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Improvement DFIG Behaviour against Symmetrical Short Circuit Fault by Superconducting Current Limiter

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ABSTRACT

With the increase of DG in distribution network, good management of these systems is faced with new challenges. One of the most DG sources is doubly-fed induction generator (DFIG). By connecting them, the short circuit level (SCL) of network has been increased and it may be exceeded over the capacity of equipment such as breaker. So reliability will reduce in compare with the absence of DFIG in the network. In this paper, the superconducting fault current limiter (SC-FCL) has been used as a new technology for reducing large fault currents, increased security, reliability and stability of DFIG transient. Dynamic Model of SC-FCL is simulated with regard to all basic details including control algorithms, sequence of operation and error detection techniques in (PSCAD/EMTDC) software. Different cases with DFIG connected to the network and the impact of SC-FCL on it have been investigated. The result show that SC-FCL limits the fault current contribution of DFIG to a certain amount (that is improve the security and transient stability of DFIG during short circuit in the network) and operates as a compensator in such situation. Voltage sag as a very important index in power quality improves at the point of DFIG connection to grid.

Key words: SC-FCL, DFIG, Fault Current, DFIG Security, Voltage Sag

INTRODUCTION

Due to the increases in energy demand and environmental changes, the capacity of DG sources that mainly connected to the distribution networks, is developing [1]. Wind-turbine based generation system (WTGS) represents one of the renewable energy sources. Due to the rapid development and increasing the capacity of the resource, the short-circuit current level increases during the fault occurrence [1-3]. That would be creating a negative impact on the basic Parameters of power system (such as transient stability) at the point of their connection to the network. Moreover, the performance of protective equipment such as circuit breakers may also be affected. In such circumstances, the capacity of short circuit protective equipment in the network, should be fit proportional to new short circuit level or replaced with new equipment. One of the most fault current control methods is network topology reconfiguration and break system into several smaller parts. This method is affected system characteristic and stability. Another way to decrease fault current is usage of fault current limiter (FCL). This device is consist of two types; resistive and inductive. Resistive type is simpler and more compact from the point of structural view. This kind is more considered because of its affectivity, especially after rapid development in producing second generation superconductor windings [3-11]. It is possible to reach more benefits by placing SC-FCL in proper location of network. Some of these advantages are as follows [1-2]:

- Reduce fault current to a tolerable level for instrument.
- Avoid replacing of existing breakers with higher cutting capacity ones.
- Possibility of transformer installation with a low impedance that leads to lower investment cost.
- Prevent of network bus splitting.
- Increase system stability.

One solution to reduce increased short-circuit current in network with DFIG during the fault is use of SC-FCL. This device has no losses in normal operation and could be active at the first cycle of fault current rapidly and prevented the increase in short-circuit current of the network.This will be subject to improve system security and transient stability due to the current limiting. So this paper presents an accurate dynamic model for superconducting limiter in order to reduce short-circuits current of DFIG and improves its behavior.

DYNAMIC MODELING OF SC-FCL

Basic parameters that effected SC-FCL characteristics are as follow:
Fault current (I_{lim}), time duration of fault (Δ_t), tolerable temperature of superconductor windings. All of these are related together in 1 to 3 [5]:

$$R = \frac{V_0}{I_{\lim}} = \frac{\rho l}{tw} \tag{1}$$

$$I_{\lim} = t.w.\sqrt{\frac{C_p \Delta_t}{P.\Delta_t}} \tag{2}$$

$$V_{o1} = \frac{I_{\lim}.V_o}{C_p.\Delta_T} \tag{3}$$

Since the most high short-circuit current is due to 3-phase symmetrical fault, so the resistance of SC-FCL is determined under such situation. In a balanced system like as index A, resistance value for a 3-phase fault in bus k is calculated as:

$$Z_{SC-FCL} = -\frac{Z_b^2}{Z_b + Z_{sys}} \tag{4}$$

Dynamic model of SC-FCL with consideration of some basic indices such as control operation algorithm, activation time and fault detection techniques has been simulated in PSCAD/EMTDC. So this model represents specifications and real behavior of SC-FCL at the fault stages. Resistance of SC-FCL is function of temperature degree as below [12]:

$$R_{SC-FCL} = R_Q \times (1 - e^{B(T_{SC-FCL} - T_0)}) \tag{5}$$

That R_Q is SC max resistance in quenching mode and B is temperature adaptive factor.

