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Performance Analysis of the Positioning of Superconducting Fault Current Limiters for the Smart Grid Application Using MATLAB Simulink

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Abstract - By virtue of increasing amount of distributed generation due to ever-increasing the demand and consumption of electric power widely, the chances of occurrence of any kind of fault or abnormal condition are very common, due which it crosses the rated capacity of the existing circuit breakers. Among the countermeasures to solve the short-circuit problem in a power distribution system considering the increase of the DG, the superconducting fault current limiter (SFCL) has been noticed as one of the promising devices. It has the capability to limit fault current within first cycle, can suppress the unanticipated short-circuit currents in utility distribution and transmission networks, so that the underrated switchgears can be operated safely. This paper presents a wind farm based smart grid network with SFCL for fault current reduction. In this work, a resistive type SFCL model is implemented by integrating Simulink and SimPower system block in Mat lab. The designed SFCL model could be easily utilized for determining an impedance level of it according to the fault current limitation requirements of various kinds of the smart grid system. In addition, typical smart grid model including generation, transmission and distribution network with dispersed energy resource was modeled to determine the location and the performance of the SFCL, as fault current reduction differs depending on its installed location. Three phase fault have been simulated at different locations in smart grid and the fault current analysis is done with and without SFCL and their performance is also evaluated. Consequently, the optimum arrangement of the SFCL location in Smart Grid with renewable resources has been proposed and its remarkable performance has been suggested.

Keywords- Fault current, smart grid, superconducting fault current limiter, wind farm.

I. INTRODUCTION

As we know the electrical energy is the most useful, versatile energy. Electrical energy used in industry, homes, transportation and business i.e. everywhere used. [1].When power delivery networks are upgraded or added to the system, fault (short-circuit) levels can increase beyond the capabilities of the existing equipment [2] and in some cases may exceed the ratings of existing circuit breakers(CB) and damage system equipment. Blair, S.M, et al, in 2009 had summarized the merits and demerits of traditional fault current limitation techniques such as Increase system impedance, Splitting bus bars, Upgrade switchgear, Sequential CB tripping, Increasing operating voltage levels, Fuses, Is-limiters. [3]. A commonly used technique for reduction fault current is based on insertion of high impedance in the power system just after fault occurrence [4]. FCLs are capable of limiting the fault current at the first peak and also limiting short circuit current at steady state without disturbing the normal operation. Fault current limiters have very low impedance during their normal operation [5]. However when a fault occurs these devices increase their impedance But, among the countermeasures to solve the short-circuit problem in a power distribution system considering the increase of the DG, the superconducting fault current limiter (SFCL) has been noticed as one of the promising devices [6], which has the capability to reduce fault current level within the first cycle of fault current. The first-cycle suppression of fault current by a SFCL results in an increased transient stability of the power system carrying higher power with greater stability [7]. Smart grid is the novel term used for future power grid which integrates the modern communication technology and renewable energy resources for the 21st century power grid in order to supply electric power which is cleaner, reliable, resilient and responsive than conventional power system. [8]. Energy micro grids are a key building block of future smart grids. Micro grids integrate modular energy sources, such as solar, wind, thermal generators, fuel cells, etc., with energy storage devices and both critical and non-critical loads to form low-voltage distribution systems. By definition, a micro grid is a group of interconnected loads, energy storage and generation systems within clearly defined boundaries that act as a single controllable entity with respect to the grid. A micro grid can operate in both grid-connected mode (to support the local distribution system) or operate in islanded mode (to protect users from grid instability). In this context, local generation systems, also known as distributed energy resources (DER), support local thermal and electrical demand while ensuring reliability and power quality with a lower emission footprint. Maintaining this profile relies on the flexibility of advanced power electronics that control the interface between micro generation and storage sources and their surrounding AC system [9]. The integration of renewable energy sources into electric power distribution systems can provide additional economic benefits because of a reduction in the losses associated with transmission and distribution lines. In this work a SFCL model is designed. SFCL is an innovative fault current limiter. It works on the principle of Superconducting Property. It is inactive under normal condition.

II. RESISTIVE TYPE SFCL

Resistive SFCLs utilize the superconducting material as the main current carrying conductor under normal grid operation. The principle of their operation is shown in the one-line diagram below (Figure 1).

