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Fault Analysis Using Superconducting Fault Current Limiters

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Abstract- Smart grid is an advancement of the existing electrical grid. The key feature of the future smart grid is the decentralization of the main power grid into number of smaller grids (known as micro grids). Interconnection of the distributed generating (DG) sources is required with the existing electrical grid to enhance the reliability of the power system. Extensive integration of DG sources within a smart grid causes failure of a successful implementation of smart grid due to the presence of enormous fault current. Superconducting Fault Current Limiter (SFCL) has the capability to reduce the fault current level within the first cycle of the fault current resulting in an increased transient stability of the power system. In this paper an application of a resistive type SFCL, designed in Simulink / SimPower System has been proposed to limit the fault current that occurs in an interconnected power system. A resistive type SFCL model has been developed in Simulink and the performance of SFCL at different locations has been analysed in the proposed system considering wind farm (10 MVA) as a distributed generating (DG) source with the conventional power plant, to reduce the fault current in micro grids. The feasible location of the SFCL having no negative effect on the DG source has been evaluated in three phase and single line to ground faults at various positions in the smart grid.

Index Terms- conventional power plant, wind farm, micro grid, smart grid, superconducting fault current limiter, fault current.

I. INTRODUCTION

Due to the increase in the scale of the power systems by the interconnection of the distributed generation to a grid, high level fault currents might be caused during a contingency. The fault creates a surge of current through the electric power system that can cause serious damage to the grid equipment. Switchgears, such as relays, circuit breaker are deployed within transmission substations to protect substation equipments [1, 2]. This problem needs the up gradation such as the modification of substation or replacement of multiple circuit breakers. Conventional protection devices used for the protection of the existing switchgear to reduce the fault current like the fuses, air-core reactors, circuit breakers, relays etc could not limit the excessive increase in fault current due to the extensive integration of the distributed generation sources until these devices are upgraded [3, 4].

But, superconducting fault current limiter (SFCL) can be an alternative to replace the aforesaid conventional protective devices as it has the capability to improve the transient stability of the power system by suppressing the level of fault currents in a and effective manner [5, 6]. The smart grid is expected as the next generation power grid which incorporates the 21st century communication technologies and the distributed renewal energy resources into the conventional electrical grid in order to supply the electric power which is cleaner, reliable, resilient and responsive then the conventional power system [7, 8].

Until now, there were several research activities discussing the fault current issues of smart grid, but the applicability of a SFCL into micro grid was not yet [9]. Hence, the main concern of this work is to solve the problem of increasing fault current in micro grid by using SFCL technology [10, 11]. In this paper, a resistive type SFCL model has been developed in Simulink and the effect of the SFCL and its position has been investigated considering a wind farm integrated with a distribution grid model as one of the typical configurations of the smart grid [12]. The impacts of the SFCL on the wind farm integrated as the strategic location of SFCL in a micro grid which limits the fault current from all power sources and has no negative effect on the integrated wind farm has been suggested.

