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Resistive Superconducting Fault Current Limiter (RSFCL) Effect on The Wind Farm Performance

Sajjad Dadfar
Ministry of Energy, Iran Power Generation, Transmission and Distribution Management Company (TAVANIR), Tehran, Iran.
Email: s.dadfar@tavanir.org.ir

Ali Azizpour
Department of Electrical Engineering, Mazandaran University of Science and Technology, Behshahr, Iran.
Email: aliazizpour@iaubs.ac.ir

Abstract (١٢ pt, bold)

The study sought to evaluate the superconducting fault current limiter impact on network performance provided with a wind farm as distributed generation. Using wind energy to produce electricity has witnessed a remarkable and tremendous growth in recent years. Considering the development in wind turbine inclusion in electrical systems, short circuit current would face an increase trend. Short-circuit current would instigate the thermal and mechanical stress proportional to the short circuit amplitude square causing damages to the equipment. Using fault current limiters (FCLs) sits among the approaches as a simple method to reduce and prevent damages to the equipment making the distribution inevitable. Considering such growth, since the areas with wind potentiality are not necessarily in the vicinity of consumption centers, the evaluating, modeling, and analyzing the wind farms in terms of system stability and power quality and reliability are important aspects which merit attention. The study focuses on evaluating superconducting fault current limiter impact on network performance provided with a wind turbine using PSCAD / EMTDC software for the simulation.

Keywords: Distributed Generation sources, Dynamic Stability Improvement, Short Circuit Current, Superconducting Fault Current Limiter, Wind Turbine

Introduction

Owing to its many advantages, the application of wind energy has witnessed a growing trend intending to produce cheap and clean electricity through wind power installation to reduce some of the planet's environmental problems. Regarding such power plant growth, their performance and behavior in the network seems imperatively urgent [□-□]. The addition of distributed generation units into the distribution systems have advantages and disadvantages in the distribution system design and operation. One of such disadvantages encompasses its effect on increasing the network and equipment short-circuit.

Short-circuit current would generate the thermal and mechanical stress proportional to the short circuit amplitude square triggering damages to the equipment. Using fault current limiters (FCLs) serves as one of the simplest methods and approaches to condense and prevent damages to the equipment [□].

Fixed speed wind turbines use squirrel cage induction generator to convert mechanical energy into electrical energy. The Squirrel Cage induction generators consume large amounts of reactive power to establish magnetic connection and use more reactive power to produce more active power and vice versa. At the fault occurrence and reduced voltage time, the generator can only inject an insignificant amount of active power to the grid because the produced power by the generator has a direct relationship to the terminal voltage despite the fact that the mechanical power generated by the turbine is fixed. As a result of the imbalance between the mechanical and the electrical power, the generator rotor speed undergoes a rapid increase. After eliminating the fault, the squirrel cage induction generator will be operating at a higher speed consuming more reactive power from the grid which in turn will slowly cause the terminal voltage recovery. Increasing the generator speed will increase the generator reactive power consumption. Consequently, the terminal voltage drops further reduces the generator produced power. Such condition would trigger more imbalance between mechanical and electrical power instigating the generator instability. If the generator acceleration is faster than voltage recovery, the generator speed continues to increase to the extent that the generator speed steps into the its instability condition putting the whole unit off the circuit [□-□]. Multiple unit entry and exit in the circuit not only reduce the produced electricity quality but also shorten its efficient life span causing the imbalance between production and consumption in isolated or small network. Recent years have emphasized a particular importance on the wind farms stability studies and many research have been conducted, accordingly. In order to improve the stability, many approaches and methods have been proposed and studied including articles □ and □ in which the application of SVC and STATCOM to improve voltage stability and dynamics is studied. Each fault current limiter can affect the equipment, the system parameters and system behavior in fault conditions along with limiting the fault current each of which has its own characteristics. The study sought to evaluate the resistive superconducting fault current limiter behavior on dynamic behavior and stability of wind farms in short circuit condition.

