

Application of Superconducting Fault Current Limiters in Smart Grid System

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ABSTRACT: In this paper, an application of superconducting fault current limiter (SFCL) has been proposed for Smart grid, which is an advancement of the main power grid. Decentralization of the main power grid into number of smaller grids is the key feature of the future smart grid. To enhance the reliability of the power system, interconnection of the distributed generating (DG) sources is required with the existing electrical grid. Presence of fault current due to extensive integration of DG sources within a smart grid causes failure of a successful implementation of smart grid. Superconducting fault current limiter being one of the innovative solutions in the highly interconnected smart grid has the capability to reduce the fault current level within the first cycle of the fault current, which results in an increased transient stability of the power system. A resistive type SFCL model has been developed in Simulink and the performance of SFCL at different locations has been monitored 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 SFCL having no negative effect on the DG source has been evaluated in different types of faults at various positions in the smart grid. A Simulink based model has been developed and the simulation results for the proposed model have been obtained by using MATLAB.

KEYWORDS: superconducting fault current limiter (SFCL), Fault current, micro grid, smart grid, wind farm.

I. INTRODUCTION

Consumption of the electrical energy has grown now-a-days and the generation, transmission and distribution system has been more complicated. Smart grid concept has thus been suggested that provides an ample opportunity to manage the electricity consumption in real time and be more reliable, responsive, resilient and flexible than the conventional power systems [1, 2]. Smart grid is the term used for future power grid which integrates the modern communication technology and renewable energy resources for the 21st century power grid [3, 4]. One of the most important features of the smart grid is decentralization of the power grid network into smaller grids, which are known as micro grids, having distributed generation (DG) sources integrated with them [5, 6]. There is considerable rise in the penetration of DG sources within the existing grid, with the continuous rise in the demand for electricity. Major problems expected by the direct connection of DG sources with the power grid are the excessive increase in the fault current and the loss of relay co-ordination [7, 8]. Conventional protection devices used for protection of increased fault current in electric power systems are the fuse, air core reactors and circuit breaker. Fuse shut downs the whole shielded section of the system during the occurrence of fault and need to be replaced manually. Due to the air core reactors, there is continuous loss and voltage drop in the system. Circuit breakers have certain response time delay that allows initial fault current cycles to pass through it [9, 10]. The integration of DG source will cause excessive increase in the fault current level, which could not be limited by the conventional protection devices of lower rating until these devices are upgraded.

After the discovery of High Temperature Superconductors (HTS) in 1986, cooled with liquid nitrogen and showing drastic change in material properties [11], SFCL has emerged as an alternative to substitute the aforesaid conventional devices, as it has capability to reduce the fault current level within the first cycle of the fault current, which increases the transient stability of the interconnected power system [12, 13]. Limitation of the fault current with SFCL is due to the non-linear characteristics of the superconductor [14]. During the normal operating condition SFCL offers negligible

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resistance to the system. But during the occurrence of fault, current exceeds its critical value of the superconductor material which results in the transition of the device (SFCL) from its superconducting (low resistance) state to the normal (high resistant) and limits the fault current to a considerable level [15]. The suitable location of SFCL has been monitored for the successful implementation of smart grid as well as to obtain the maximum benefit of its incorporation with the smart grid [16]. In this paper, the complete power system network has been modelled by integrating 10 MVA wind farm with the conventional power plant as one of the typical configurations of the smart grid. The impacts of SFCL on the wind farm and the optimal location of SFCL in a micro grid which limits the fault current from all the power sources and has no negative effect on the integrated wind farm (as DG source) has been suggested.

II. RELATED WORK

Smart Grid is the novel term used for the future power grid that integrates the modern communication technology in order to supply the electric power that is cleaner, reliable, resilient, responsive and flexible than the conventional power system. One of the most important features of the smart grid is decentralization of the power grid network into smaller grids, which are known as micro grids, having distributed generation (DG) sources integrated with them.

The integration of DG source will cause excessive increase in the fault current level, which could not be limited by the conventional protection devices like fuse, air core reactors and circuit breakers of lower rating until these devices are upgraded. SFCL has emerged as an alternative to substitute the aforesaid conventional devices, as it has capability to reduce the fault current level within the first cycle of the fault current, which increases the transient stability of the interconnected power system. To introduce an SFCL in the power systems, the trigger current level, the limiting impedance, the maximum output impedance, the response time and the recovery time are important specifications of the SFCL. The suitable location of SFCL has to be monitored for the successful implementation of smart grid as well as to obtain the maximum benefit of its incorporation with the smart grid.

III. MODELING AND SIMULATION

A complete smart grid model including generation, transmission and distribution with an integrated wind farm (as a DG source) has been modelled in Matlab/Simulink / Sim Power System. A resistive type SFCL is also simulated in it. Simulink and SimPowerSystem has a number of advantages over other simulation software's like (EMTP, PSPICE) due to open architecture and versatile analysis. Control systems designed in Simulink can be directly integrated with the Sim Power System models [17].

