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Realization of Feasible Analysis for Optimal Position of SFCL Integrate to Smart Grid Application

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Abstract: Short circuit current limitation in distribution utilities can be an effective way to improve power quality, since the expected voltage sag amplitude during faults can be dramatically reduced. The proposed structure prevents voltage sag and phase-angle jump of the substation PCC after fault occurrence. This structure has a simple control method. The introduction of new generating facilities by independent power producers and increasing load demand can result in fault current over duty on existing transmission system protective equipment. Due to the difficulty in power network reinforcement and the interconnection of more distributed generations, fault current level has become a serious problem in transmission and distribution system operations. The utilization of fault current limiters (FCLs) in power system provides an effective way to suppress fault currents and result in considerable saving in the investment of high capacity circuit breakers is felt. In this work, a resistive type SFCL model was implemented by integrating Simulink and SimPowerSystem blocks in Matlab. The designed SFCL model could be easily utilized for determining an impedance level of SFCL 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. A Simulink based model is developed and the simulation results for the proposed model are obtained by using MAT LAB.

Keywords: Fault Current, Micro Grid, Smart Grid, Superconducting Fault Current Limiter, Wind Farm.

I. INTRODUCTION

Power quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power. The term power quality has become one of the most prolific buzzwords in the power industry since the late 1980s. Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive power electronic equipment and non-linear loads are widely used in industrial, commercial and domestic applications leading to distortion in voltage and current waveforms. Both electric utilities and end users of electric power are becoming increasingly concerned about the quality of electric power.

The modern lifestyle depends tremendously on the use and existence of fossil fuels. With levels of these fuels constantly decreasing, we should act now to become less dependent on fossil fuels and more dependent on renewable energy sources. The decreasing level of fossil fuels isn’t the only reason why we should begin to use renewable energy. Pollution is becoming a huge problem in many countries around the world, especially the developing world. With carbon emissions at an all time high, air quality can be very low in some areas, this can lead to respiratory diseases and cancer. The main reason to switch to cleaner energy production methods is the global warming aspect. The more carbon dioxide we pump into the atmosphere, the greater the effect becomes. We can't just stop using fossil fuels thinking that global warming will go away, but we can slow down and dilute the effects of global warming through the wide spread use of renewable energy resources. Renewable energy flows involve natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat, as the Agency explains, Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth.

Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio fuels and hydrogen derived from renewable resources. Smart grid is a 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, effervescent and responsive than conventional power systems. Smart grid is based on the principle of decentrali-zation of the power grid network into smaller grids (Microgrids) having distributed generation sources(DG) connected with them, One critical problem due to these integrations is excessive increase in fault current due to the presence of DG within a micro grid [1],Conventional protection devices installed for protection of excessive fault current in power systems, mostly at the high voltage substation level circuit breakers tripped by over-current protection relay which has a response-time delay resulting in power system to pass initial peaks of fault current [2].But, SFCL is a novel technology which has the capability to quench fault currents instantly as soon as fault current exceeds SFCL's current limiting threshold level [3]. SFCL achieves this function by losing its superconductivity and generating impedance in the circuit. SFCL does not only suppress the amplitudes of fault currents but also enhance the transient stability of power system [4].Up to now, there were some research activities discussing the fault current issues of smart grid [4], [5].But the applicability of SFCLs into micro grids was not found yet. Hence, in order to solve the problem of increasing fault current in power systems having multiple micro grids by using SFCL technology is the main concern of this work.

The utilization of SFCL in power system provide them most effective way to limit the fault current and results inconsiderable saving from not having to utilize high capacity circuit breakers. With Superconducting fault current limiters (SFCLs) utilize superconducting materials to limit the current directly or to supply a DC bias current that affects the level of magnetization of a saturable iron core. Being many SFCL design concepts are being evaluated for commercial expectations, improvements in superconducting materials over the last 20 years have driven the technology [4]. Case in point, the discovery of high-temperature superconductivity (HTS) in 1986drastically improved the potential for economic operation of many superconducting devices. This growth is due to the capability of High temperate Sensitive materials to operate at temperatures around 70Kinstead of near 4K, which is required by conventional superconductors. The advantage is that refrigeration overhead associated with operating at the higher temperature is about 20 times less costly in terms of initial capital cost, operational cost and maintenance cost. In this paper, the effect of SFCL and its position was investigated considering a wind farm integrated with a distribution grid model as one of typical configurations of the smart grid. The impacts of SFCL on the wind farm and the strategic location of SFCL in a micro grid which limits fault current from all power sources and has no negative effect on the integrated wind farm was suggested.

II. SELECTION OF OPTIMAL SFCL RESISTANCE BY SIMULATION

A. Resistive SFCL Model

To simplify the analysis, a binary SFCL model is used. The SFCL has zero impedance before fault inception but is assumed to reach its full resistance immediately when a fault occurs. This will yield a reasonably accurate estimation of the reduction of a steady-state root-mean-square (RMS) fault current (as defined in [7]) but will overestimate the reduction of the peak fault current; hence, the following sections only comment on the effect that the SFCL has on reducing the steady-state fault current. Although this model does not account for the development of SFCL resistance during a quench, tests with a more realistic SFCL model have shown that the results in this paper only differ by approximately 6%, for a relatively long quench time.