II. SIMULATION SET-UP

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

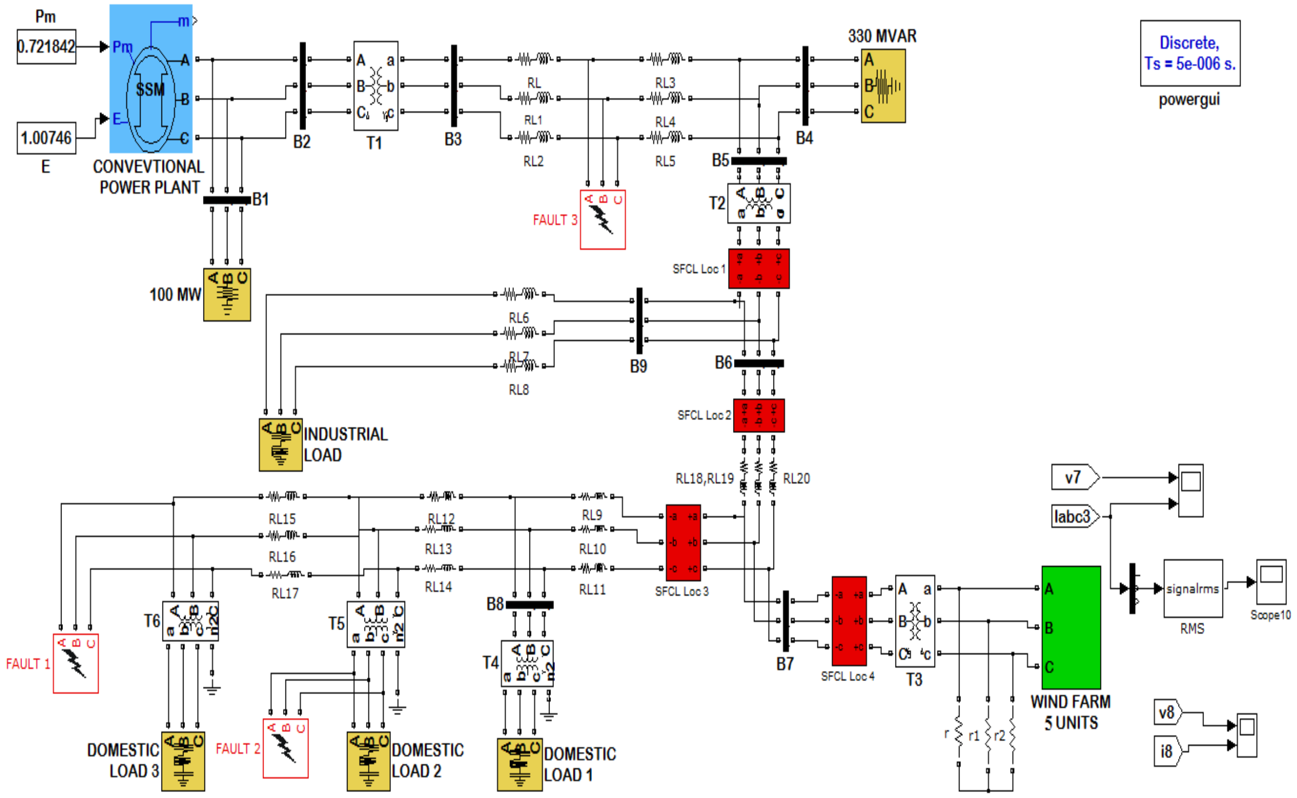

Fig.1. Micro grid model implemented in Simulink/SimPowerSystem showing locations of fault and SFCL positions in the grid.

A. Micro Grid Model

Fig.1 above demonstrates the micro grid model created in Simulink. The power system model consists of a 100 MVA conventional power plant using 3 phase synchronous generator generating electricity at 20 kV which is stepped up to 154 kV for transmission purpose by a step up transformer. The power is then transmitted to a receiving station by using 200 km long transmission line at 22.9 kV via step down transformer. 100 MW load is connected before T1 through bus B1. High power industrial load (6 MW) is supplied by a separate branch. A 330 MVAR load is connected through bus B4 with the conventional power plant. Low power domestic loads of (10 KW) each are also being supplied by separate distribution branch networks consisting of transformers T3, T4 and T5. The wind farm is directly connected with the branch network B6 with transformer T3. 10 MVA wind farm is composed of five induction type wind turbines having a rating of 2 MVA each. Three domestic loads are separated with each other through 5 km transmission line and connected by 3 step-down distribution transformers (T4, T5 and T6) of rating 22.9KV/400V each.

B. Resistive type SFCL Model

The four fundamental parameters which are considered during the modeling of a three phase resistive type SFCL are:

- *Triggering current = 550A*
- *Transition or response time = 2msec*

- *Minimum impedance = 0.01 ohms and maximum impedance = 20 ohms*
- *Recovery time = 10msec*

Its operating voltage is 22.9 kV.

Fig.2 shows the SFCL model developed in Simulink/SimPowerSystem. The working of SFCL model is as follows: First of all, RMS value of the flowing current is calculated by RMS block and then this value is compared with the SFCL characteristic table.