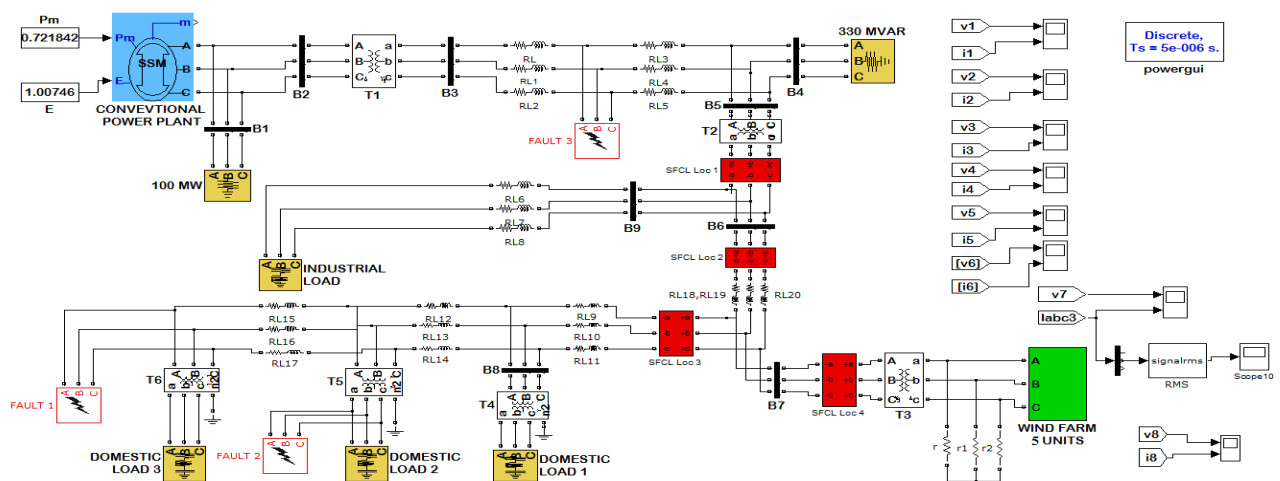


Fig.1. Simulation model of Micro grid

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2.1 Micro Grid Model

A 10 MVA wind farm has been taken as a distributed generating (DG) source with the conventional power plant in the newly developed micro grid.

The complete power system model is composed of a 100MVA, 20KV conventional power plant consisting of a three phase simplified synchronous machine, connected with a 200 km long transmission line through a step up transformer T1 (20KV/154KV). 100 MW load is connected before T1 through bus B1. Voltage is stepped down to 22.9 KV from 154 KV at the substation T2. 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. 14 MVA wind farm is composed of seven 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/415KV each.

2.2 Resistive SFCL Model

The four fundamental parameters which have been considered during the modelling 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.

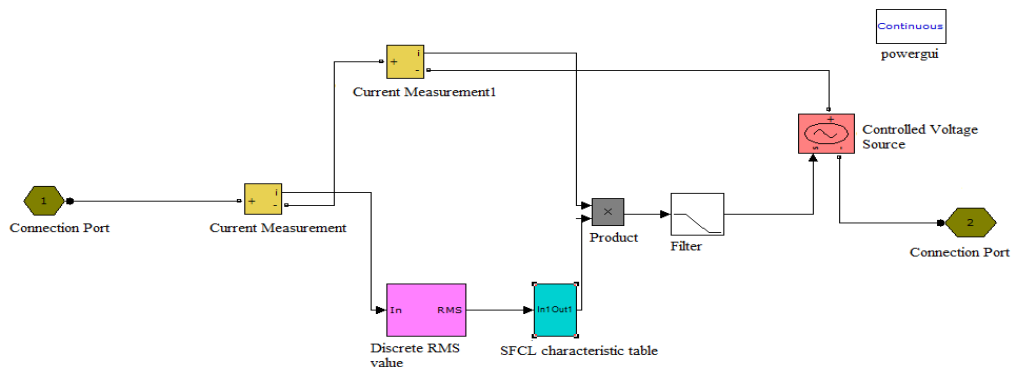


Fig. 2. SFCL Simulink model

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. For reducing the harmonics first order filter is used. As we know that the flow of current causes voltage sag, therefore controlled voltage source is connected in the circuit to compensate the induced voltage sag.