B. Comparison of System Voltage Levels on the Energy Dissipation

The SFCL may be effective at several locations in the power system [1], [2], but this paper concentrates on a DG application in which DG is the source of a fault-level increase. Therefore, only one modification to an electrical network is required, i.e., the installation of the SFCL in series with DG, rather than the installation of a number of SFCLs at different locations. Nevertheless, the analysis is relevant to SFCLs at any location. A three-phase to-ground fault with negligible resistance is applied at the point where the DG is connected to the existing network. The power system has been simulated in PSCAD/EMTDC software tool using the impedance data in, such that the X/R ratios, which are important for a fault study, are indicative of a typical system. The unrestricted steady-state fault current, i.e., without an SFCL, is approximately 1-kA RMS per phase. Initially, the shunt impedance R shunt is ignored; this is explored in Section III-C. The total energy Q dissipated in each phase of the SFCL during the fault is calculated in the simulation using (1), where t 0 is the time of fault occurrence (0 s), and t f is the time that the fault is cleared (tf≈ 0.1 s, depending on the current zero crossing required for a circuit breaker to interrupt the fault current). This is given as follows:

$$Q = \int_{t_0}^{t_f} i_{\mathrm{SFCL}}(t)^2 R_{\mathrm{SFCL}} dt \qquad (1)$$

Resistance values (on the 33-kV side of the DG transformer). Fig.1 illustrates the level of fault-current reduction and the corresponding total energy dissipation in one phase of the SFCL for faults on the system. For the parameters used in the simulation, the following regions have been identified.

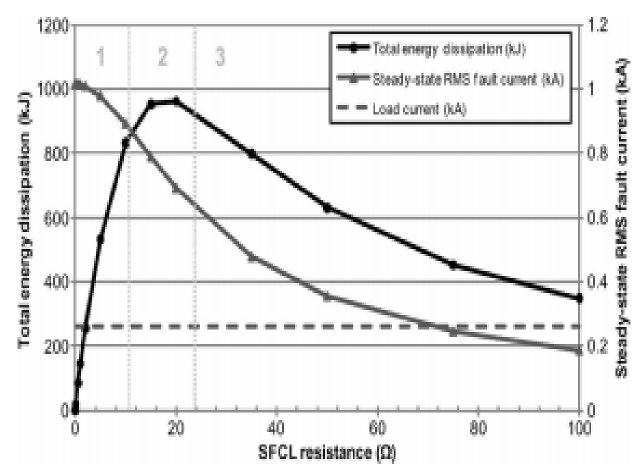

Fig.1. Energy dissipation and fault-current limitation for various SFCL.

1. When RSFCL < 12 Ω, the steady-state fault current is slightly reduced, reaching the magnitude of

approximately 2.6 times of the load current, but the corresponding energy dissipation steeply rises, as shown in Fig. 1.

2. When 12 Ω < RSFCL < 24 Ω, the fault current reduces with increasing SFCL resistance, but the increasing resistance causes the energy dissipation to reach its maximum in this region. This large energy dissipation would lengthen the recovery time; therefore, this range of SFCL resistance values should be avoided. This result is in accordance with the maximum power transfer theorem [10]. The equivalent 33-kV. The venin source has an impedance of 18.7 Ω therefore, the maximum energy dissipation in the SFCL occurs when its resistance is equal to the source impedance value.

3. When RSFCL > 24 Ω, the fault current continues to decrease with increasing SFCL resistance (almost linearly with resistance, as shown in Fig. 1), but the energy dissipation reduces. This is the most desirable region, i.e., a relatively low fault current combined with low energy dissipation. It can be observed in Fig. 1 that an SFCL value of approximately 70Ωreduces the steady-state fault current to the same value as the maximum load current. If the SFCL had been located at the 690-V side of the DG transformer instead of at 33 kV, then, for a given energy dissipation value, resistance values obey the law RSFCL33 kV ≈ RSFCL0.69 kV(33 kV/0.69 kV).

Therefore, far smaller resistance values are required for equivalent levels of fault-current limitation; however, the current-carrying capability of the SFCL is increased by a factor of 33 kV/0.69 kV. At either voltage level, the energy dissipation is approximately the same for a given level of fault-current reduction relative to the load current. Assuming that the SFCL device is available at both voltage levels, there is a tradeoff between the Quenched-state resistance of the superconductor and the current it must be rated to carry. This is explored further in Section IV. Although either SFCL would limit the fault current, an SFCL at 690 V with a load rating of 15 MVA would be required to have a full load-current rating of over 12 kA per phase, which would present serious difficulties in design. By contrast, a 33-Kv SFCL would have a full load current of 250 A and would be easier to design, despite the higher voltage rating. However, operation at lower voltages leads to higher a.c. losses in the superconductor when in the superconducting state.

III.PROBLEM DESCRIPTION

A. SFCL Application in Power System

In recent years, the SFCL has been considered one of the most attractive protection devices for limiting the fault current levels in power systems. Various types of SFCLs [11] based on different circuit structures and superconducting materials have been developed. In this paper, a resistive SFCL is adopted to investigate the power system planning problem. Fig. 2 illustrates. The equivalent circuit of the SFCL. The SFCL includes a conventional current limiting resistor(CLR) to decrease the voltage stress on the super-conducting device. The operational scheme for employing the SFCL device in an electric power system needs to be determined. In this study, a bus-tie SFCL scheme [7]–[9] has been employed for power system application. In this bus-tie scheme, the SFCL is located at a splitting bus. The splitting bus can be separated in the event Of a fault. The bus-tie scheme requires fewer SFCL devices than do other application schemes to decrease the fault current levels. The fault current levels limited by the SFCL should be less than the critical currents in the power system. 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. The diagram of a bus-tie SFCL scheme in the power system is illustrated in Fig. 3.

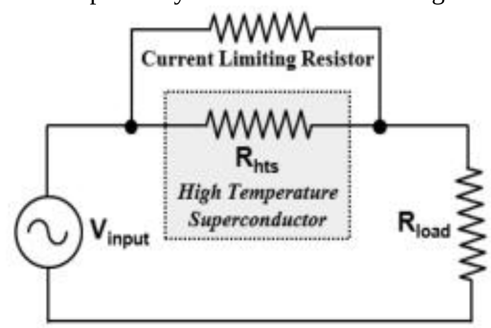

Fig.2. Simple equivalent circuit of SFCL.