In this paper, a variable resistor is used for the modeling of superconducting windings. In large fault currents, the resistance of SC-FCL has been increased. The variable resistor is very small (about 0.01 ohms) in normal operation of network and begin to rise with a certain slope (100 ms / ohms) during the fault. Model and Timing diagram of the various intervals have been shown in fig (1-2) respectively.

The sequence of SC-FCL function at various time intervals can be expressed as follows:

1. At $t < t_1$ Steady state line to line current passes of Route 1 and SC-FCL resistance value is almost zero.
2. At $t=t_1$ fault is detected and control system activates the switch at 1-2 ms interval, at the moment of t_2 switch is opened , fault current passes of Route 2 and variable resistance value is began to rise.
3. At $t_3=t_2+2$ ms, the resistance of SC-FCL, began to rise until it reaches the maximum value.
4. At t_4, when the fault is cleared, control circuit activates the switch and resistance value starts to reduce with a high gradient.
5. At t_5, variable resistance reaches to its initial value (R_{min})

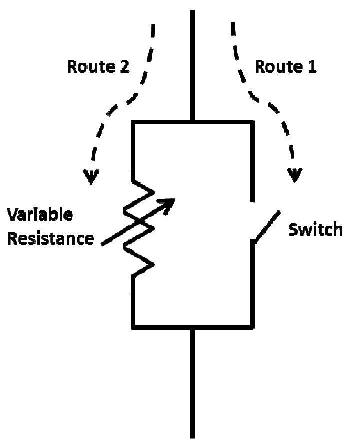