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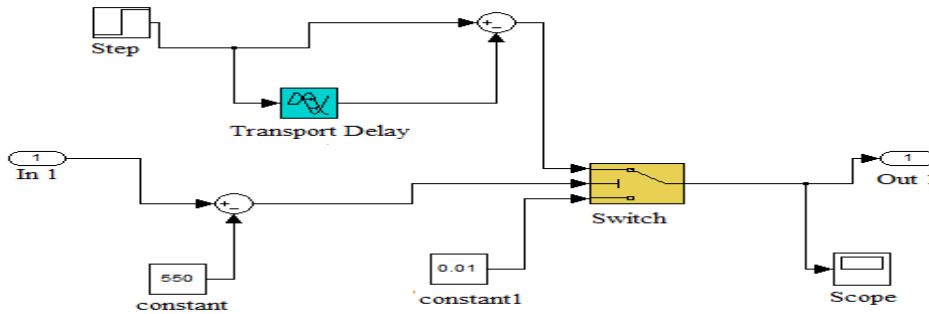


Fig.3. Subsystem of SFCL characteristic table

IV. RESULTS AND DISCUSSION

Four feasible locations of the SFCL in smart grid have been analysed for three different fault arising points in the grid as depicted in Fig.1. First, we consider that single SFCL located at Location 1(near Substation). Second, single SFCL located at Location 2(near Branch Network). Third, single SFCL located at Location 3(near Wind farm integration point with the grid). Fourth, double SFCLs located at Location 1(Substation) and Location 4(Wind Farm). Five different cases of SFCL locations

Case 1 without SFCL

Case 2 SFCL at location 1

Case 3 SFCL at location 2

Case 4 SFCL at location 3

Case 5 Dual SFCLs at location 1 and location 4.