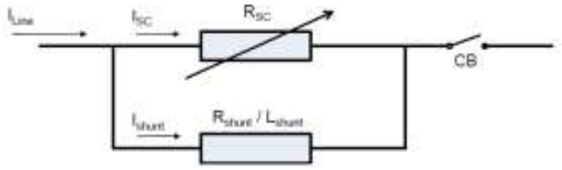


Figure 1: Resistive type SFCL with shunt element

When the current passes through the superconductor and when a high fault current begins, the superconductor quenches: it becomes a normal conductor and the resistance rises sharply and quickly. This extra resistance in the system reduces the fault current. Superconductor quenches under excessive fault current reverting to a normal conductor, inserting resistance. The current level at which the quench occurs is determined by the operating temperature, and the amount and type of superconductor. The rapid increase in resistance produces a voltage across the superconductor and causes the current to transfer to a shunt, which are a combined inductor and resistor. The shunt limits the voltage increase across the superconductor during a quench. In essence, the superconductor acts like a switch with millisecond response that initiates the transition of the load current to the shunt impedance. Ideally, the incipient fault current is limited in less than one cycle. Early resistive SFCL designs experienced issues with "hot spots", or non-uniform heating of the superconductor during the quench. This is a potential failure mode that occurs when excessive heat damages the HTS material. Recent advances in procedures for manufacturing HTS materials coupled with some creative equipment designs have reduced the hotspot issue. The grid characteristic of the resistive SFCL after a quench is determined by the shunt element. Thus, because the shunt is typically quite reactive, a resistive SFCL typically introduces significant inductance into the power system during a fault. During the transition period when current is being transferred from the superconductor to the shunt, the voltage across the combined element is typically higher than it is after the current has transitioned into the shunt. The dynamics of this process depend on the two elements and their mutual inductance. The quench process in resistive SFCLs results in heat that must be carried away from the superconducting element by the cryogenic cooling system. Typically, there is a momentary temperature rise in the superconducting element that causes a loss of superconductivity until the cryogenic system can restore the operating temperature. This period of time is known as the recovery time. To effectively ensure the reliability of power systems, an appropriate SFCL location needs to be considered. An installation site of SFCL can be set to suitable candidate location to improve the fault-current limiting performance.

III. SIMULATION SETUP

Mat lab/Simulink/SimPowerSystem was selected to design and implement the SFCL model. Simulink/SimPowerSystem has number of advantages over its contemporary simulation software (like EMTP, PSPICE) due to its open architecture, a powerful graphical user interface (GUI) and versatile analysis and graphics tools. Control systems designed in the Mat lab/Simulink can be directly integrated with SimPowerSystem models. A complete smart grid power network including generation, transmission, and distribution with wind farm model was also implemented in it.

A. Design of Power System

An existing micro grid model is designed by integrating a 9 MW wind farm with the distribution network. Fig. 4.2 shows the power system model designed in Simulink / SimPowerSystem. The power system is composed of a 220 MVA centralized power plant, composed of 3-phase synchronous machine, connected with distributed-parameters transmission line through a step-up transformer of 11/25 kV. Three phase loads 1, 2 and are being supplied by separate distribution branch networks. The wind farm is connected to the system through a transformer of rating 25kV/575V. The 9 MVA wind farm is composed of DFIG-based wind turbine each having a rating of 1.5 MVA. The most severe fault in the power system is three phase to ground fault, it results in very high current in the system. The designed fault current limiter is in such a way that it should reduce the fault current due to three phase to ground fault, then it can successfully reduce the fault current in micro grids for all remaining faults Artificial faults and locations of super conducting fault current limiter (SFCL) are indicated in the figure 2. Three kinds of fault points are marked as Fault 1, Fault 2 and Fault 3 which represent three phase to ground faults in transmission line at different locations. Three prospective locations for SFCL installation are marked as Location 1 (at main generator i.e. in incoming feeder), Location 2 (branch network) and

Location 3(Wind farm connection point with the grid). Generally, centralized fault Current protection devices are located in Location 1 and Location 2. The output current of wind farm as well as centralized power plant for each and every fault have been measured. To reduce this wind farm fault current the Superconducting fault current limiter used and analyzed for determining the optimum location of SFCL in a micro grid. First, we assumed that single SFCL was located at Location 1 just after the step up transformer in incoming grid feeder. Second single SFCL was located at Location 2.