Resistive type superconducting limiter characteristics

Equation must be written in a two column table with no border like the following example. (Using Microsoft Equation recommends)

Regarding the presence of different types of limiters, high temperature resistive type superconducting limiters, if being well designed, will be more effective, compact and less expensive than the other limiters. The resistive type superconducting limiters are self-sensing and self-triggering limiters which would limit the current by changing to normal condition if the fault current exceeds that of superconducting critical current. Since the superconducting resistance in grid normal conditions is zero, the flow passes the superconducting limiters with no energy loss. However, when the critical fault surpasses the critical current (S-N), the superconductors will be shifted to normal transition mode. Taking the outbreak of such phenomenon into account, being referred to as Superconductor Quench, the limiter resistance increases and the fault current will be limited. After reducing and stopping the fault current, the superconductor returns to superconducting state.

The resistive type superconducting limiters is modelled using the following formula.

$$R_{FCL} = R_m(1 - exp\ (t\ /\ -T_{sc})\qquad (\square)$$

Where Rm is the maximum resistance and Tsc is the time constant going from the superconducting state to the normal state [□].

Induction Generator characteristics and its equivalent circuit

Fixed speed wind turbine behavior is determined by the relationship between active power, reactive power, terminal voltage and squirrel cage generator speed. Such relationship can be expressed by the circuit model shown in Figure ۱ in which the V_T is the terminal voltage, R_r, X_r, R_S and X_S are resistance, rotor and stator reactance, respectively, and X_M is the magnetizing reactance, P_W and Q_W are the generator produced or consumed active and reactive power.

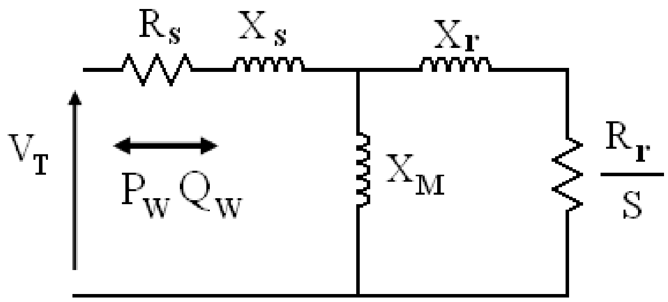

Figure □. The squirrel cage induction generator circuit model

The active-slip power characteristics for a constant speed generator is shown in Figure ۲. It is observed that, during steady state operation, the machine works with low slip velocity resulting into less nonconformity and deviance from synchronous speed. The absorbed reactive power by the generator for different slips is shown in Figure ۳. In the case of near zero slips, corresponding to the no-load generator mode, the generator reactive power is negligible. As the generator produced active power increases, the slip increases leading to generator reactive power increase. As shown in Figure ٤, the squirrel cage induction generator requires more reactive power to produce active power which may affect the system performance. That is, the squirrel cage induction generator (SCIG) reactive power consumption is uncontrollable. Such reactive power uncontrollability in this turbine serves as one of the main disadvantages. In practice, the capacitor banks are used for reactive power compensation required for this type of generator in each turbine. Although the speed in these compensators can only meet the demand at steady state mode, they are not as much efficient in transient speed mode. The fixed speed wind turbine output power is continuous. And their instantaneous and continuous power output causes the rapid and continuous terminal voltage fluctuations. Considering the suitable reactive power compensation for squirrel cage induction generators in wind farm, the rapid and dynamic compensators are needed.