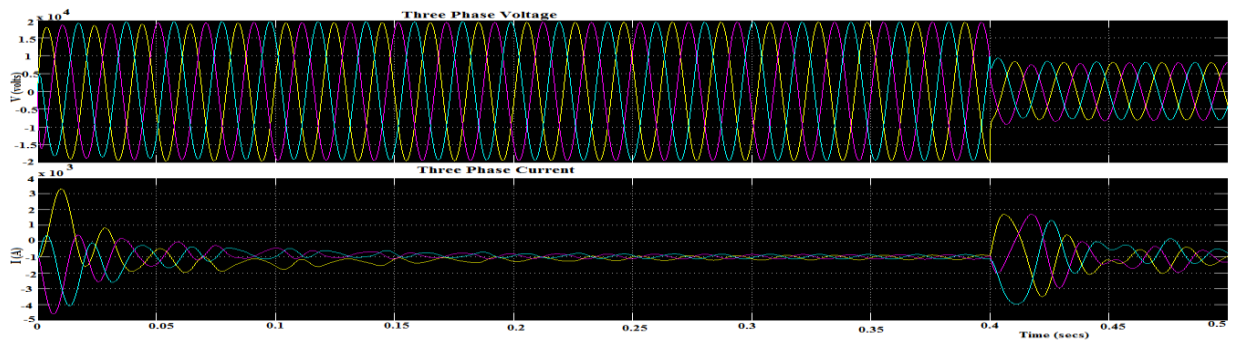


Fig. 4 without SFCL

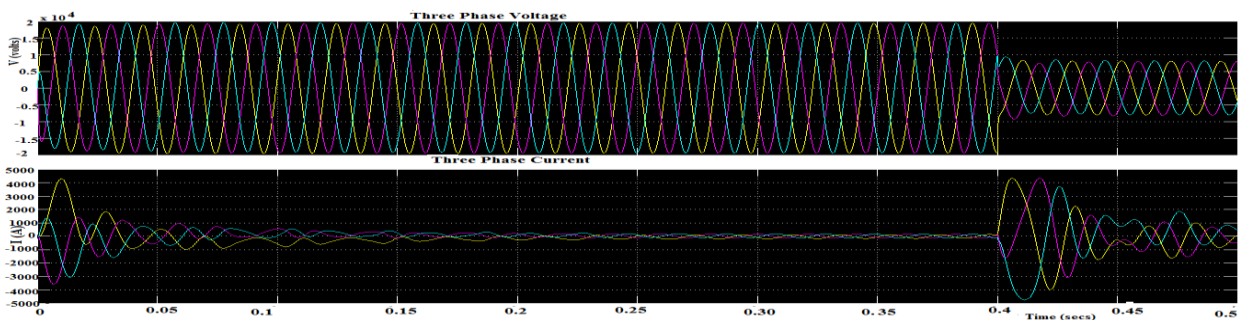


Fig.5. SFCL at location 1

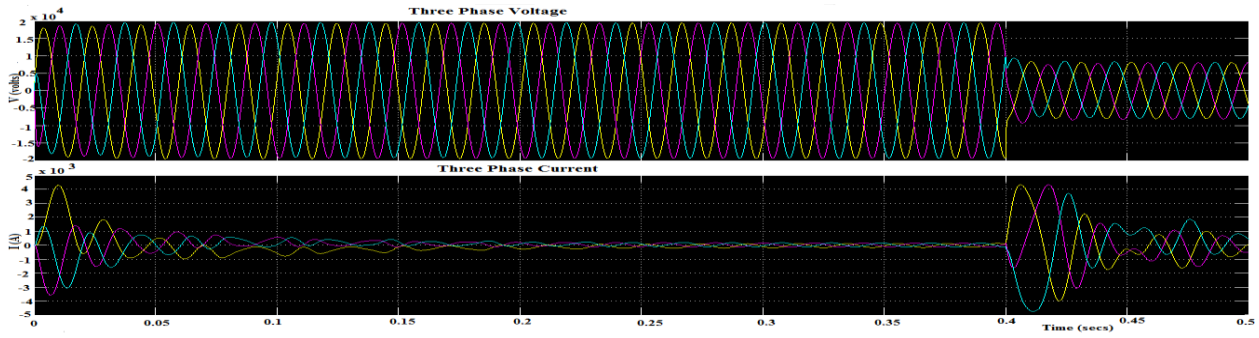


Fig. 6 SFCL at location 2

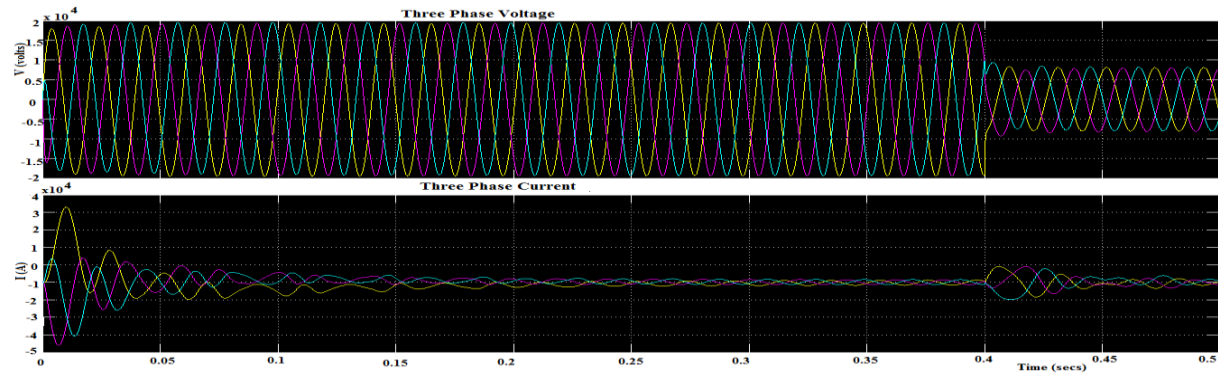


Fig.7 SFCL at location 3

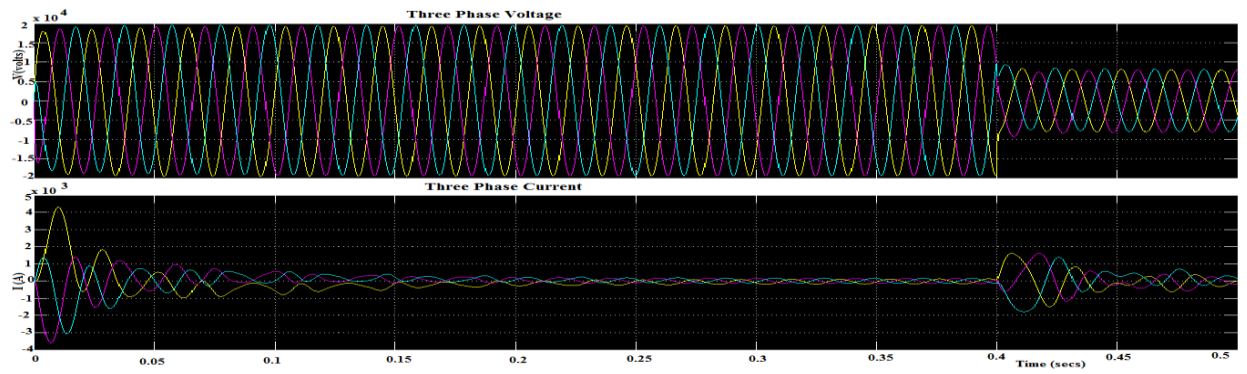


Fig. 8 dual SFCLs at location 1 and location 4

3.1 Fault at the Distribution Grid (Fault 1)

Fig.4, 5, 6, 7 and 8 shows the five different conditions of the wind farm voltages and currents for the different SFCL locations when fault has occurred in distribution grid (Fault 1). For the fault at distribution grid, when SFCL was located at Location 1 (Substation) or Location 2 (Branch network), fault current contribution to the wind farm was increased and the magnitude of fault current was more than 'No SFCL' case.

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.