Fig.1 SC_FCL simple power circuit diagram

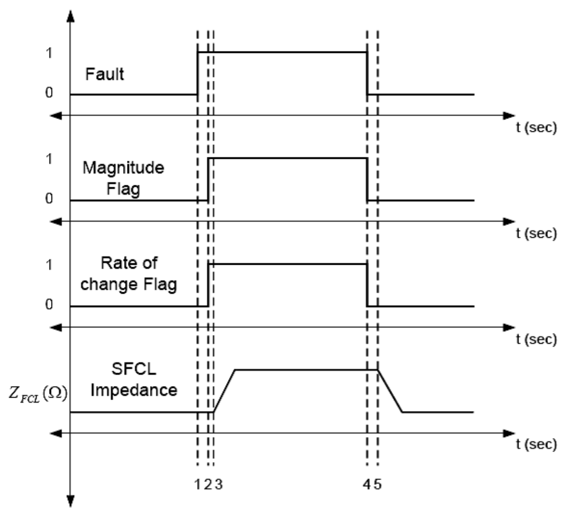

Fig.2Performance diagram of SC-FCL at various time intervals

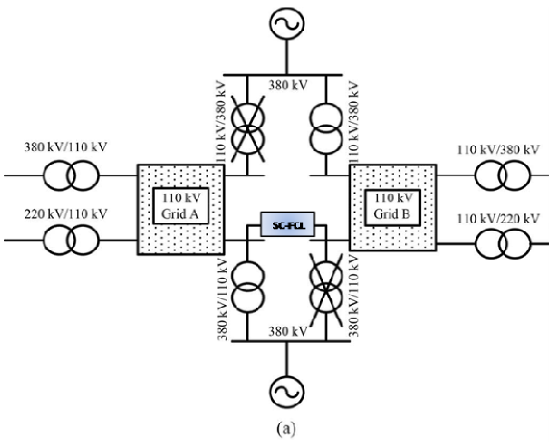

Fig.3 (a) Connection of two 110 KV grids by SC-FCL

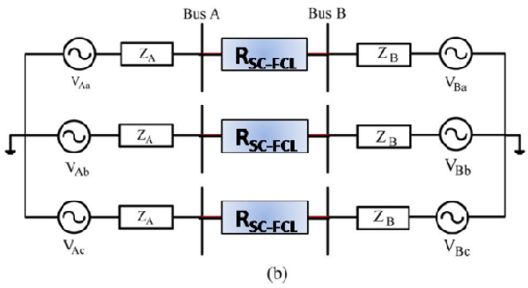

Fig.3 (b) network equivalent circuit after SC-FCL connection

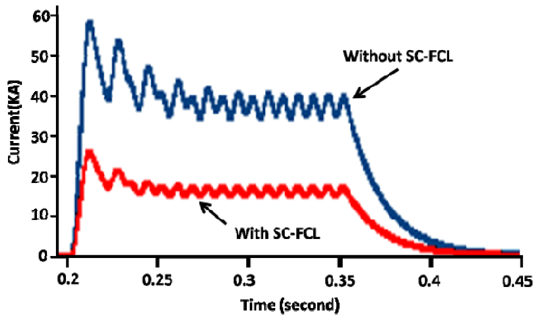

Fig. 4 (a) Phase A effective current for 3-phase fault to ground in bus B

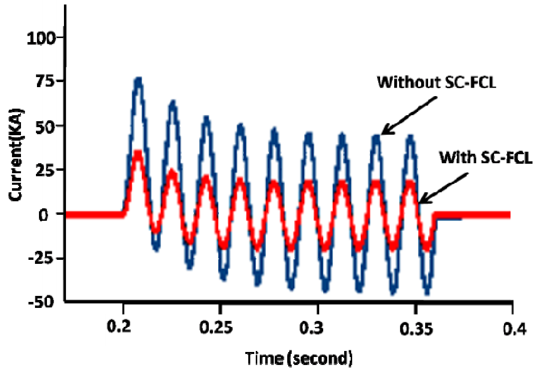

Fig. 4 (a) Phase A instantaneous current for 3-phase fault to ground in bus B

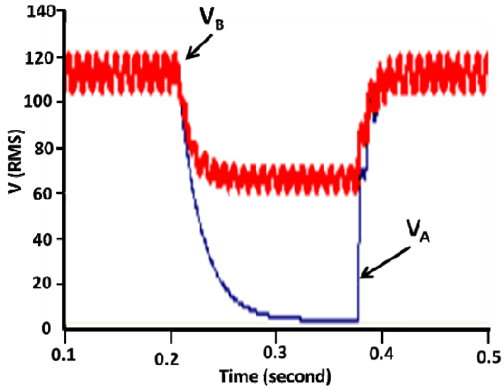

Fig. 4 (c) Bus A voltage sag reduction rate for 3-phase fault to ground in bus B

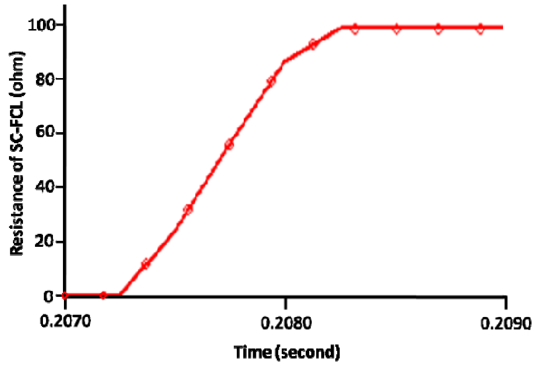

Fig. 4 (d) SC-FCL dynamic response for 3-phase fault to ground in bus B

To study the characteristics and performance of the mentioned SC-FCL in terms of operating time and its ability to reduce fault currents, the model is investigated on tested network of Fig.3. Information of given network is available in [13].

According to Fig.3, SC-FCL has been placed between A and B buses for each phase that is shown by RSC-FCL the network impedances are as below:

$$Z_A = 0.26 + j3.18\,\Omega$$

$$Z_B = 0.35 + j3.3\,\Omega$$

SC-FCL Activation procedure is based on proposed algorithm. The proposed algorithm is then started where the current magnitude (Irms) and the rate of change of current (di/dt) is monitored during the entire simulation time. After achieving some steady state operating point a three phase-to-ground fault is inserted into the system external to the FCL. As soon as the fault is inserted, the magnitude of the line current jumps up instantaneously and achieves a new steady state value as long as the fault is present. However, in order to make sure that there is indeed a fault in the distribution system and that the Resistance is not falsely triggered, the rate of change of current is also monitored. A fault will change the rate instantaneously. After setting the necessary flags, the Resistance is ramped up at a rate Rslope(Ω). As long as the fault is present, the Resistance will keep increasing till a maximum value Rmax(Ω). After the fault is cleared the Resistance will be ramped down to the initial impedance. This cycle takes place whenever there is a fault. Results show that SC-FCL is able to reduce fault current amplitude almost 50 percent when a 3-phase symmetrical fault is in bus B (Fig. 4A-4D). Furthermore SC-FCL operates as a voltage amplifier (booster) so that voltage profile in bus A is improved, during 3-phase symmetrical fault in bus B.This device acts as a stabilizer in order to recovery transient stability and voltage stability during the fault and also reduces voltage sag (important index of power quality) in bus A.

DFIG MODELLING

Among the different types of production systems based on wind energy, doubly-fed wind turbine (DFIG), are most commonly used because of its unique features. DFIG consists of a doubly fed induction generator, and a variable frequency converter. The stator and the rotor are connected to the network directly and via a converter respectively. The major property of DFIG is producing of power with constant frequency in variable speed. This is very important in wind energy unit commitment. It is also possible to recycle the rotor power at the speeds higher than synchronous speed and inject it to the network in such system. Power direction in rotor windings is bilateral and in stator ones is toward network. To achieve the above circumstances a bi-directional converter is used in the rotor. Power of applied transducer is a fraction of the total machine power which is an advantage. The original configuration of doubly-fed wind turbine system is shown in Fig.5.

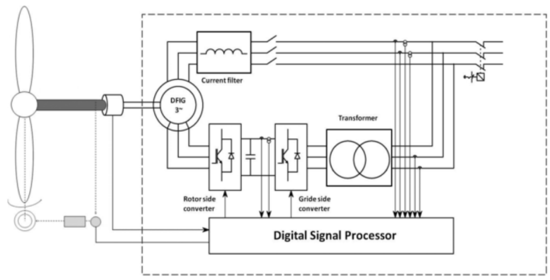

Fig.5Overview of DFIG system

In this paper proposed model of [6], is used for modelling of DFIG. Mechanical power from wind energy can be calculated according to Equation [6]:

$$P_{wt} = \frac{1}{2}\rho A V_w^3 C_p \tag{6}$$

The considered model of the DFIG, including turbines, gearboxes, shafts and other mechanical parts of the wind turbine, which is mostly expressed with a second-order mechanical model as shown below [8,9]:

$$T_{wtT_{mec}} = 2H_r \frac{d_{wr}}{d_t} \tag{7}$$

$$T_{mec} = D_{mec}(W_r - W_g) + K_{mec}\int((W_r - W_g)dt \tag{8}$$

$$T_{mecT_e} = 2H_g \frac{d_{wr}}{d_t} \tag{9}$$

In the above equations, (T_{wt}) is the mechanical torque of wind turbine rotor shaft, (T_{mec}) is the mechanical torque of generator shaft, (T_e) is electric generator torque, D_{mec} and K_{mec} are damping and stiffness coefficients of mechanical connections respectively. Details about the DFIG and its mathematical modelling are available in [6-9].

SIMULATION AND NUMERICAL RESULTS

To evaluate the effect of SC-FCL on DFIG units connected to the network, two different cases have been investigated. In the first case, a 10 MW wind farm, which consists of five 2 MW DFIG units, is connected to the typical standard single machine infinite bus (SMIB) network of IEEE. The wind speed was kept constant at 13 m/s. Thus there is no change in the wind turbine output power versus wind speed changes. Then a three-phase to ground fault with duration of 0.01 seconds is applied to infinite bus, and wind farm behavior has been investigated without SC-FCL during symmetrical short circuit at infinite bus. In the second case, by placing the SC-FCL between wind farms and infinite bus as in Fig.6, the behavior of DFIG Wind Turbines is studied during symmetrical short circuit at infinite bus. Resistance value intended for SC-FCL in this case, reaches to the maximum of 2 (ohm) after quenching that is a decent amount according to the short circuit capacity of studied grid. A comparison has been performed between the phase A current amplitude at the connection point of wind farms to the infinite bus, output active power of the wind farm, voltage sag in point of wind farms connected to infinite bus, the rotor speed, the phase A effective current of the rotor and middle capacitor voltage in DFIG converter in the presence or absence of SC-FCL at connection point of wind farm and infinite bus and results is shown in Fig. 7-A till Fig. 7-F. According to the results, the amplitude of the phase A, after the placing SC-FCL between the network and the wind farm is reduced to 50% at fault. As a result the fault current is not exceeding than the short circuit capacity of the network protection equipment (such as breaker), that it will increase the security and reliability of the protection system. Wind farm output active power and its voltage at the connection point to infinite bus is opposite to zero during symmetrical short circuit, with the SC-FCL located at this point, which can improve the transient stability of the system. According to fig 7-D, DFIG rotor speed damped faster by placing SC-FCL between wind farm and infinite bus and reaches its steady-state with less volatility. The voltage of middle capacitor has minor changes in presence of SC-FCL in compare with its absence. So the value of effective current in rotor phase A decreased about 50 percent. This will help the wind farm to remain stable.