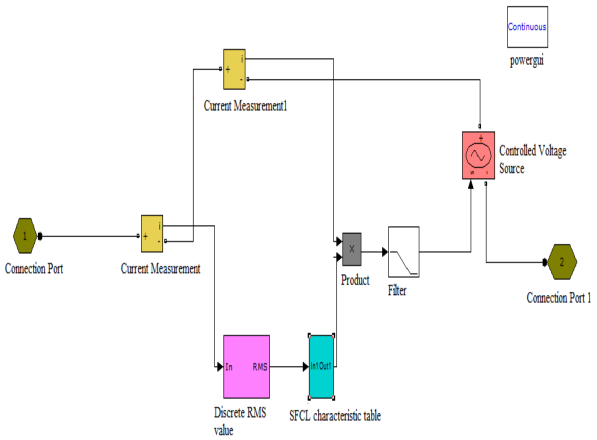

Fig.2. Single phase Resistive SFCL Simulink model

The SFCL characteristic table subsystem is shown in Fig.3. Now, if the flowing current is more than the triggering current level, SFCL's resistance increases to maximum impedance level in a predefined time known as response time. Finally, when the current level falls below the triggering current level the system waits until recovery time and goes into the normal operating state. To indicate the transition or response time step block is used and for recovery time of superconducting fault current limiter transport delay block is employed. To decide the minimum or maximum resistance offered to the flow of fault current output switch block is employed. For reducing harmonics first order filter is utilized. As we know that the flow of fault current causes voltage sag therefore to compensate the induced voltage sag controlled voltage source is connected in the circuit.

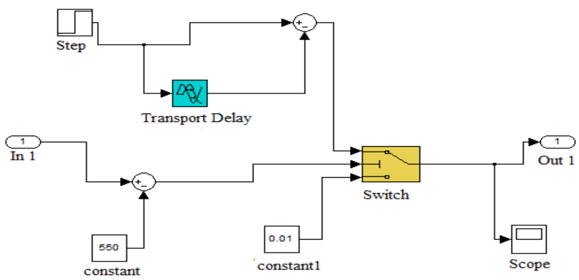

Fig.3. SFCL characteristic table

III. RESULTS AND DISCUSSION

Four different scenarios of SFCL's possible locations has been analyzed for three different fault occurring points in the power system depicted in Fig. 1. First, we assumed that single SFCL was located at Location 1 (Substation). 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). Fourth, double SFCLs were located at Location 1(Substation) and Location 4(Wind Farm) in order to clarify the usefulness of the dual SFCLs installed together.

A. FAULT AT DISTRIBUTION GRID (FAULT 1)

The different results obtained for the fault occurring in distribution grid (Fault 1) have been shown below. For the fault at distribution grid, when SFCL has been placed at Location 1 (Substation) or Location 2 (Branch network), fault current contribution to the wind farm has been increased and the magnitude of fault current is more than 'No SFCL' case.

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This signifies that the placement of SFCL at location 1 and location 2 causes increase in the value of the DG fault current level instead of reducing it. This sudden rise in the fault current value from the wind farm is due to the abrupt change in the power system impedance, as SFCL at locations 1 and 2 has entered in the current limiting mode due to occurrence of fault and reduced the fault current coming from the conventional power plant due to rapid increase in its resistance. Therefore, wind farm which has been considered as the other power source and also nearer to Fault1 is now forced to contribute larger fault current to the fault point.