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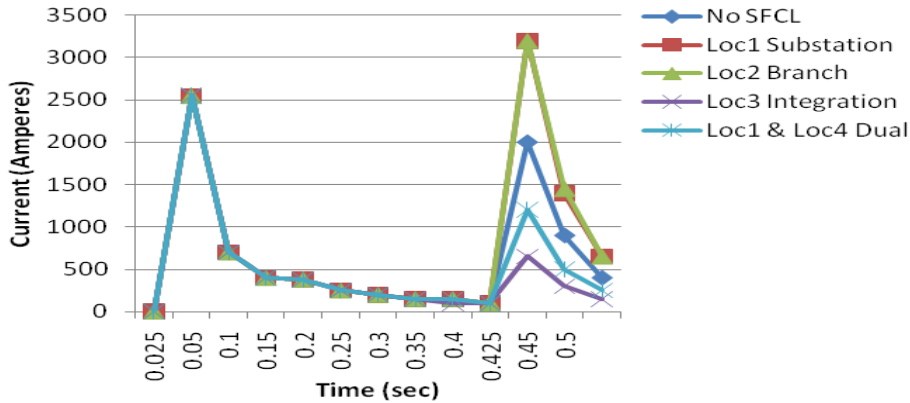


Fig.9: Comparison of wind farm fault currents for four SFCL locations in case of fault in distribution grid (Fault 1)

This sudden rise in the fault current value from the 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 is the other power source and also nearer to Fault1 is now forced to contribute larger fault current to the fault point.

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.

3.2 Fault at the Customer Grid (Fault 2)

Fig.10, 11, 12, 13 and 14 shows the five different conditions of the wind farm voltages and currents for the different SFCL locations when the fault has occurred at the customer grid (Fault 2). Fault 2 is comparatively small fault as it occurred in low voltage customer side distribution network. The results obtained for fault 2 are similar to those as we have seen for fault 1. Once again we can analyse from the outputs that the maximum reduction in the fault current is obtained for a single SFCL at location 3, which is the integration point of the wind farm and the distribution grid. Five different SFCL locations considered for Fault 2