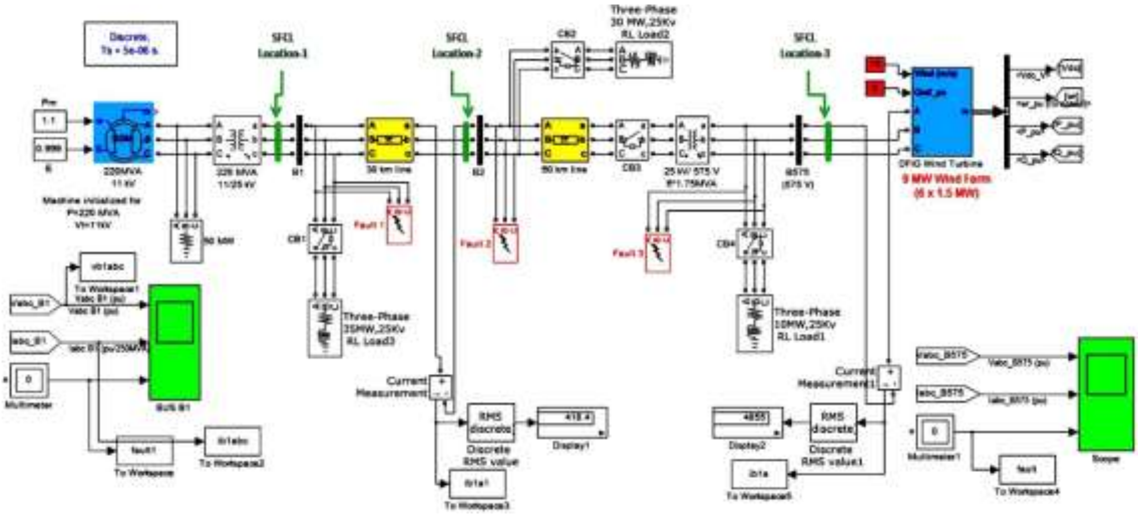


Figure 2 Power system model designed in Simulink/SimPowerSystem. Fault and SFCL locations are indicated in the diagram

Third, single SFCL was located at Location 3 (Wind farm connection point with the grid). Finally, dual SFCL placed together in different locations, SFCLs were located at Location 1 (incoming grid feeder) and Location 3 (Wind Farm connection). The three phase resistive type SFCL was modeled considering four fundamental parameters of a resistive type SFCL. These parameters and their selected values are as follows: Transition or response time = 2 msec, Minimum impedance = 0.01ohms, Maximum impedance = 20 ohms, Triggering current = 500 A, Recovery time = 10 msec. To determine the minimum or maximum impedance to output switch block is used. Here the RMS value of the incoming current is calculated using RMS block. To reduce harmonics, first order filter is used. The SFCL model works as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic table. Second, if a passing current is larger than the triggering current level, SFCL's resistance increases to maximum impedance level in a pre-defined response time. Finally, when the current level falls below the triggering current level the system waits until the recovery time and then goes in to the normal state.

B. Simulation Analysis

Four scenarios of SFCL's possible locations were analyzed for three different fault occurring points in the power system depicted in Fig. 2. First, we assumed that single SFCL was located at Location 1 (incoming grid feeder just after step up transformer). Second, single SFCL was located at Location 2 (Branch Network). Third, single SFCL was located at Location 3 (Wind farm integration point with the grid). Finally, in order to clarify the usefulness of dual SFCL installed together for different locations, SFCLs were located at Location 1 (incoming grid feeder) and Location 4 (Wind Farm) respectively. The feasibility analysis has been done by considering three faults at different locations i.e. Fault 1, Fault 2 and Fault 3 as shown in Fig. 2.Three phase fault has been simulated for a period of 0.05 seconds to 0.08 seconds that is fault occurred at 0.05 second and it cleared at 0.08 second. When a fault occurs in power system the fault current always flows towards fault point.