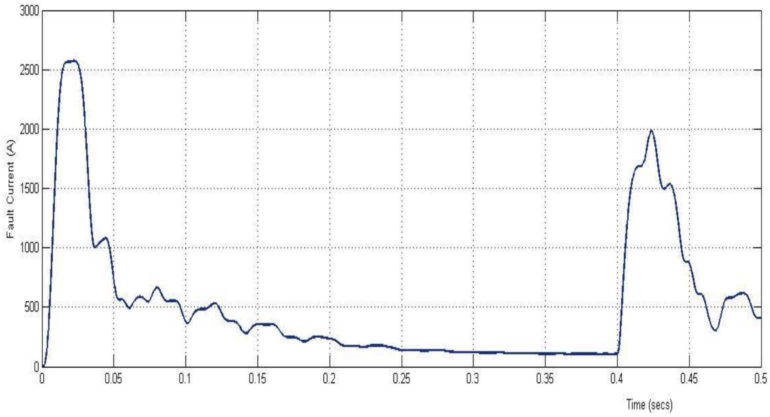

Fig.4. RMS value of fault current for Fault 1 without SFCL

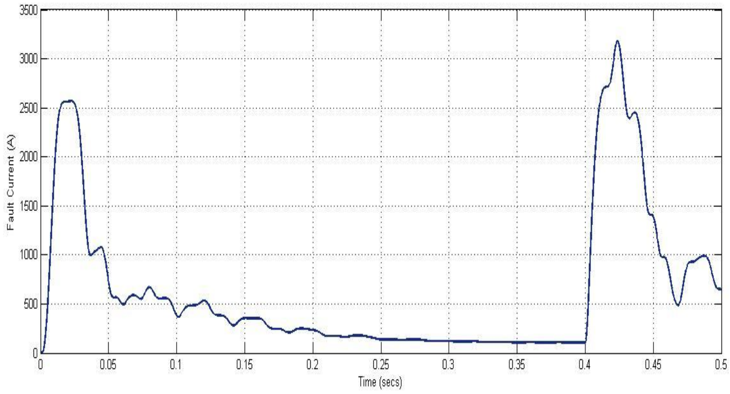

Fig.5. RMS value of fault current for Fault 1 with SFCL at Location 1

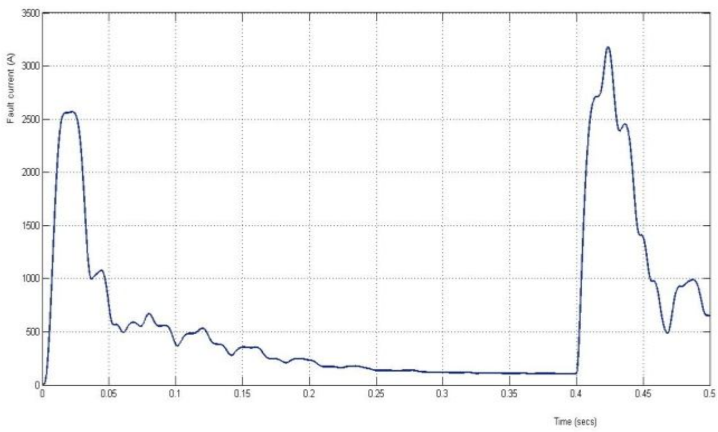

Fig.6. RMS value of fault current for Fault 1 with SFCL at Location 2

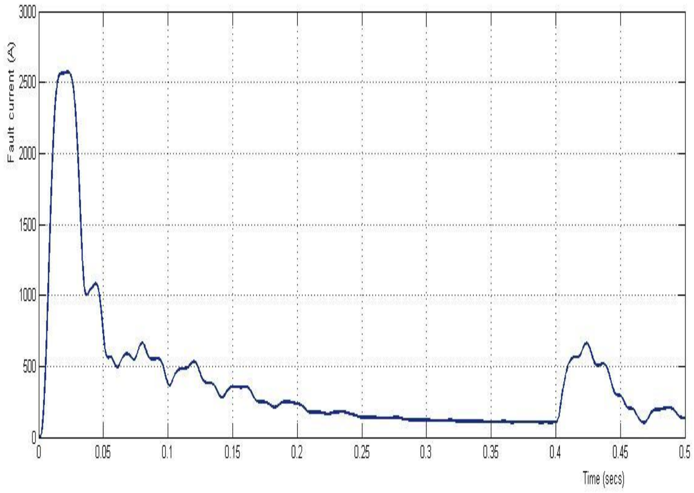

Fig.7. RMS value of fault current for Fault 1 with SFCL at Location 3

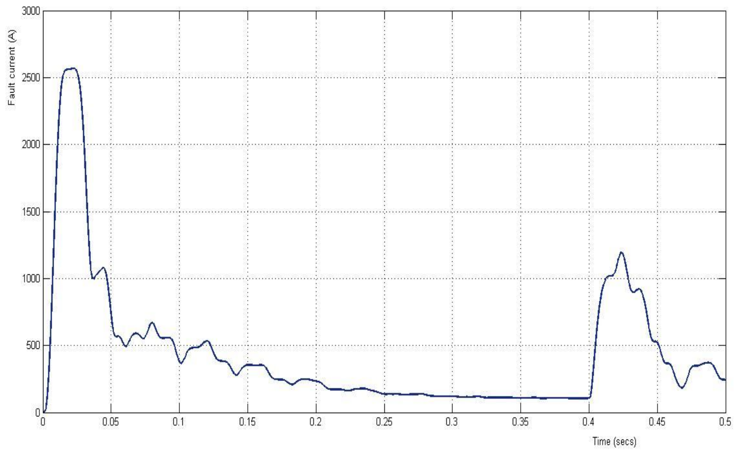

Fig.8. RMS value of fault current for Fault 1 with SFCL at Location 1 and Location 4

Fig.9. shows a comparison between fault currents from the wind farm for different SFCL locations when a three-phase fault was initiated at the distribution grid.