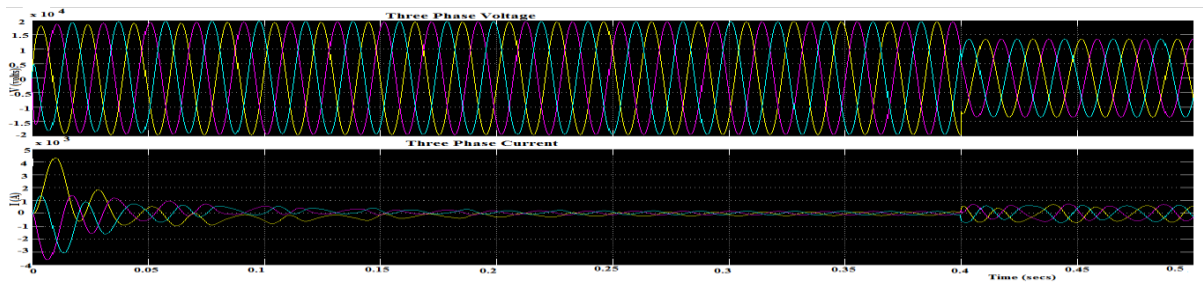


Fig. 10 without SFCL

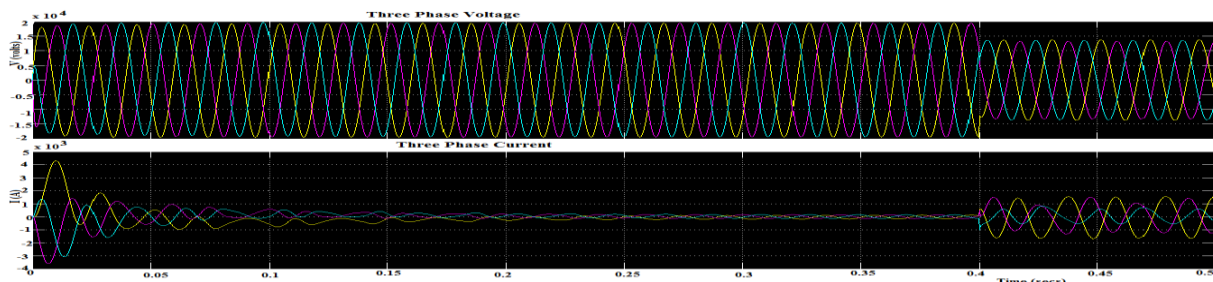


Fig.11 SFCL at location 1

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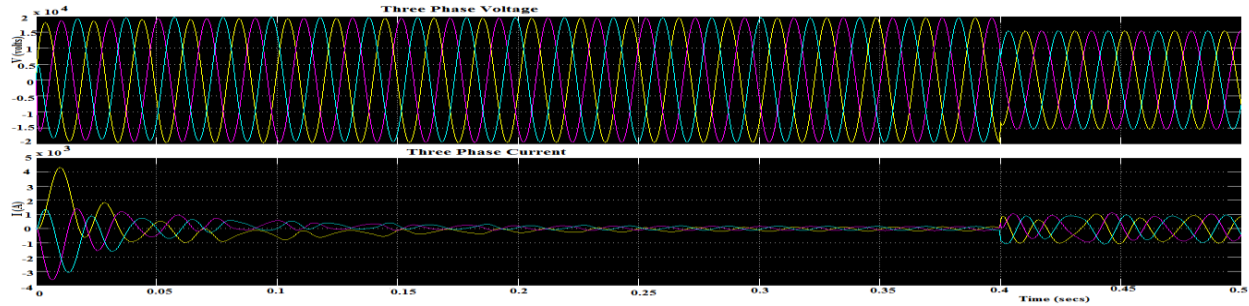


Fig.12 SFCL at location 2

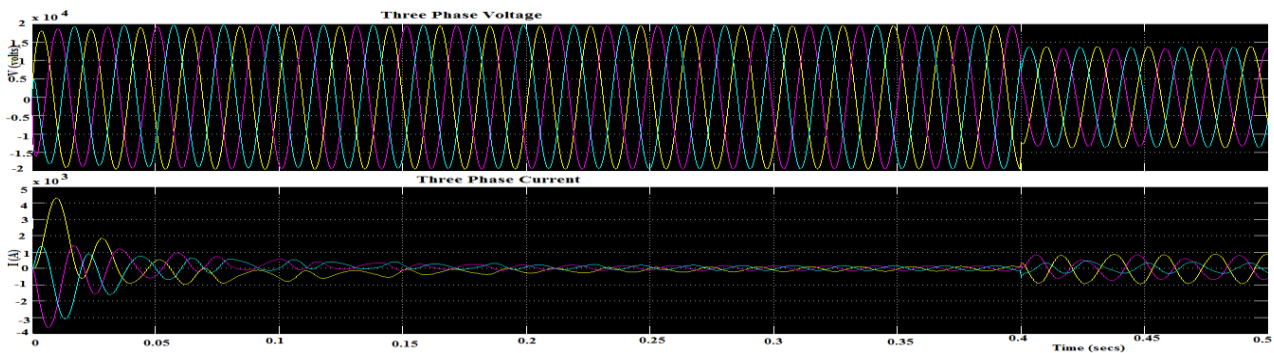


Fig.13 SFCL at location 3

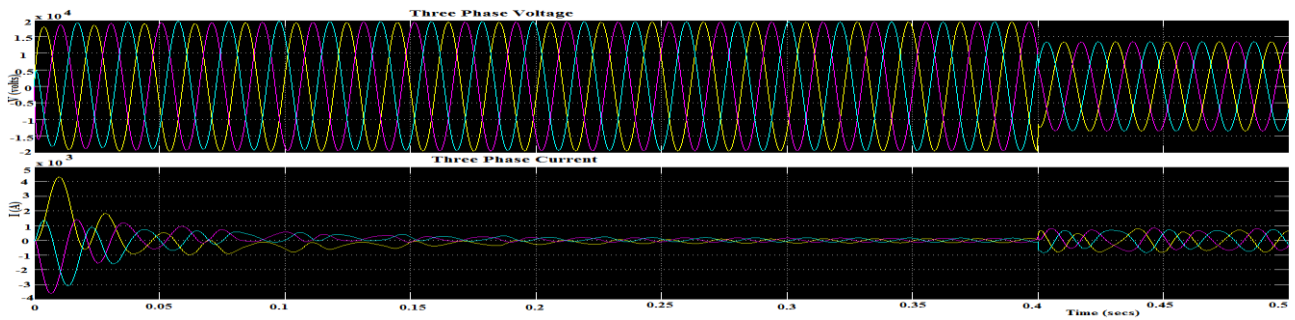


Fig.14 dual SFCL at location 1 and location 4

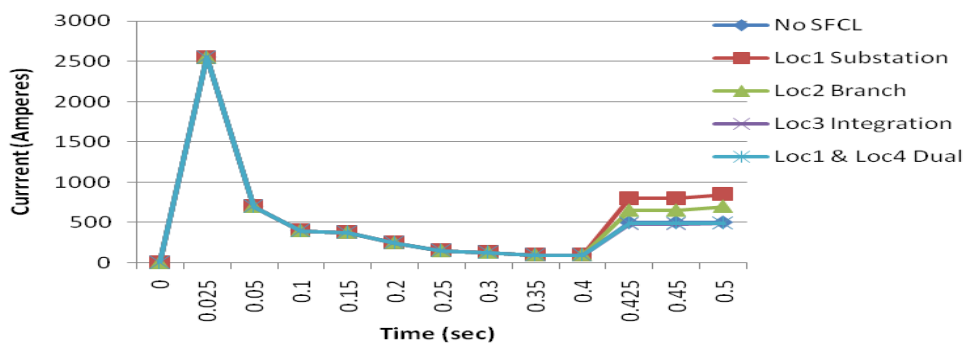


Fig.15 Comparison of wind farm fault currents for four SFCL locations in case of fault in customer grid (Fault 2)

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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.