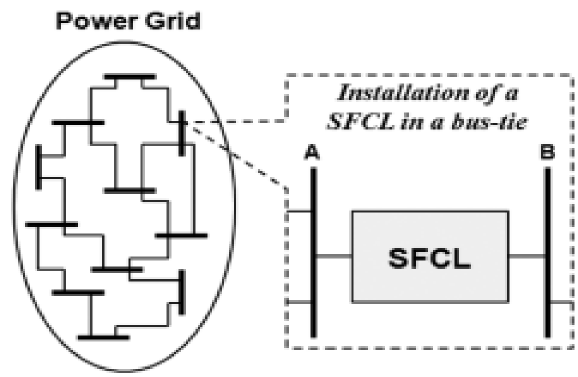

Fig.3. Application of SFCL to power systems in event of a fault.

IV.PROPOSED CONCEPT

Matlab/Simulink/SimPowerSystem was selected to design and implement the SFCL model. A complete smart grid power network including generation, transmission, and distribution with an integrated wind farm model was also 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 [7].

A. Power System Model

Newly developed micro grid model was designed by integrating a 10MVA wind farm with the distribution network. Fig. 4 shows the power system model designed in Simulink/SimPowerSystem. The power system is composed of a 100 MVA conventional Power plant, composed of 3-phase synchronous machine, connected with 200 km long 154 kV distributed-parameters transmission line through a step-up transformer TR1. At the substation (TR2), voltage is stepped down to 22.9 kV from 154 kV. High power industrial load (6 MW) and low power domestic loads (1 MW each) are being supplied by separate distribution branch networks. The wind farm is directly connected with the branch network (B1) through transformer TR3 and is providing power to the domestic loads. The 10 MVA wind farm is composed of five fixed-speed induction-type wind turbines each having a rating of 2MVA. At the time of fault, the domestic load is being provided with 3 MVA out of which 2.7 MVA is being provided by the wind farm.

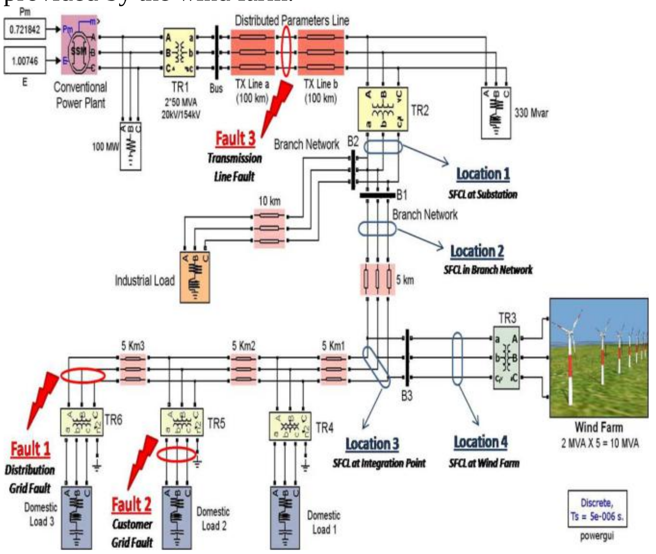

Fig.4. Power system model designed in Simulink/Sim PowerSystem. Fault and SFCL locations are indicated in the diagram.

In Fig. 4 artificial fault and locations of SFCL are indicated in the diagram. Three kinds of fault points are marked as Fault 1, Fault 2 and Fault 3, which represent three-phase-to-ground faults in distribution grid, customer grid and transmission line respectively. Four prospective locations for SFCL installation are marked as Location 1 (Substation), Location 2 (Branch Network), Locations 3 (Wind farm integration point with the grid) and Location 4 (Wind Farm). Generally, conventional fault current protection devices are located in Location 1 and Location 2.The output current of wind farm (the output of TR3 in Fig. 4) for various SFCL locations have been measured and analysed in Section III for determining the optimum location of SFCL in a micro grid.

B. Resistive SFCL Model

The three phase resistive type SFCL was modeled considering four fundamental parameters of a resistive type SFCL [9]. These parameters and their selected values are: 1) transition or response time=2msec, 2) minimum impedance =0.01ohms and maximum impedance=20ohms, 3) triggering current=550A and 4) recovery time=10msec. Its working voltage is 22.9 kV. Fig. 5 shows the SFCL model developed in Simulink/Sim-PowerSystem. 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 into normal state.

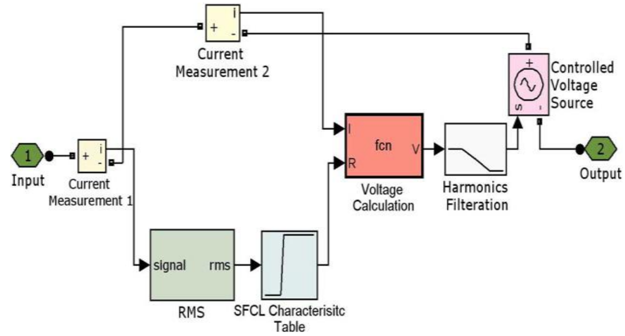

Fig.5. Single phase SFCL model developed in Simulink/ Simpowersystem

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Fig. 6 shows the result of verification test of SFCL model conducted on power network model depicted in Fig. 4. SFCL has been located at substation (Location 1) and for a distribution grid fault (Fault 1), various SFCL impedance values versus its fault current reduction operation has been plotted. Maximum fault current (No SFCL case) is 7500 A at 22.9 kV for this arrangement.

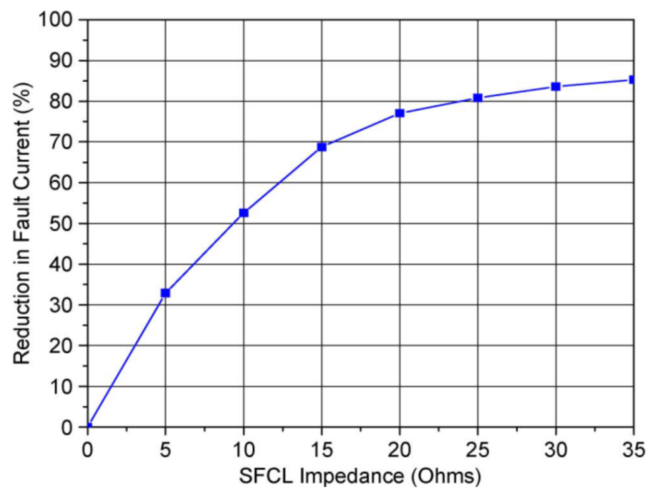


Fig.6. SFCL performance evaluation graph indicating the relationship between SFCL impedance and reduction in fault current.