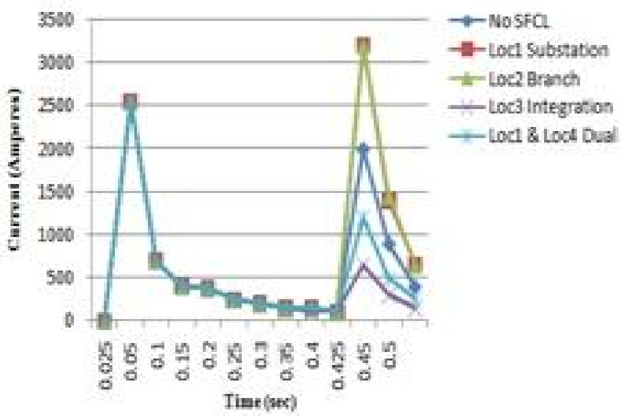

Fig.9. Comparison of wind farm fault currents for four SFCL locations in case of fault in distribution grid (Fault 1)

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B. FAULT AT CUSTOMER GRID (FAULT 2)

The different results obtained for the fault occurring in the customer grid (Fault 2) have been shown below. Fault 2 is comparatively small fault as it has occurred in low voltage customer side distribution network. The results obtained for fault 2 are similar to those as it has been seen for fault 1.