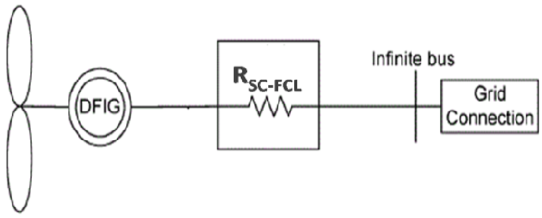

Fig.6 Wind farm connection to infinite bus via SC-FCL

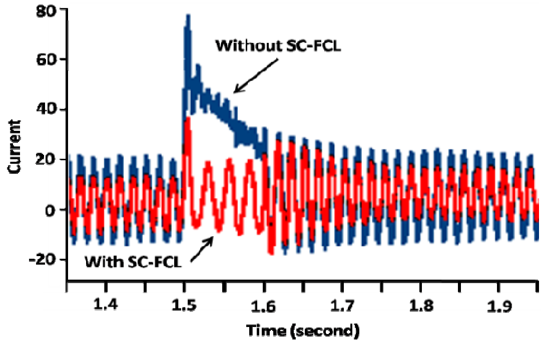

Fig. 7 (A) Current amplitude of phase A at the connection point of wind farm to the grid

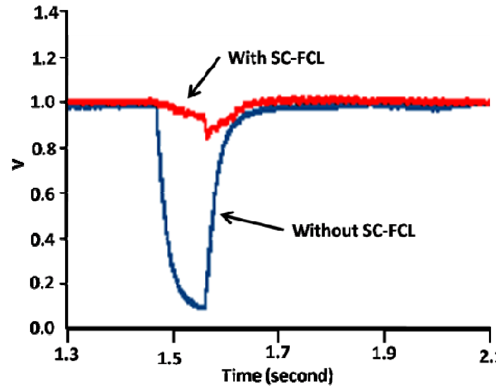

Fig. 7 (C) Voltage sag reduction rate at the connection point of wind farm to the grid