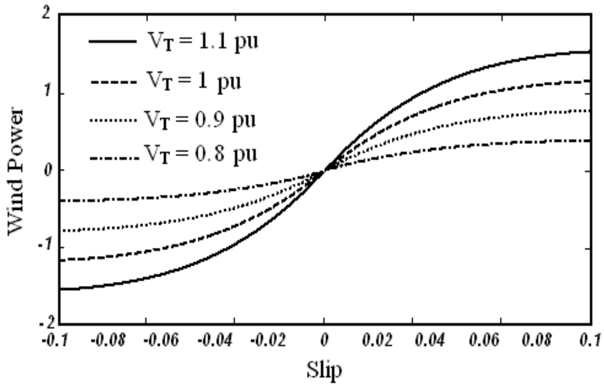

Figure ▯. The induction generator active power based on slips

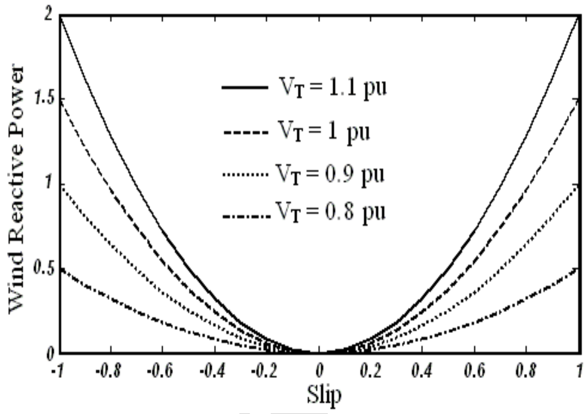

Figure ▯. The induction generator reactive power based on slips

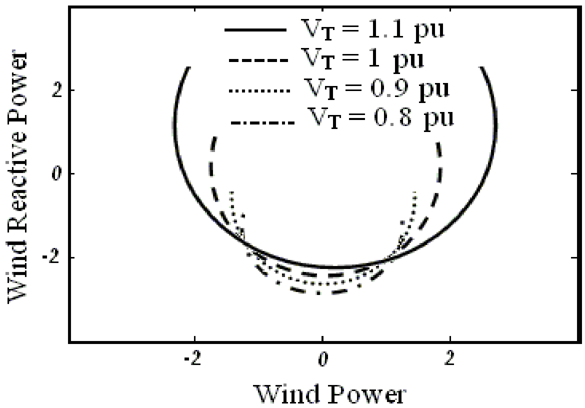

Figure ▯. The circular induction generator power

Concurrent with the fault and reduced voltage condition, the generator delivered power to the grid is reduced and the generator will be accelerated. If the generator acceleration is faster than voltage recovery, the generator speed continues to increase to the extent that the generator speed steps into the its instability condition putting the whole unit off the circuit. The short circuit causes the generator not to transfer their production capacity to the grid, therefore, increasing the speed. Since the torque in induction generator is proportional to terminal voltage square, accordingly, by employing a current limiter, the stator current fault decreases thus leading to a decrease in generator terminal voltage which in turn increases the generator electrical torque and terminal voltage [□-□].

Simulation

The wind farm under study has a capacity of ٥٠٠kW. These units are connected to the grid through two ١٣,٨kV distribution transmission lines over ٢٠km through a ١٣,٨ / .٦٩ kV transformer. The squirrel cage induction generators are used in this model. The specified capacitor banks supply ٧٠٪ of the required reactive power for the wind farm. Figure ٥ shows the sample distribution and the placement of the model in the system. The system parameters are listed in Table ١. Using the PSCAD / EMTDC software in the example in Figure ٥, the resistive type superconducting limiters impact on the wind farm transient stability is analyzed and simulated in the following two modes:

- Without limiter
- With resistive type superconducting limiters

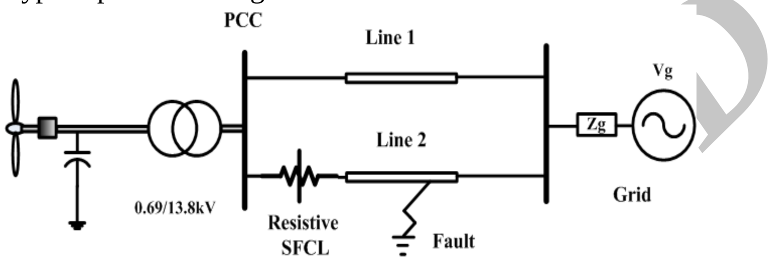

Figure □. The sample grid under study

Table □. The sample grid parameters

Parameters		Values
Grid	Supply	١٣,٨ kV
	Frequency	٥٠Hz
	X/R ratio	٨
Line	R	٠,١(Ω/km)
	X	٠,٢(Ω/km)
	Length of F١	٢٠ km
	Length of F٢	٢٠ km
	Voltage	٦٩٠ V
	Frequency	٥٠ Hz
	Number of poles	٤
	Slip	١/٨ %
	Power factor	٠,٨٨
	Reactive power(no load)	١٨٦ kvar
	Stator resistance	٠.٠٠٥٧٧ Ω
	Stator reactance	٠,٠٧٨٢ Ω
	Rotor resistance	٠.٠١٦١ Ω
	Rotor reactance	٠,١٠٢١ Ω
	Magnetizing reactance	٢,٤٣٤ Ω
Fault current limiter	Rm	١ Ω