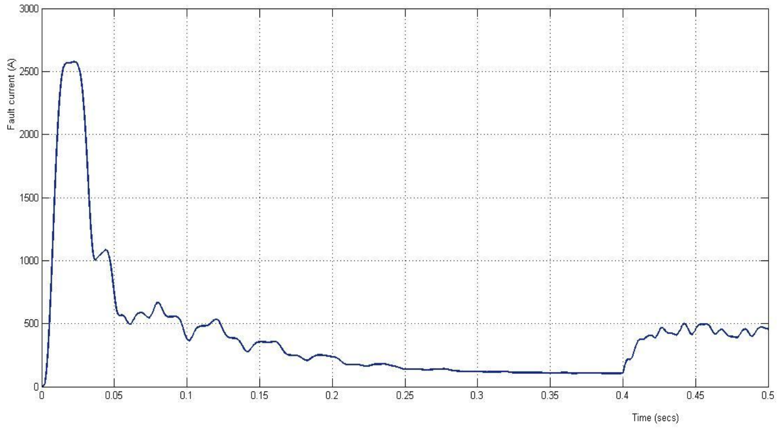

Fig.10. RMS value of fault current for Fault 2 without SFCL

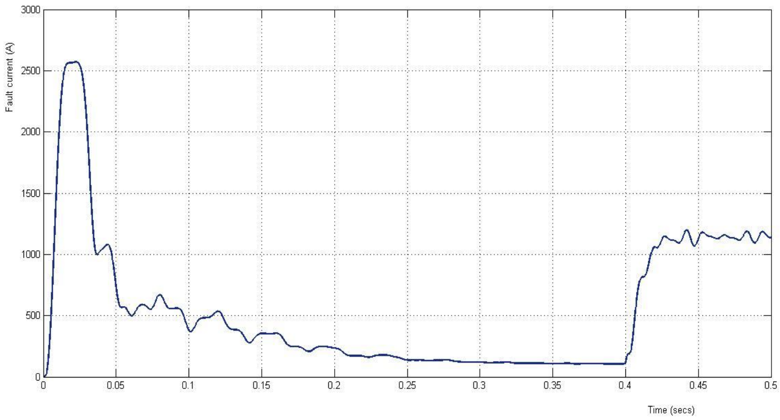

Fig.11. RMS value of fault current for Fault 2 with SFCL at Location 1

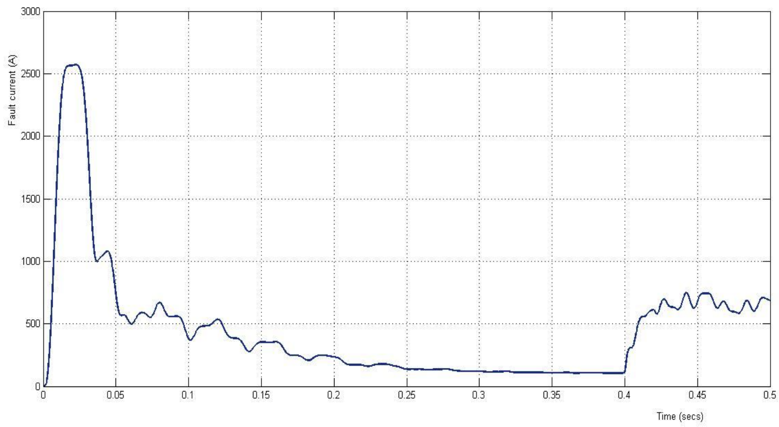

Fig.12. RMS value of fault current for Fault 2 with SFCL at Location 2

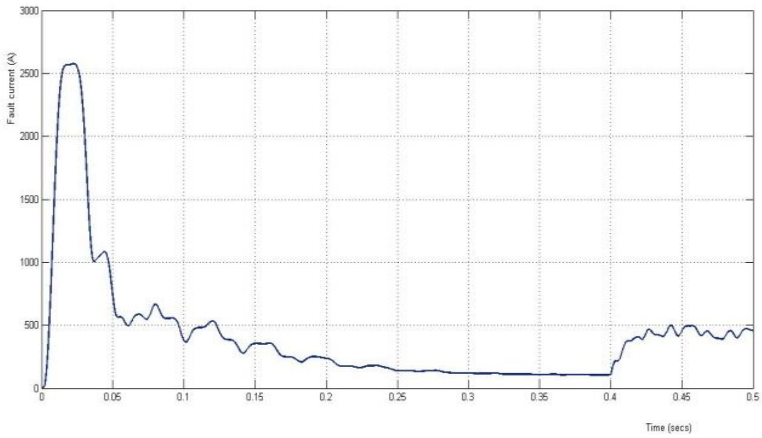

Fig.13. RMS value of fault current for Fault 2 with SFCL at Location 3

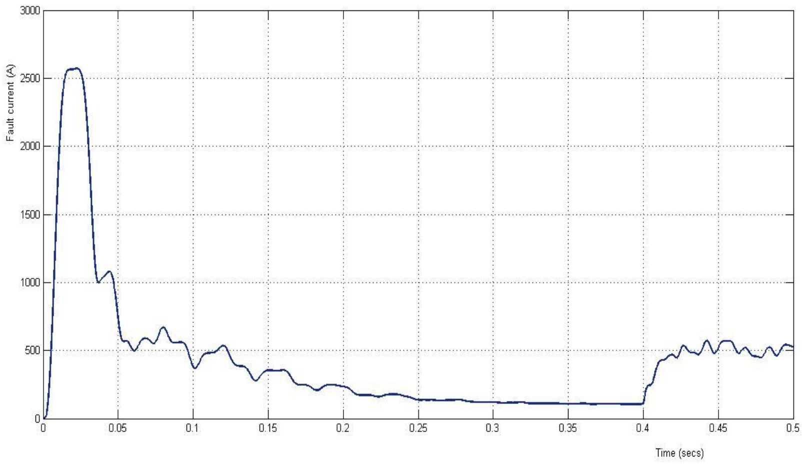

Fig.14. RMS value of fault current for Fault 2 with SFCL at Location 1 and Location 4

Fig.15. shows a comparison between fault currents from the wind farm for different SFCL locations when a three phase fault was initiated at the customer grid.

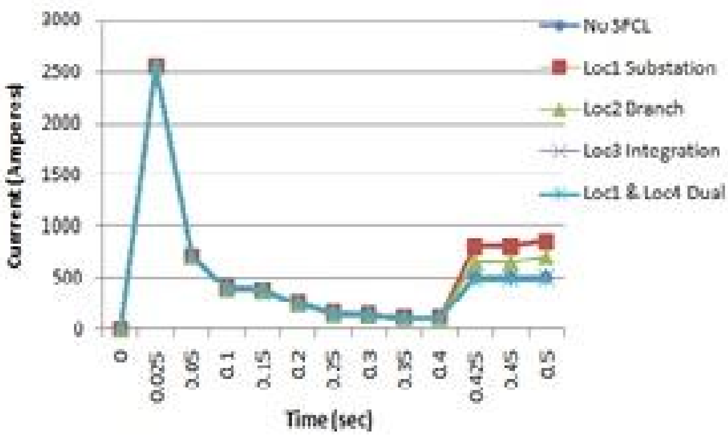

Fig.15. Comparison of wind farm fault currents for four SFCL locations in case of fault in customer grid (Fault 2)