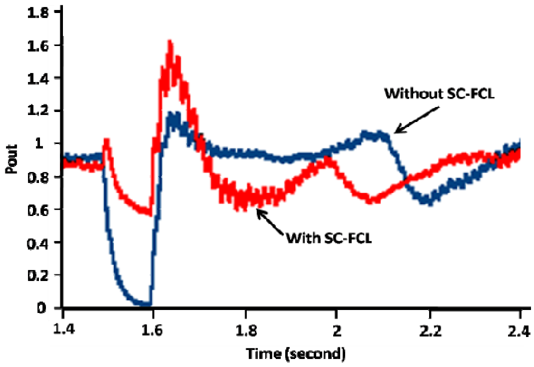

Fig. 7 (B) Output active power of wind farm

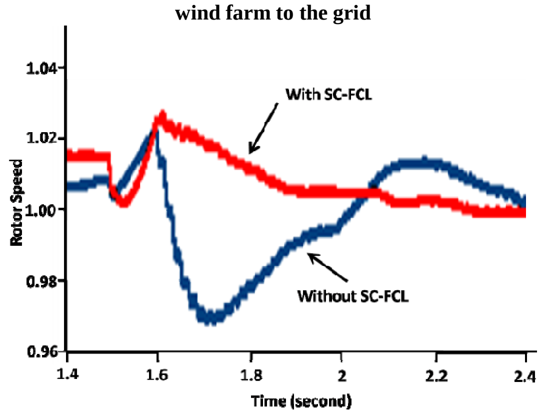

Fig. 7 (D) DFIG rotor speed during short-circuit

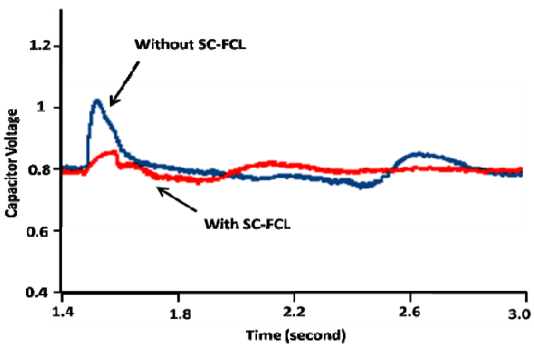

Fig. 7 (E) Middle capacitor voltage in DFIG converter

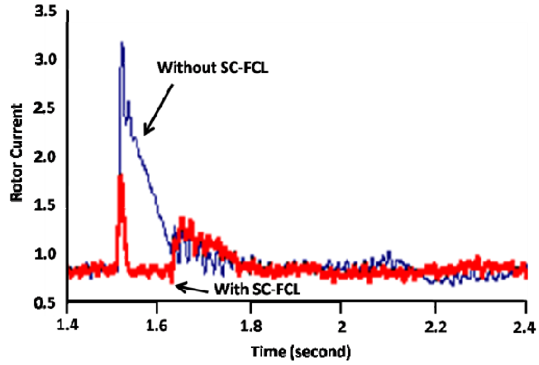

Fig. 7 (F) The value of effective current in rotor phase A

CONCLUSION

In this paper the behavior of doubly-fed wind turbines (DFIG) connected to the grid in a symmetrical three-phase short circuit to ground fault were examined using PSCAD / EMTDC software. By connecting the wind turbines to the grid, the fault current is exceeded than the short circuit capacity of the network protection equipment (such as breaker), Which can affect the performance of this equipment and it will decrease the security and reliability of the protection system. In this paper, the superconducting fault current limiter (SC-FCL) was used to solve the above problem. Therefore, the SC-FCL, with all the details, including function control algorithm and activation time is simulated in PSCAD / EMTDC and its characteristics were tested for a prototype system. The obtained results show that the proposed model can simulate the dynamic behavior of SC-FCL before, during and after a short-circuit fault correctly.

Then, two different scenarios by connecting wind farm consists of DFIG units to infinite bus, one without the SC-FCL, and another by placing SC-FCL between the wind farm and the grid was studied. According to the results, SC-FCL is able to reduce the short-circuit current of the wind farm up to 50%, which could improve the transient stability and security of the wind farm DFIG units when connecting to the main grid.

Index A

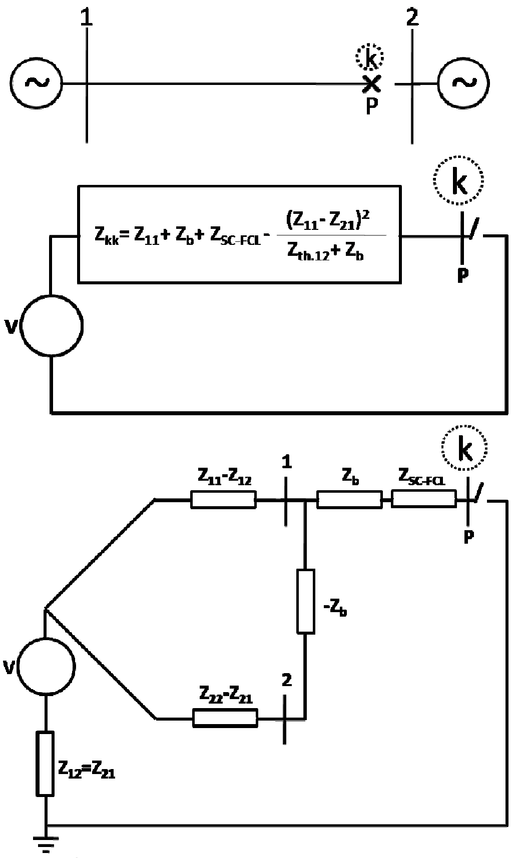

Fig. 8 The equivalent circuit for SC-FCL impedance calculation in symmetrical three-phase fault

