:

$$E = \frac{1}{2} L I^2$$

$$P = \frac{dE}{dt} = LI\frac{di}{dt} = VI$$

Where ;L’ is the inductance coil , ’I’ be the dc current flowing through the coil and ‘V’ is the voltage across the coil.This controller regulates the power supply and calculates the required real power for the charging and discharging of the superconducting magnet and the reactive power of the SMES system. Then, the reference *d* and *q* axis currents for compensation is taken . The reference currents which is obtained can now used to control the converter AC output voltage. The PWM generator signals are generated to control the operation of converter and inject a real/reactive power for improving the stability of a system.

V. SIMULINK MODEL OF 9 BUS SYSTEM WITH SMES

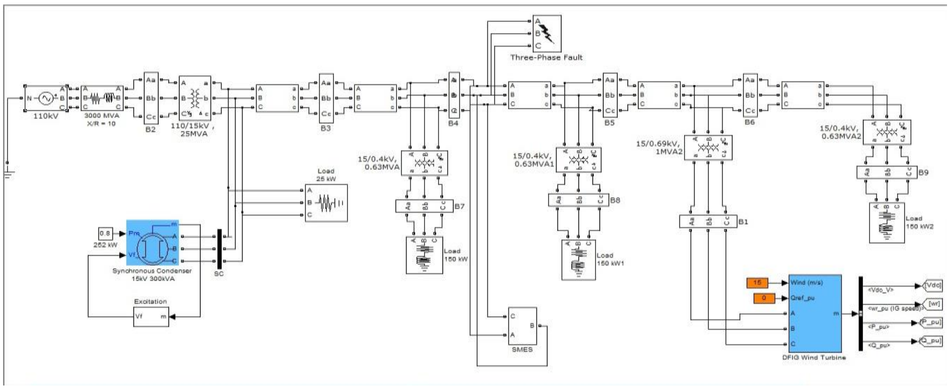


Fig.4. SIMULINK DIAGRAM OF A MODIFIED 9 BUS SYSTEM WITH SMES

RESULTS and ANALYSIS

CASE 1 THREE PHASE TO GROUND FAULT with or without SMES

ACTIVE AND REACTIVE POWER

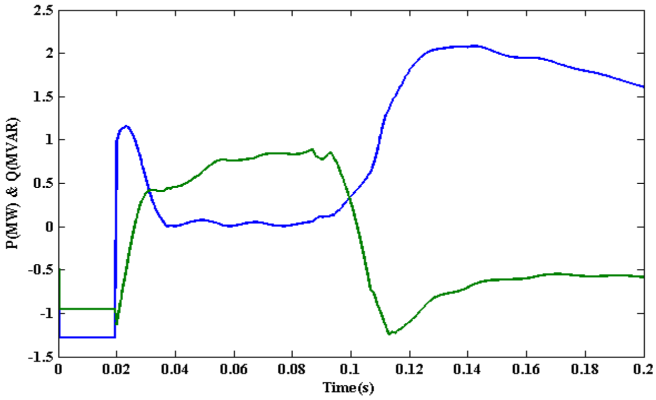