Simulation results

In the first simulation, a symmetrical three-phase fault occurred on feeder ٢ (F٢) shown in Figure ٥. Starting at ١٠ seconds, the fault lasted for ٢٠٠ milliseconds. Figures ٦ and ٧ show the PCC bus voltage and feeder ٢ fault current limiter in the limiters absence and presence, respectively. As shown in Figure ٦, with the presence of the limiter, the fault current was changed from ١،٥ kA in Feeder ٢ to ٠/٢٥ kA and one of its advantage is that the sudden increase in the fault current is prevented.
Figure ٧ shows the PCC bus voltage in presence and absence of the limiter. As depicted in Figure ٧, using the limiter has increased the PCC bus voltage from .٠٥pu to .٩pu.

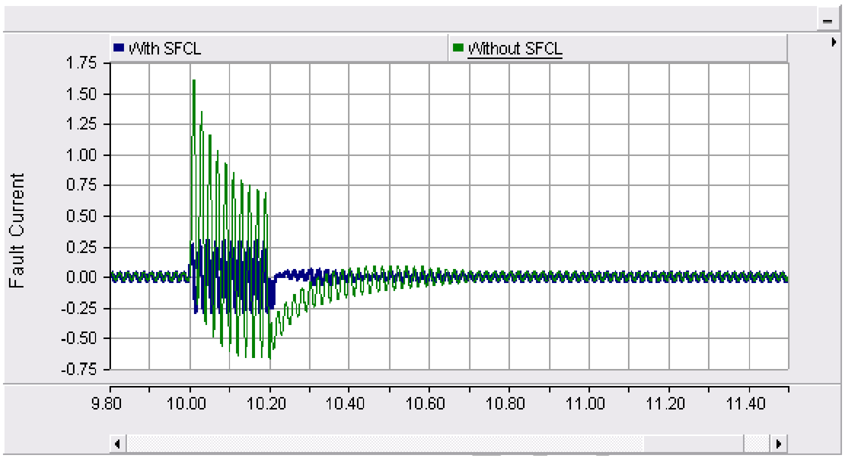

Figure □. Fault current in feeder ٢

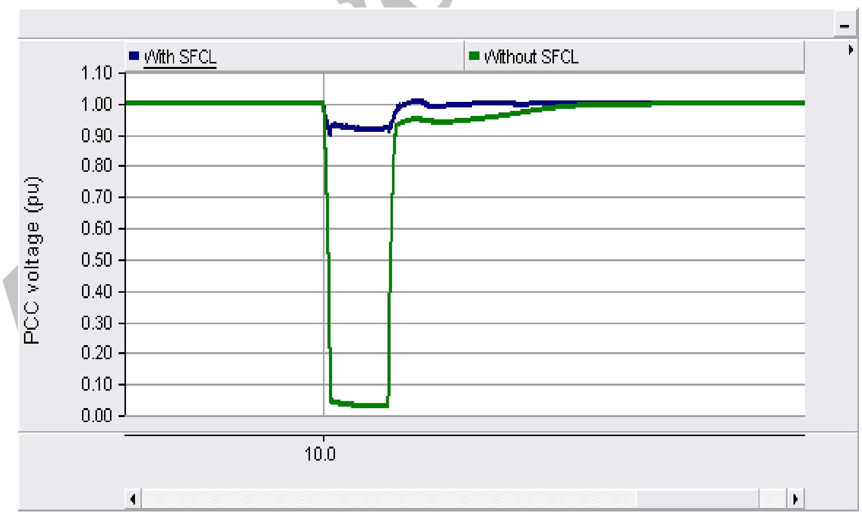

Figure □. The PCC volatage in fault current condition

Figures ٨ and ٩ show the wind farm active and reactive power in the limiter absence and presence, respectively. As illustrated in these figures, the exchanged active and reactive power variations in the fault time witnessed a decrease due to the limiter presence. The PCC bus voltage increase at the fault time can bring about power drop resulting from bus voltage drop.