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REFERENCES

[1] Lin Ye, M Majoros, T Coombs and AM Campbell, System Studies of the Superconducting Fault Current Limiter in Electrical Distribution Grids, *IEEE Transactions on Applied Superconductivity*, **2007**, 17 (2), 2339 - 2342

[2] M Jafari, SB Naderi, M Tarafdar Hagh, M Abapour, SH Hosseini, Voltage Sag Compensation of Point of Common Coupling (PCC) Using Fault Current Limiter, *IEEE Transactions on Power Delivery*, **2010**, 26 (4), 2638 - 2646

[3] JC Llambes, CS Weber and D Hazelton, Transmission Level SC Fault Current Limiter, *Superconductivity for Electric Systems- 2008, DOE Annual Peer Review*, Arlington, VA, **2008**.

[4] V Manish, Comprehensive Overview, *Behavioral Model and Simulation of a Fault Current Limiter*, Master of Science in Electrical Engineering Thesis, Virginia Tech, Blacksburg, VA, **2009**.

[5] S Kalsi and A Malozemoff, Resistive High Temperature Superconductor Fault Current Limiter, *The Power Delivery Applications of Superconductivity Task Force*, New York, **2003**.
[6] S Gasemzadeh and SH Hosseini, Unified Modeling of Wind Power Station Including DFIG for Distributed Generation Studies, *Journal of Faculty of Tabriz University(Electrical Eng.)*, **2008**, 35 (1), 38-46
[7] JJ Grainger and WD Stevenson, *Power System Analysis*, New York: McGraw-Hill International Editions, **1994**.
[8] T Abedinzadeh, M Ehsan and DTalebi, Dynamic Modeling and Control of Induction Generators in Wind Turbines, *International Journal of Computer and Electrical Engineering*, **2012**, 4 (2), 45-52
[9] T Abedinzadeh, Hadi Afsharirad and Mohammad Nazaraliloo, Modelling and Performance Analysis of Doubly-Fed Induction Wind Turbines Using PSCAD/EMTDC,*Canadian Journal on Electrical and Electronics Engineering*, **2012**, 3 (1), 31-38
[10] Bart Diaz, Thomas H Ortmeyer, Bruce Pilvelait, Mike Izenson, Weibo Chen and Nathan Spivey, System Study of Fault Current Limiter for Shipboard Power System , *IEEE*, Electric Ship Technologies Symposium,2009.
[11] Nand K Singh, Ryan M Tumilty, Graeme M Burt, Chris G Bright, Cornel C Brozio, DA Roberts, Alexander C Smith and Mark Husband, System-Level Studies of a MgB_2 Superconducting Fault-Current Limiter in an Active Distribution Network , *IEEE Transactions on Applied Superconductivity*, **2010**, 20 (2), 54 - 60
[12] M Stemmle, C Neumann, F Merschel, U Schwing, KH Weck, M Noe, F Breuer and S Elschner, Analysis of Unsymmetrical Faults in High Voltage Power Systems with Superconducting Fault Current Limiters, *IEEE Transactions on Applied Superconductivity*, **2007**, 17 (2), 2347–2350.
[13] Byung Chul Sung, Dong Keun Park, Jung-Wook Park and Tae Kuk Ko, Study on a Series Resistive SFCL to Improve Power System Transient Stability: Modeling, Simulation, and Experimental Verification, *IEEE Transactions on Industrial Electronics*, **2009**, 56 (7), 2412 - 2419
[14] D Gautam, V Vittal and T Harbour, Impact of Increased Penetration of DFIG-Based Wind Turbine Generators on Transient and Small Signal Stability of Power Systems, *IEEE Transaction on Power System*, **2009**, 24 (3), 1426–1434.
[15] MS El-Moursi, MH Abdel-Rahman and B Bak-Jensen, Coordinated Voltage Control Scheme for SEIG-based Wind Park Utilizing Substation STATCOM and ULTC Transformer, *IEEE Transaction on Sustainable Energy*, **2011**, 2 (3), 246–255.