Fig.5 Active and Reactive Power at PCC without SMES

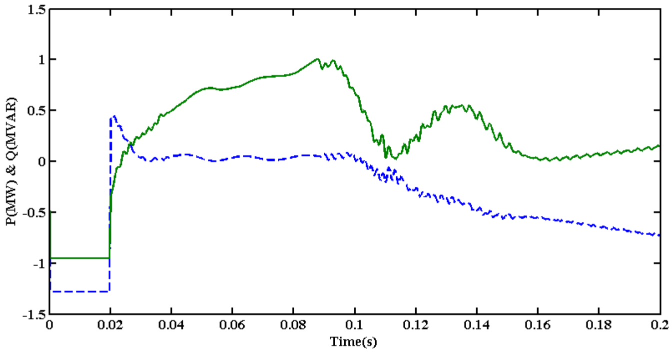


Fig.6 Active and Reactive Power at PCC with SMES

Bus Voltages at B1 & B4

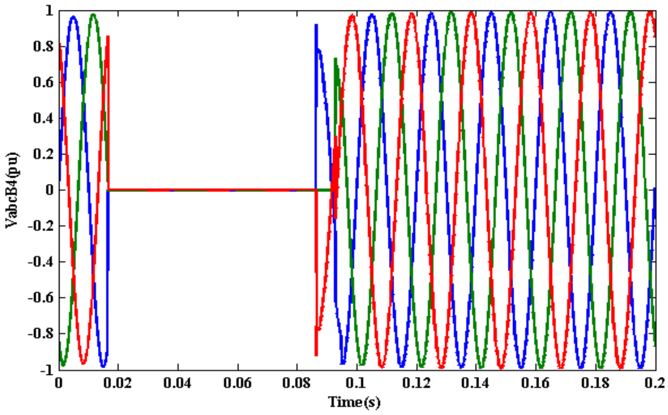


Fig.7 Bus voltage B4 without SMES

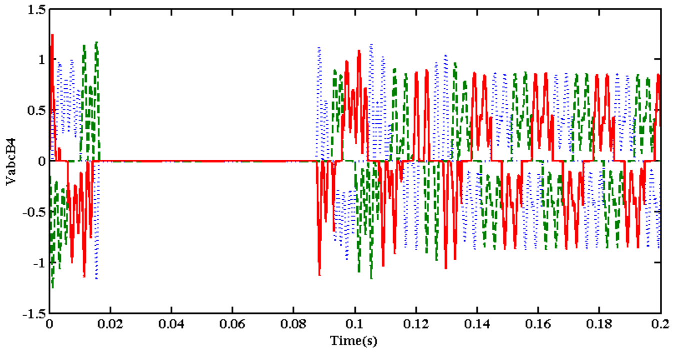


Fig.8 Bus voltage B4 with SMES

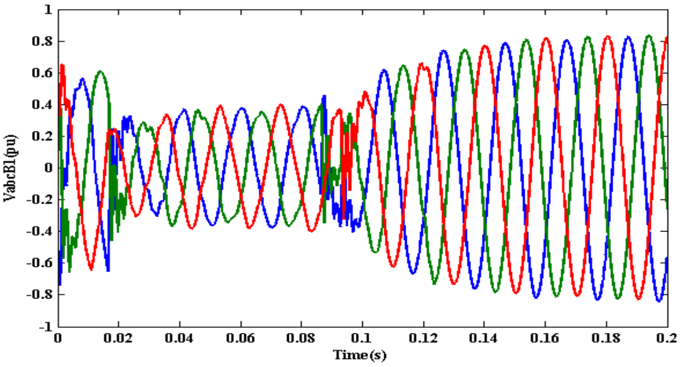


Fig. 9 Bus Voltage B1 without SMES

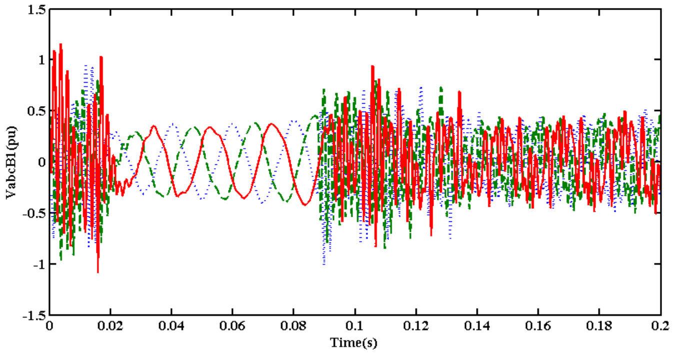


Fig. 10 Bus Voltage B1 with SMES

CONCLUSION

This study represents the modified nine bus system with DFIG wind farm and Synchronous diesel generator and investigate the purpose of SMES with grid code and enhance a LVRT capability of large scale wind farm during voltage dip. To consent with a system Indian grid code is used. This result shows that the SMES system is able to enhance LVRT capability of a wind farm to reduce abnormal current during fault and support real/reactive power to improve stability.

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