VI. MATLAB MODELING AND SIMULATION RESULTS

Three scenarios of SFCL's possible locations were analyzed for four different fault occurring points and no fault in the power system depicted in Fig. 1. As per the first assumption the 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.

A. Fault in the Distribution Grid (Fault 1)

In the case of SFCL located at Location 1 Substation or Location 2 Branch Network. Fault current contribution from the wind farm was increased and the magnitude of fault current is higher than No SFCL situation. These critical observations imply that the installation of SFCL in Location 1 and Location 2, instead of reducing it increased the DG fault current. This sudden rise of fault current from the wind farm is caused by the abrupt change of power system's impedance. The SFCL at these locations (Location 1 or

Location 2) entered into current limiting mode and reduced fault current coming from the conventional power plant due to rapid increase in its resistance. Therefore the wind farm which is other power source and also closer to the Fault 1 is now forced to supply larger fault current to fault point (Fault 1). In the case when SFCL is installed at the integration point of wind farm with the distribution grid, marked as Location 3 in Fig. 1, fault current in the wind farm has been successfully reduced. SFCL gives 68% reduction of fault current from wind farm and also reduce the fault current coming from conventional power plant because SFCL is located in the direct path of any fault current flowing towards Fault 1.

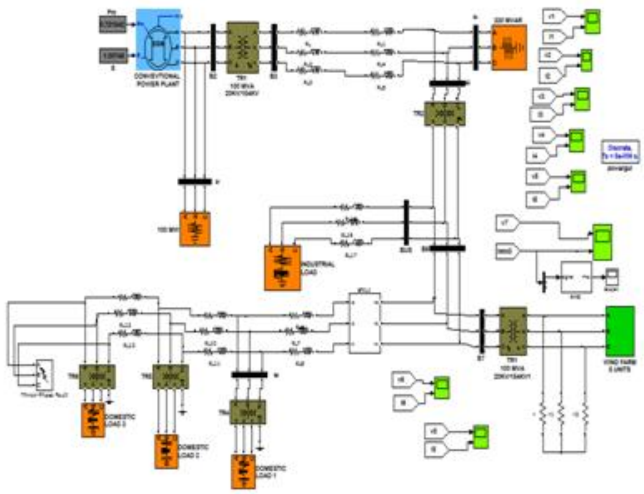
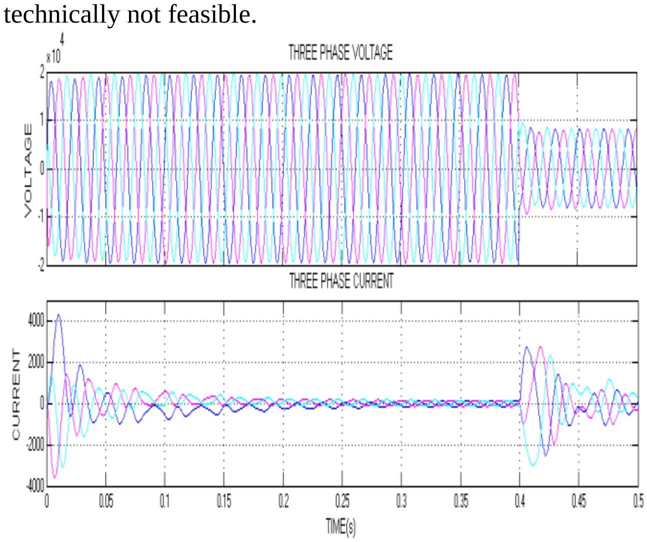


Fig.7 Matlab/Simulink Model of proposed Positioning of Superconducting Fault Current Limiters for the Smart/ micro Grid Application.

Fig.7 shows the Matlab/Simulink Model of proposed Positioning of Superconducting Fault Current Limiters for the Smart/micro Grid Application using Matlab/Simulink Platform. With dual SFCL installed at Location 1 and Location 4, 45% reduction in fault current is observed. Even though two SFCLs were installed, fault current reduction of wind farm is lower than what was achieved by the single SFCL installed at Location 3. By observing the simulation results it was known that the installation of two SFCLs at both Location 1 and Location 4 is economically and technically not feasible.



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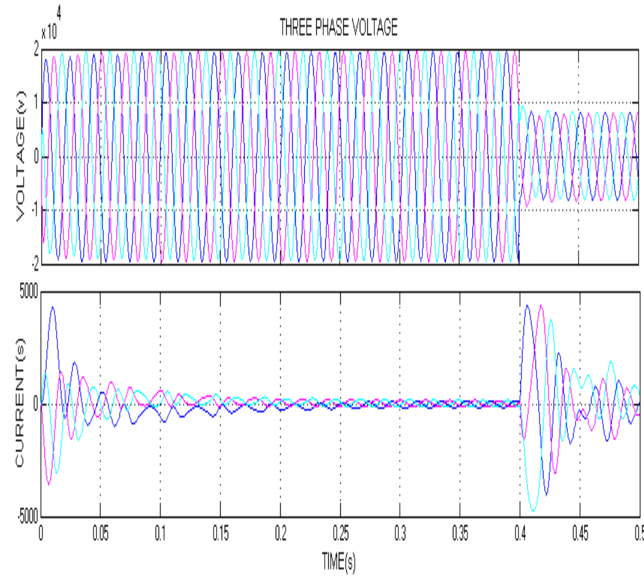