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C. Fault at Transmission Line (Fault 3)

Fault 3 shown in Fig.1. indicates the rarely occurring transmission line fault which results in a very high fault current from the wind farm (measured at output of bus 7 in fig.1).Now when the SFCL was placed at different locations for fault occurred in transmission line, location 3 came to be the best location (which is the integration point of wind farm and distribution grid) as at this location maximum reduction of the fault current was observed. Fig.16. shows a comparison between fault currents from the wind farm for different SFCL locations when a three-phase fault was initiated at the transmission line.

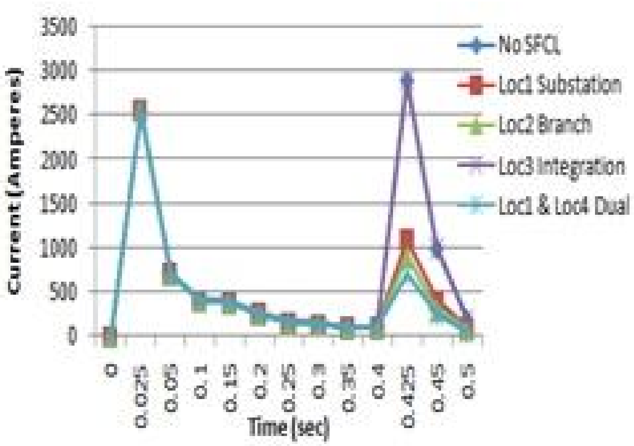

Fig.16. Comparison of wind farm fault currents for four SFCL locations in case of fault in transmission line (Fault 3)

TABLE I

Percentage variation in fault current approaching from the wind farm due to four different SFCL positions in the grid in case of Three Phase Fault.

	Fault 1 (at Distribution Grid)	Fault 2 (at Customer Grid)	Fault 3 (at Transmission Line)
SFCL Locations	% change in fault current	% change in fault current	% change in fault current
Location 1	61% increased	60 % increased	60 % decreased
Location 2	59% increased	30 % increased	68 5 decreased
Location 3	70 % decreased	20 % decreased	0%
Location 1 and Location 4	45 % decreased	2% decreased	75 % decreased

TABLE II

Percentage variation in fault current approaching from the wind farm due to four different SFCL positions in the grid in case of Single Line to Ground (LG) Fault.

	Fault 1 (at Distribution Grid)	Fault 2 (at Customer Grid)	Fault 3 (at Transmission Line)
SFCL Locations	% change in fault current	% change in fault current	% change in fault current
Location 1	60 % increased	87 % increased	66 % decreased
Location 2	60 % increased	50 % increased	72 % decreased
Location 3	70 % decreased	0 %	0%
Location 1 &Location 4	40 % decreased	20 % increased	77 % decreased

On comparing Table I and Table II we can see that the results obtained for the four different SFCL installation scenarios for three phase and single line to ground (LG) faults, the maximum fault current reduction has been achieved for the SFCL located at the point of integration of the wind farm with the grid (Location3). It has also been observed that the performance of SFCL placed at Location 3 is even better than the dual SFCLs placed at Location 1 and Location 4 at a time. Thus, the multiple SFCLs in a micro grid are not only costly but also less efficient than the strategically located single SFCL for both the types of faults.

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IV. CONCLUSION

This paper presented a feasibility analysis of positioning of the SFCL in rapidly changing modern power grid. A complete power system along with a micro grid (having a wind farm connected with the grid) has been modeled and transient analysis for three-phase-to-ground faults and single line to ground faults at different locations of the grid have been performed with SFCL installed at key locations of the grid. It has been observed that SFCL should not be installed directly at the substation or the branch network feeder. This placement of SFCL results in abnormal fault current contribution from the wind farm. Also multiple SFCLs in micro grid are inefficient both in performance and cost. The strategic location of SFCL in a power grid which limits all fault currents and has no negative effect on the DG source is the point of integration of the wind farm with the power grid.

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