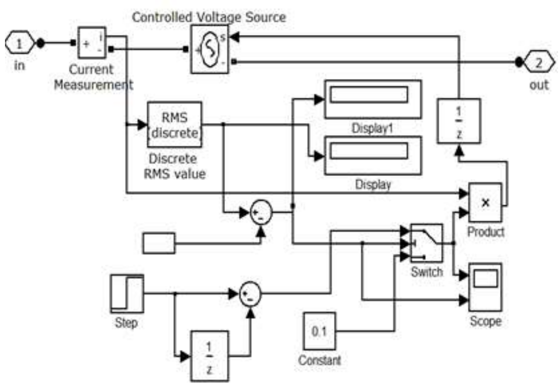
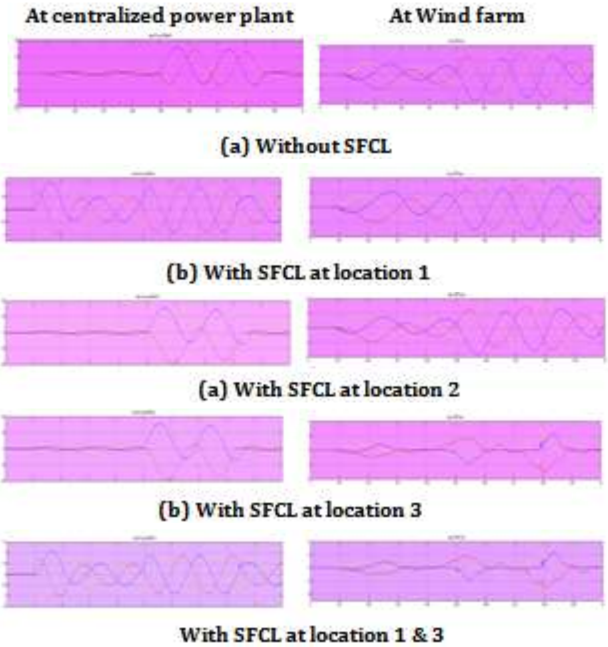


Figure 3 Single phase SFCL model developed in Simulink/SimPowerSystem

Case I: Transmission grid fault in close proximity to CPP (fault 1) Fault current at the fault point 1 which is in close proximity to centralized power plant is higher than fault current at the fault point 3 which is in close proximity to Wind farm. Because of centralized power plant (CPP) which is power source of higher rating and also closer to the Fault 1 is now forced to supply larger fault current to fault point (Fault 1).



In case of fault at point 1 with SFCL located at location 1, fault current approaching from wind farm does not flow through the SFCL located at location 1. Thus, fault current approaching from wind farm towards fault point 1 cannot be controlled to much extent as like fault current running from CPP towards fault point 1, because it traverse from SFCL at location 1. Similarly, in the presence of SFCLs at location 2 and 3 each, fault current running from CPP towards fault point 1 can't be curtailed because SFCLs at location 2 and 3 are not in path of fault current flowing from CPP towards fault point 1. And finally, the dual SFCL location at 1 and 3 both is the optimum location at which fault current coming from two sources is restricted to a limit because both the SFCLs are in direct path of fault current from centralized power plant as well as wind farm respectively.

Case II: Transmission line fault (approximately in the mid length of CPP and wind farm) When a fault occurs in transmission line, fault current from the centralized power plant as well as the wind farm would flow towards fault point. For the wind farm condition, fault current would flow in reverse direction through the substation and into the transmission line to fault. An important aspect to be noted here is that wind farms on distribution side can contribute fault currents to transmission line faults and this phenomenon must be considered. In case of fault at point 2 with SFCL located at location 1 and 2 each, fault current approaching from wind farm does not flow through these SFCLs. Thus, fault current flowing from wind farm towards fault point 2 cannot be controlled too much extent but fault current running from CPP towards fault point 2is curtailed because of traversing through SFCLs at location 1 and 2 each. Similarly, in the presence of SFCLs at location 3, fault current running from CPP towards fault point 2 can't be curtailed because SFCLs at location 3 is not in path of fault current flowing from CPP towards fault point 2. However fault current from wind farm can be reduced satisfactorily. And finally, the dual SFCL location at 1 and 3 both is the optimum location.

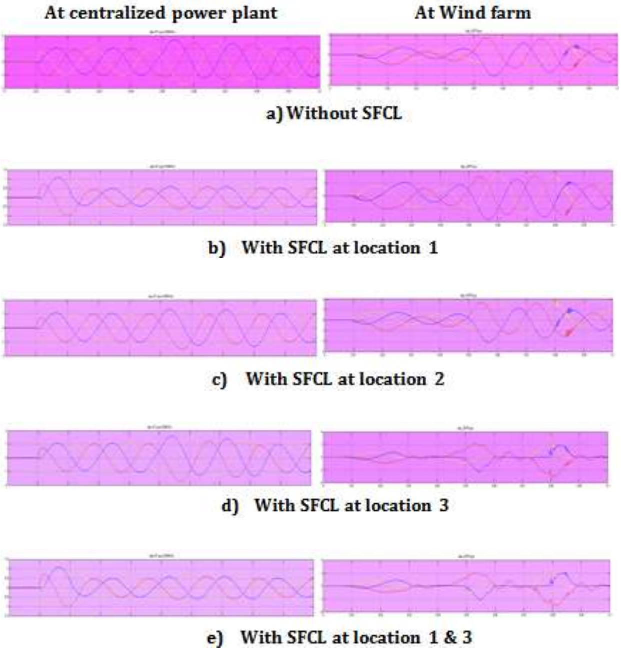


Figure 5 Fault at fault point 2

Case III: Transmission line fault in close proximity to the wind farm Fault point 1 and fault point 3 are in close proximity to CPP (220 MVA) and Wind Form (9 MVA) respectively.