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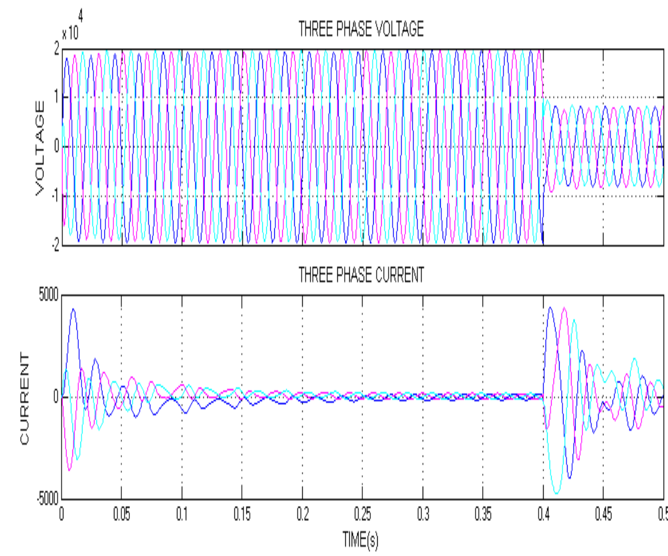

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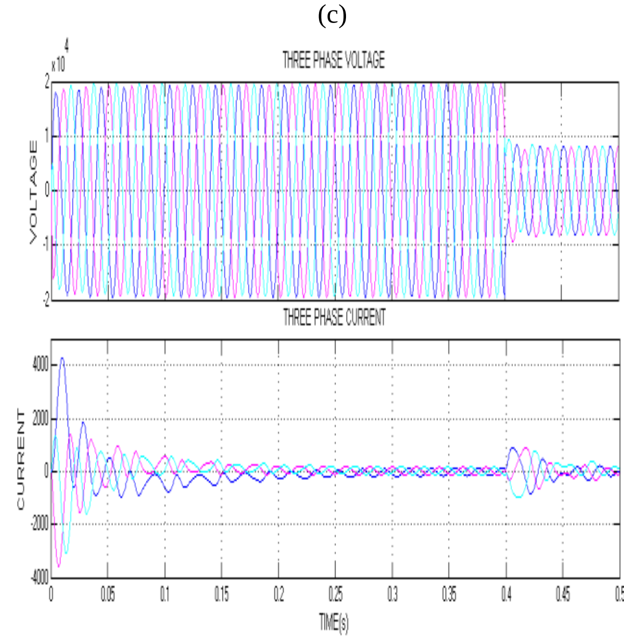

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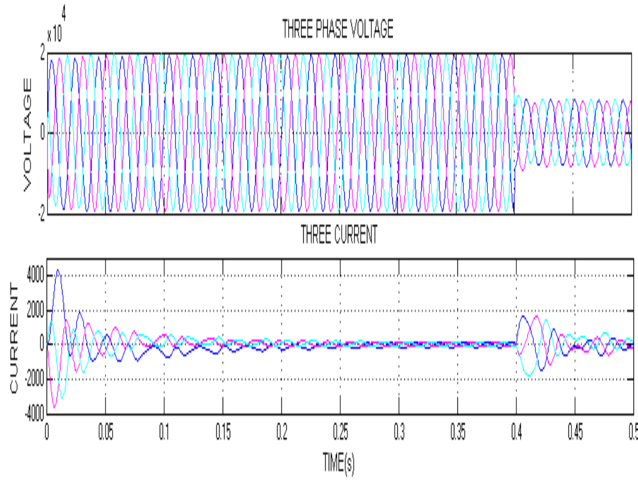
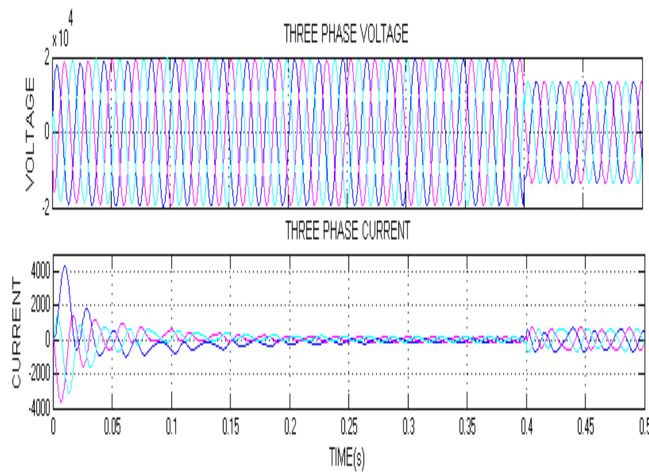


(e)

Fig.8. Five different fault conditions considered at location 1 (a) without any sfcl, (b) sfcl at location 1, (c) sfcl at location 2, (d) sfcl at location 3, (e) sfcl at location 4.

B. Fault in Customer Grid (Fault 2)

Fig. 9 shows a comparison between fault current from the wind farm (measured at output of TR3) for different SFCL locations in the case when a three-phase-to-ground fault was initiated in the customer grid Fault 2 in Fig. 1. Fault 2 is comparatively a small fault as it occurred in low voltage customer side distribution network.



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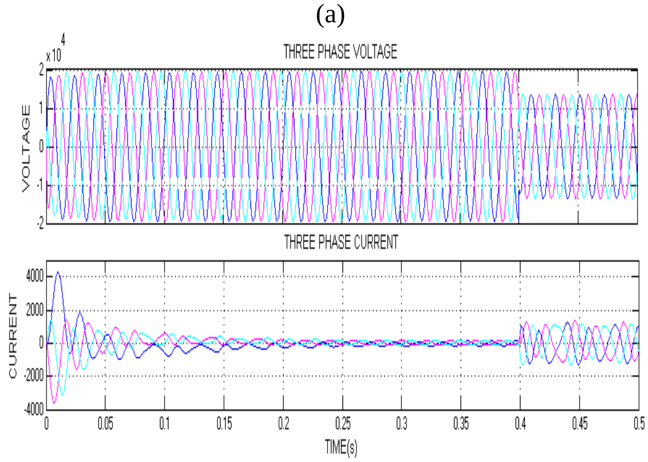