3.3 Fault in the 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.

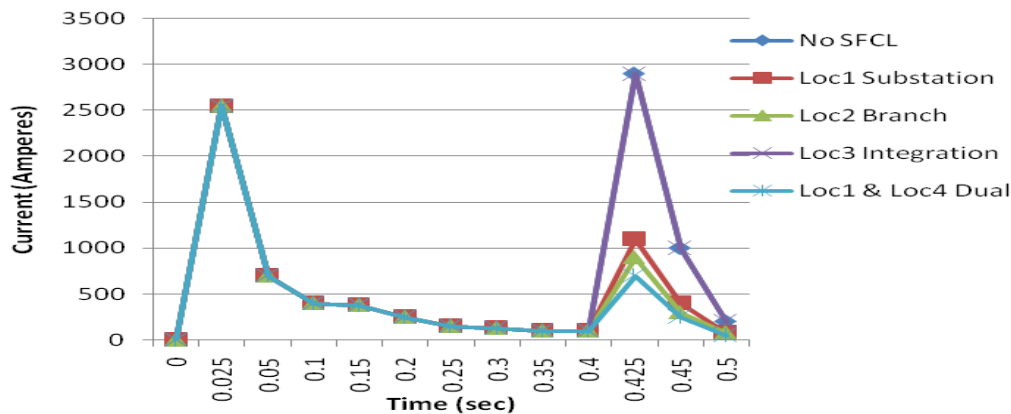


Fig.16: Comparison of wind farm fault currents for four SFCL locations in case of fault in transmission line (Fault 3)

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.

Table 1, 2, 3 and 4 shows the percentage change in wind farm fault current due to the SFCL locations for three phase, LG, LL and LLG faults respectively at different positions in the smart grid. On comparing the results obtained for the four different SFCL installations scenarios for all the four types of faults, we can observe that the maximum fault current reduction was achieved when the SFCL was located at the point of integration of the wind farm with the grid (Location3). Also, the performance of SFCL placed at Location 3 was even better than the dual SFCLs placed at Location1 and Location4 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.

TABLE 1: Percentage Change in Wind Farm Fault Current due to SFCL locations for **Three Phase Faults** at different positions

	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 4	45 % decreased	2% decreased	75 % decreased

TABLE 2: Percentage Change in Wind Farm Fault Current due to SFCL locations for **Single Line to Ground (LG) Fault** at different positions

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	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 and 4	40 % decreased	20 % increased	77 % decreased

TABLE 3: Percentage Change in Wind Farm Fault Current due to SFCL locations for **Line to Line (LL) fault** at different positions

	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	65 % increased	77 % increased	63 % decreased
Location 2	65 % increased	54 % increased	68 % decreased
Location 3	67 % decreased	8 % decreased	0 %
Location 1 and 4	42 % decreased	15 % increased	75 % decreased

TABLE 4: Percentage Change in Wind Farm Fault Current due to SFCL locations for **Double Line to Ground (LLG) fault** at different positions

	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	67% increased	77 % increased	63 % decreased
Location 2	67% increased	54 % increased	70 % decreased
Location 3	72 % decreased	8% decreased	0%
Location 1 and 4	39 % decreased	16% increased	77 Decreased

V. CONCLUSION

This paper presented a feasibility analysis of positioning of Superconducting Fault Current Limiter (SFCL) in the Smart grid and its effects on the wind farm connected as a distributed generating (DG) source. A complete micro grid model consisting of a wind farm has been designed in simulink. A resistive type SFCL (modelled in Matlab) has been installed at the key locations of the grid for all the four types of faults (3 phase, LG, LL and LLG). It has been observed that the SFCL should not be installed directly at the substation (Location1) and at the branch network (Location2) as

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this placement of SFCL results in the abnormal rise in fault current from the wind farm. Also, multiple SFCLs in the micro grid are not feasible, both in performance and economic aspects. The optimal location of the SFCL in a smart grid which reduces the fault current from the wind farm as well as from the conventional power plant and has no negative effect on the distributed generation (DG) source is the point of integration of the wind farm with the main power grid.