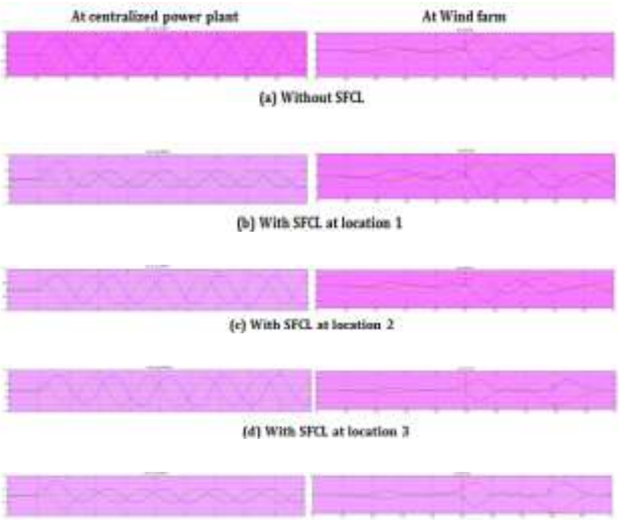


Figure 6: Fault at fault point 3

Table 1

Therefore fault current at fault point 3 is less than fault current at fault point 1. Fault current in this case is

83000A. In case of fault at point 3 with SFCL located at location 1, fault current approaching from CPP had significantly reduced because this fault current passes through SFCL at location 1. With SFCL at location 2, no discernible reduction in fault current from both the CPP and wind farm had been observed since this fault current had entered into different distribution loads. With SFCL at location 3 remarkable reductions in fault current contribution from wind farm is noted. Once again the best results are obtained when a dual SFCL is located at Location 1& 3. The Percentage decrease in centralized power plant (CPP) fault current and wind farm fault current for all considered SFCL locations are tabulated in table no 1.

	Fault 1				Fault2				Fault3			
	CPP	W. Farm	CPP	W. Farm	CPP	W. Farm	CPP	W. Farm	CPP	W. Farm	CPP	W. Farm
Fault current without SFCL	16	1.75			1.65	1.7			1.16	3.3		
SFCL Locations	Fault current with SFCL		%Decrease		Fault current with SFCL		%Decrease		Fault current with SFCL		%Decrease	
1	0.8	1.3	95%	26%	0.6	1.6	63%	5%	0.51	2.8	56%	15%
2	15.5	1.3	3%	26%	1.3	1.65	21%	3%	1.1	3.1	5%	6%
3	15.5	1.5	3%	14%	1.6	0.8	3%	53%	1.05	0.75	9%	77%
1&3	0.85	0.83	96%	52%	0.58	0.8	65%	53%	0.47	0.66	60%	80%

IV. CONCLUSION

On connecting a Distributed Generator of large size to the distribution network the fault levels definitely increase to certain extent. This increased fault current is to be limited using the fault current limiting methods. Therefore, an application of superconducting fault current limiter (SFCL) is proposed to instantaneously limit the unanticipated fault current that occurs in power system. In the present paper, the smart grid power system model that includes centralized power plant as well as Wind farm was developed using MATLAB Simulink. To limit fault current in the developed system, by considering the fundamental parameters, single phase resistive type SFCL model was successfully developed using MATLAB Simulink. Then three R- SFCLs are collaborated to construct a three phase R-SFCL. To suppress the fault current within a minimum possible recovery time, the three phase faults have been simulated at different locations in smart grid with and without SFCL and their performance was evaluated. When a single SFCL was evaluated in an integrated power system, it can't limit fault current from each source at a time at any fault point in the smart grid because fault current from any location can't pass through that SFCL at any occurrence of fault. Consequently, the optimum location of SFCL in a smart grid which limits all fault currents adequately was a dual SFCL at located at main generator i.e. in incoming feeder & wind farm connection point with the grid and its remarkable performance has been suggested. Ultimately, the reliability and stability of the power system can be improved.

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