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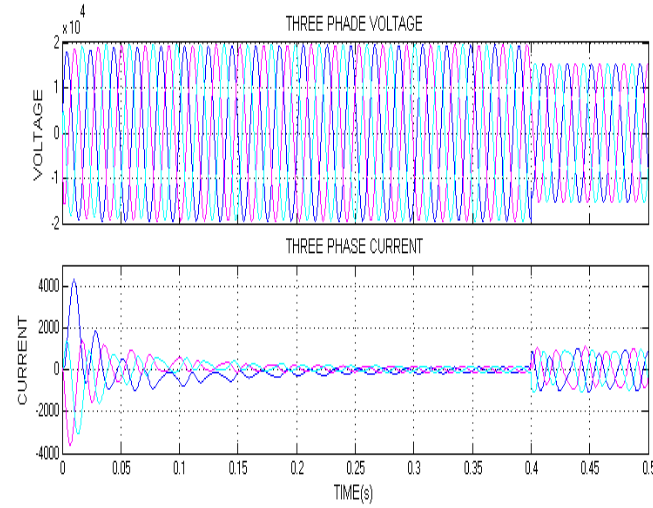

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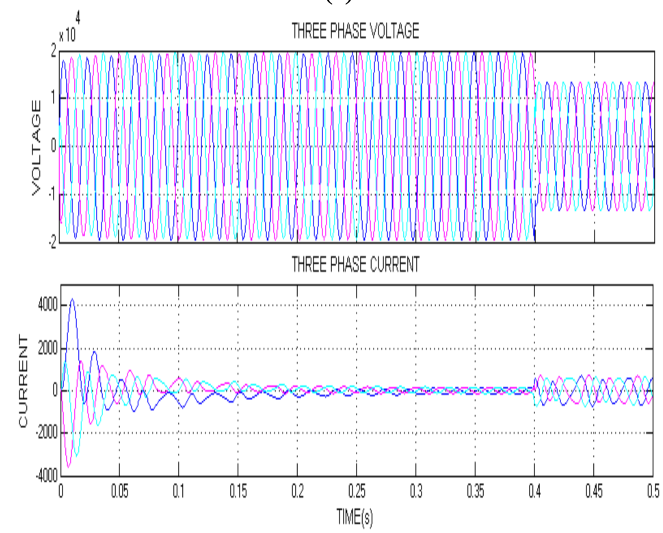

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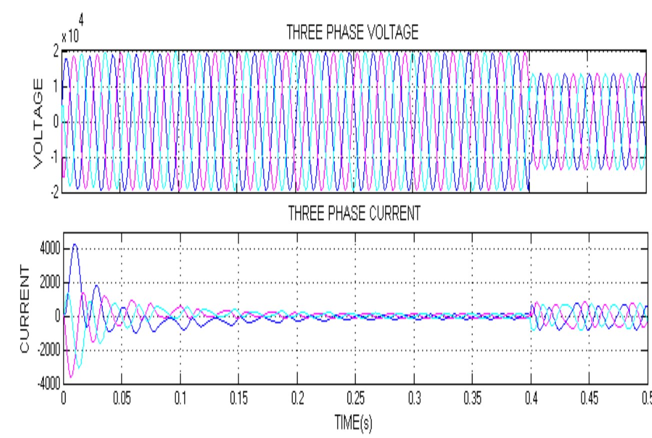


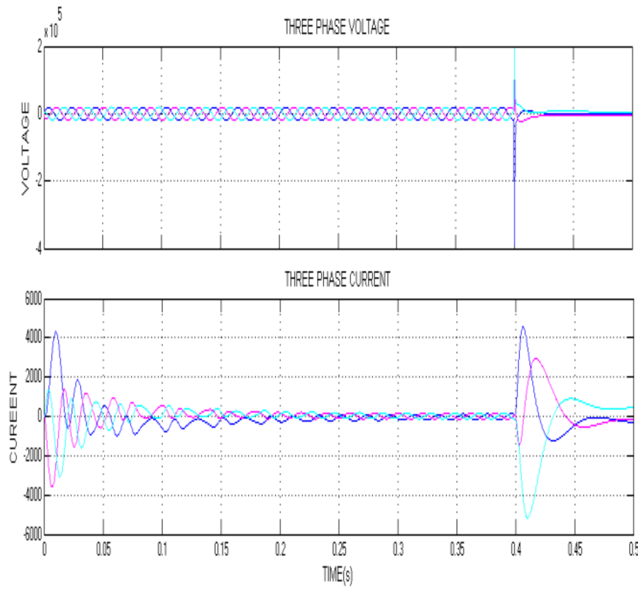
(e)

Fig.9. five different fault conditions considered at location 1 (a) without sfcl, (b) sfcl at loc 1, (c) sfcl at loc 2, (d) sfcl at loc 3, (e) sfcl at loc 4.

The results observed are similar to what were observed in the case of distribution grid (Fault 1) as explained in Section III-A. Once again the best results are obtained when a single SFCL is located at Loc 3 which is the integration point of the wind farm with the distribution grid.

C. Fault in Transmission Line (F3)

The Fault 3 in Fig. 10 indicates the rarely occurring transmission line fault which results in very large fault currents. Fig. 6 shows a comparison between fault current from the wind farm (measured at output of TR3 in Fig. 10) for different Super conducting fault current limiter (SFCL) locations in the case when a three-phase-to-ground fault was initiated in the transmission line (Fault 3 in Fig. 10). When a fault occurs in transmission line, fault current from the conventional 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. Thus, on the contrary to the previous results obtained in Sections IIIA and IIIB, SFCL positioned at Location 1(Substation) or Location 2 (Branch Network) reduces the fault current in wind farm. This result comes from the fact that SFCL is installed directly in the path of reverse current being generated by the wind farm towards fault point.