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REFERENCES

- [1] Jae-Sang Hwang, Umer .A. Khan, Woo-Ju Shin, Jae-Kyu Seong, Jong-Geon Lee, Yong-Han Kim, and Bang-Wook Lee, "Validity analysis on the positioning of Superconducting Fault Current Limiter in neighboring AC and DC micro grid," IEEE Trans. on Applied Superconductivity, vol.23,NP.3,June 2013.
- [2] Jinsung Byun, Insung Hong, Byeongkwan Kang, and Sehyun Park, Member, IEEE, "A Smart Energy Distribution and Management System for Renewable Energy Distribution and Context-aware Services based on User Patterns and Load Forecasting," IEEE Transactions on Consumer Electronics, Vol. 57, No. 2, May 2011.
- [3] Xi Fang, Student Member, IEEE, Satyajayant Misra, Member, IEEE, Guoliang Xue, Fellow, IEEE, and Dejun Yang, Student Member, IEEE, "Smart Grid- The New and Improved Power Grid: A Survey," IEEE Communications Surveys & Tutorials, Vol. 14, No.4, Fourth Quarter 2012.
- [4] Meysam Shamshiri, Chin Kim Gan, Chee Wei Tan, "A Review of Recent Development in Smart Grid and Micro-Grid Laboratories," IEEE International Power Engineering and Optimization Conference (PEOCO2012), Melaka, Malaysia: 6-7 June 2012.
- [5] F. Salvadori, Member, IEEE, C. S. Gehrke, A. C. de Oliveira, M. de Campos, and P. S. Sausen, "Smart Grid Infrastructure using a Hybrid Network Architecture," IEEE Trans .On Smart Grid, vol.4, No.3, September 2013.
- [6] Umer A. Khan, J. K. Seong, S. H. Lee, S. H.Lim, and B. W. Lee, Member, IEEE, "Feasibility Analysis of the Positioning of Superconducting Fault Current Limiters for the Smart Grid Application Using Simulink and Sim Power System," IEEE Trans. Applied Superconductivity, vol. 21, no. 3, june 2011.
- [7] Jae-Chul Kim, Member, IEEE, Sung-Min Cho, Member, IEEE, and Hee-Sang Shin, "Advanced Power Distribution System Configuration for Smart Grid," IEEE Trans. On Smart Grid, vol. 4, No. 1, March 2013.
- [8] S. Sugimoto, J. Kida, H. Arita, C. Faku, and T. Yamagiwa, "Principle and characteristics of a fault current limiter with series compensation," IEEE Trans. Power Delivery, vol. 11, no. 2, pp. 842–847, Apr. 1996.
- [9] Lin Ye and Klaus- Peter Juengst, "Modeling and Simulation of High Temperature Resistive Superconducting Fault Current Limiters," IEEE Trans. On Applied Superconductivity, vol.14, No.2, June 2004.
- [10] B. C. Sung, D. K. Park, J. W. Park, and T. K. Ko, "Study on a series resistive SFCL to improve power system transient stability: Modeling, simulation and experimental verification," IEEE Trans. Industrial Electron., vol. 56, no. 7, pp. 2412–2419, Jul. 2009.
- [11] Leonard Kovalsky, Xing Yaun, Kasegn Tekletsadik, Albert Keri, Joachim Bock, and Frank Breuer, "Application of Superconducting Fault Current Limiters in Electric Power Transmission Systems," IEEE Trans. On Applied Superconductivity. vol. 15, No. 2, June 2005.
- [12] A. Girgis, and S. Brahma "Effect of Distributed Generation on Protective Device Coordination in Distribution System". Large Engineering Systems Conference on Power Engineering 115-119, 2001.
- [13] Steven M. Blair, Student Member, IEEE, Campbell D. Booth, Nand K. Singh, Member, IEEE, Graeme M. Burt, Member, IEEE, and Chris G. Bright, "Analysis of Energy Dissipation in Resistive Superconducting Fault- Current Limiters for optimal Power System Performance," IEEE Trans. On Applied Superconductivity. vol. 21, No. 4, August 2011.
- [14] Steven M. Blair, Student Member, IEEE, Campbell D. Booth, Graeme M. Burt, Member, IEEE, and Chris G. Bright, "Application of Multiple Resistive Superconducting Fault Current Limiters for Fast Fault Detection in Highly –Interconnected Distribution Systems," IEEE Trans. On Power Delivery.
- [15] Won- Sik Moon, Jong-Nam Won, and Jae-Chul Kim, "A Study on the Application of a Superconducting Fault Current Limiter for Energy Storage Protection in a Power Distribution System," IEEE Trans. On applied superconductivity 23, 5603404(June 2013).
- [16] B. W. Lee, J. Sim, K. B. Park, and I. S. Oh "Practical Application Issues of Superconducting Fault Current Limiters for Electric Power Systems" IEEE Trans. On applied superconductivity, vol. 18, no. 2, June 2008.
- [17] L. Dessaint, K. Al-Haddad, H. Le-Huy, G. Sybille, and P. Brunelle, "A power system tool based on simulink," IEEE Trans. Industrial Electron., vol. 46, no. 6, pp. 1252–1254, Dec. 1999.