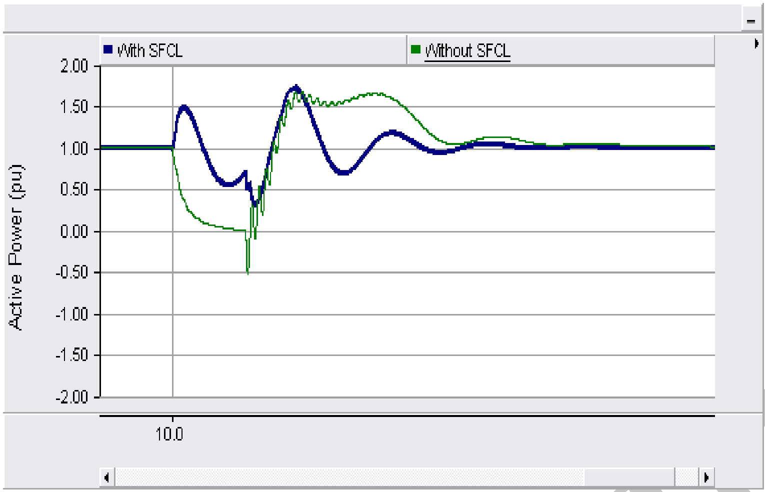

Figure □. The wind farm active power at the fault time

Figures ١٠ and ١١ show the wind farm rotor speed and electric torque curves with and without limiter the electrical shows. As shown in these figures, the electric torque and speed fluctuation at the fault time has perceived reduction due to the limiter presence.

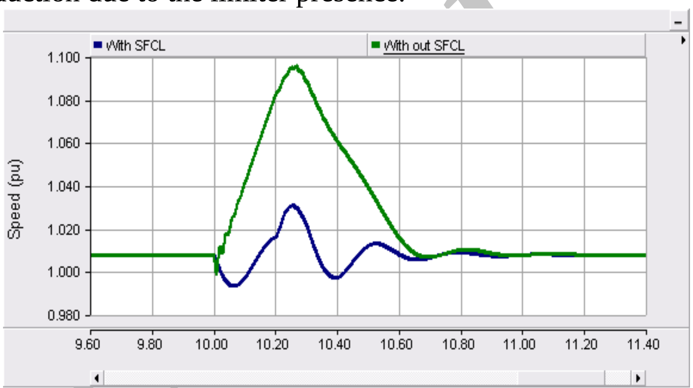

Figure □. Generator speed at the fault time

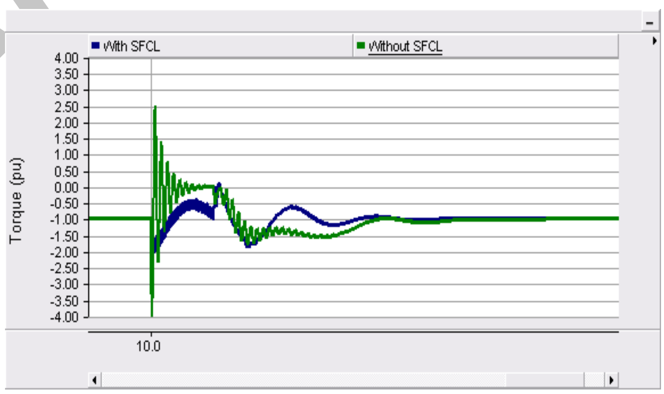

Figure □□. The generator electric torque at the fault time

Conclusion

One of the main issues raised in the wind farm is their stability at the fault occurrence and disturbances in the network. The study sought to evaluate and simulate the resistive type superconducting fault current limiter impact on voltage stability and wind farm dynamic transient behavior in short circuit condition using PSCAD / EMTDC software. The simulation results revealed that in the presence of fault current limiter not only the fault current is limited, but also the PCC bus voltage drop decreases. Also, limiter presence in the system leads to reduced fluctuations in power, torque and speed. Therefore, the limiter presence in the system not only reduces the fault current and the risk of damages to the equipment, but also improves the system stability.

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