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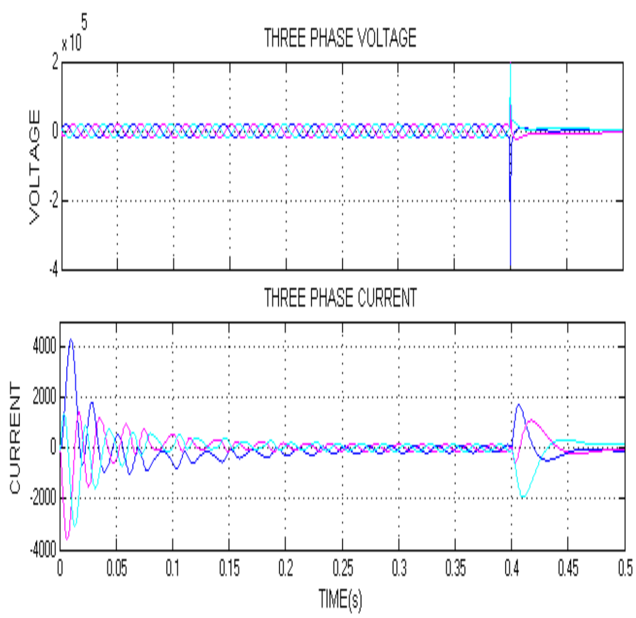

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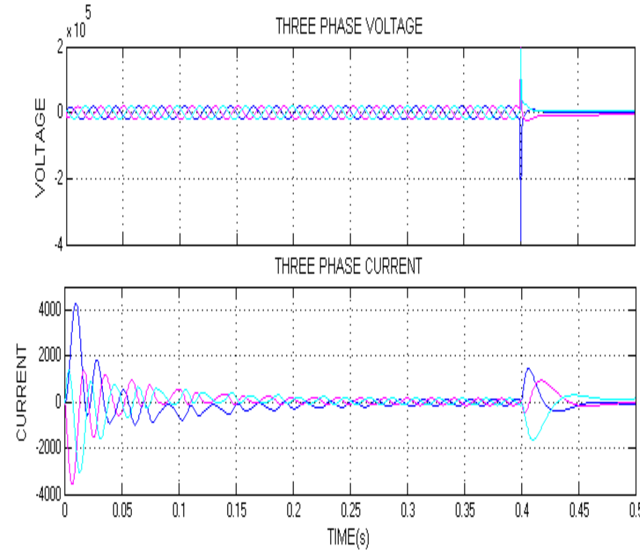

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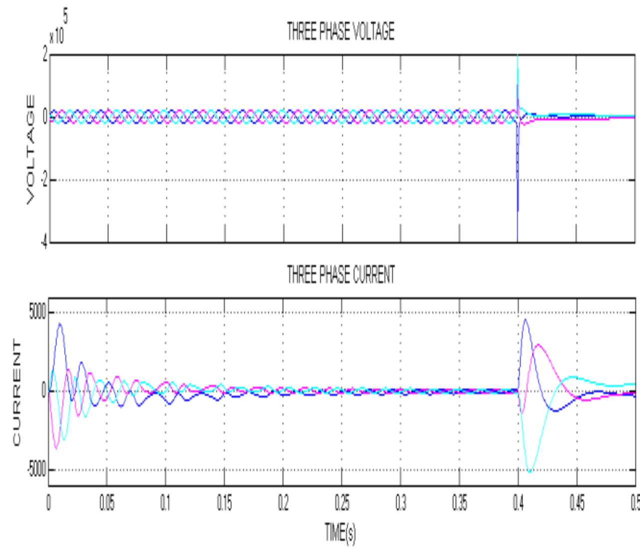

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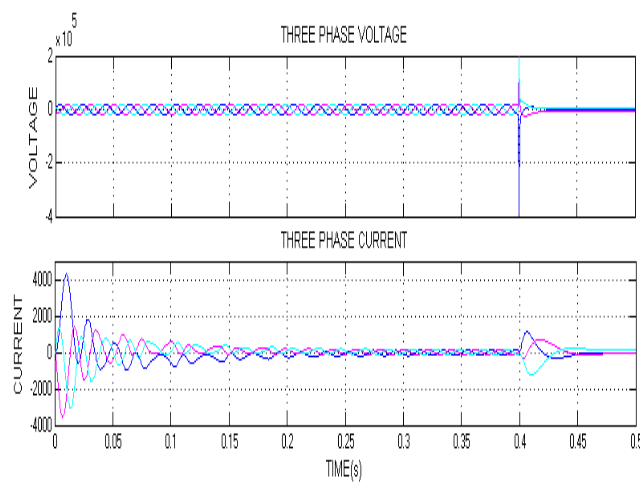

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Fig.10. Five different fault conditions considered at location 1 (a) without any sfcl, (b) sfcl at location 1, (c) sfcl at location 2, (d) sfcl at location 3, (e) sfcl at location 4.

The majority of faults in a power system might occur in the distribution grid and the SFCL designed to protect micro-grid should not be expected to cater for the transmission line faults (Fault 3). 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 while designing the protection schemes for the smart/micro grid. When the SFCL was strategically located at the point of integration of the wind farm with the grid Location 3, the highest fault current reduction was achieved. Performance of SFCL at this location was even better than dual SFCL located at Location 1 and Location 4 at a time. Thus the multiple SFCLs in a microgrid are not only costly but also less efficient than strategically located SFCL. Moreover, at Location 3 fault current coming from the conventional power plant was also successfully limited. Further this is extended by adding another two wind farms to the existing. Once again the process is repeated and the location of SFCL is analyzed. The analysis is carried out at only fault F1 condition. Here also the fault is created at 0.4s of run time. The analysis concludes that SFCL works effectively when placed at location 3 in three wind farm systems.

D. System Containing Three Wind Farms

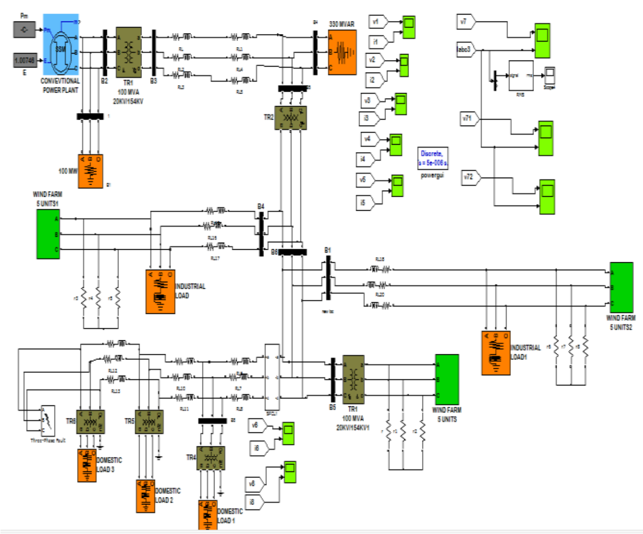
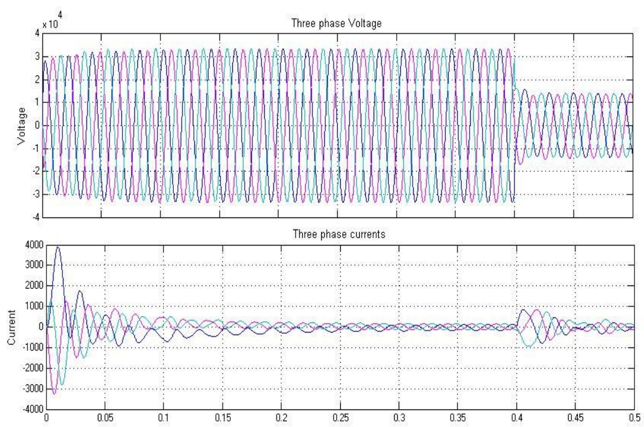


Fig.11 Matlab/Simulink Model of proposed Positioning of Superconducting Fault Current Limiters for containing three wind farms.



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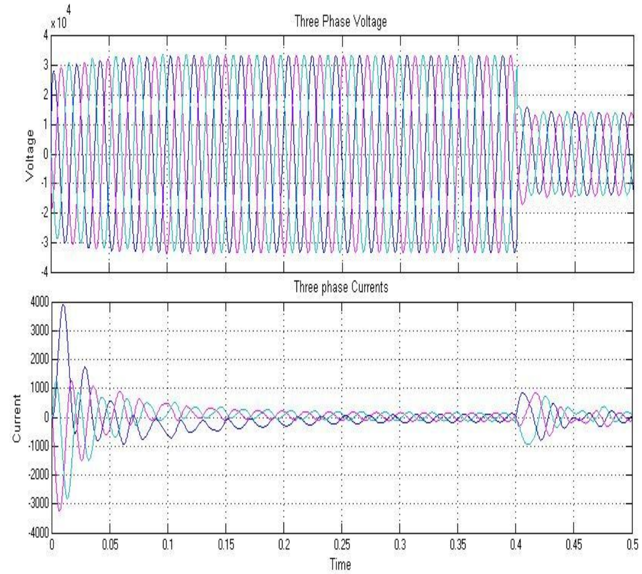

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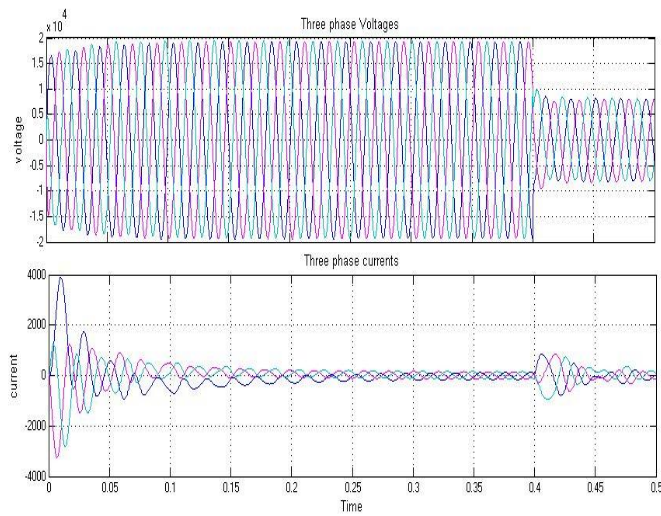
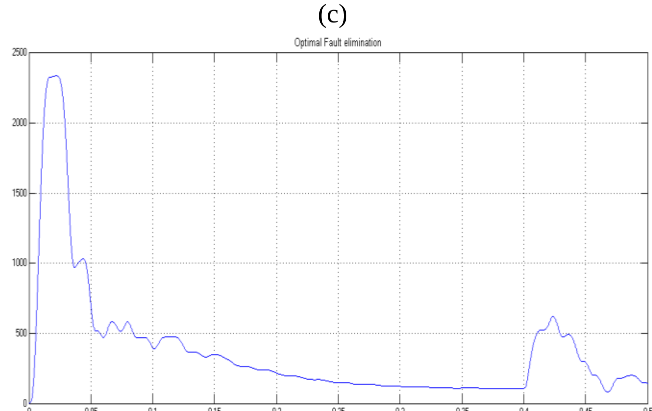


(c)



(d)

Fig.12 (a),(b),(c). (d) Fault currents and voltage wave forms, optimal fault location at different locations in the system containing three wind farms.

VII.CONCLUSION

An optimal energy storage system (ESS) management procedure devoted to full renewable energy sources (RESs) exploitation is presented in this paper. It consists of an appropriate scheduling procedure and a real-time control strategy, which both aim to increase the RES penetration level as much as possible. This paper presented an analysis for optimal positioning the SFCL in rapidly changing modern power grid; compare to FCL, SFCL performs better compensation. A complete power system along with three micro grids cascaded to the grid was modeled and transient analysis for three-phase-to-ground faults at different locations of the grid were performed with SFCL installed at key locations. It has been observed that SFCL should not be installed directly at the substation or the branch network. This placement of SFCL results in abnormal fault current contribution from the wind farm. Also number of SFCLs in micro grid is inefficient both in performance and cost. The optimal 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, same compensation principle applied to three wind farms in a proposed topology getting better results using the optimal location of SFCL.

VIII. REFERENCES

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