Analysis on Investigation of Optimal Location of Fault Current Limiters in Smart Grid Applications

[1]CH.Srinivas, [2]M.Bharathi
[1, 2]Assistant Professor
D.M.S.S.V.H. College of Engineering
Email: [1]srinivas. chodagam@gmail.com, [2]m.bharathi602@gmail.com

Abstract— **Modern electric power systems are becoming more and more complex in order to meet new needs. Nowadays a high power quality is mandatory and there is the need to integrate increasing amounts of on-site generation. All this translates in more sophisticated electric network with intrinsically high short circuit rate. This network is vulnerable in case of fault and special protection apparatus. The SFCL has been announced as better solution among many methods to limit a fault current effectively. This paper describes the power system model with three phase faults at different locations. The paper proposes a superconducting fault current limiter to limit the fault current and finding the optimal location of SFCL in the wind farm integrated power system model at different locations is used to evaluate the effectiveness of the proposed device with the case studies based on time-domain simulation.**

Index Terms— **Consumer grid fault, Distributed grid faults, micro grid, superconducting fault current limiter, Transmission line faults, wind farm.**

I. INTRODUCTION

DEVELOPMENT of the energy infrastructure requires changes to be made involving interconnection of power systems and adding renewable energy resources. These factors lead to higher fault current levels in the altered system [8]. On the other hand, older but still operational equipment gradually becomes underrated, e.g., some transformers, switchgear, cables, or other underground equipment, can be very expensive to replace.

Conventional protection devices installed for protection of excessive fault current in power systems, mostly at the high voltage substation level are 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. Reference [9] offers an expanded list of conventional solutions for reduction of fault currents, giving advantages and disadvantages for using the fault current limiting reactors. These devices will suppress fault currents by generating the limiting impedance. Insertion of the limiting impedance happens faster than a conventional circuit breaker will clear the fault. However, current limiting reactors have a voltage drop under normal conditions. Also, the interaction with other system components can cause transient over voltages or other problems in some cases [9]. 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. SFCL achieves this function by losing its superconductivity and generating impedance in the circuit. SFCL doesn't only suppress the amplitudes of fault currents but also enhance the transient stability of power system. There were some research activities discussing the fault current issues of smart/micro grid. Superconducting fault current limiters (SFCLs), unlike reactors or high-impedance transformers, will limit fault currents without adding impedance to the circuit during normal operation. From [4], utilities will achieve financial benefits with installing SFCLs versus investments for multiple upgrades of circuit breakers, fuses, and bus works. Other benefits from installing SFCLs are safety, reliability, and power quality. But the applicability of SFCLs into micro grids wasn't found yet. Hence, in order to solve the problem of increasing fault current in power systems having micro grids by using SFCL technology is the main concern of this work. A good overview of the state-of-the-art of fault current limiting devices is given in [5]. This reference also identifies the most suitable types of fault current limiters (FCLs) for specific types of locations in smart grids.

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. These devices have the promise of controlling fault currents to levels where conventional protection equipment can operate safely. To select the optimal location of the SFCL, the sensitivity analysis of power changes and/or power losses in the system with respect to its resistive value occurred in series with a transmission line during a fault is introduced.A significant advantage of proposed SFCL technologies is the ability to remain virtually invisible to the grid under nominal operation. Ideally, once the limiting action is no longer needed SFCL quickly returns to its nominal low impedance state. SFCL 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.

II. SIMULATION MODEL & CONFIGURATION

A. Power System Configuration

The developed micro grid model was designed by integrating a 10 MVA wind farm with the distribution network. The power system having a 100 MVA conventional power plant, composed of 3-phase synchronous machine, connected with 200 km long 154 kV distributed-parameters trans-mission line through a step-up transformer TR1. At the substation transformer TR2 is placed to step-down the voltage to 22.9 kV from 154 kV. High power industrial load with 6 MW capacity and low power domestic loads with 1 MW capacity of 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 as Distributed power generation. The wind farm is composed of five fixed-speed induction-type wind turbines each having a rating of 2 MVA.

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. The output current of wind farm is taken from transformer TR3 for various SFCL locations with different faults are placed in the power system model.

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.

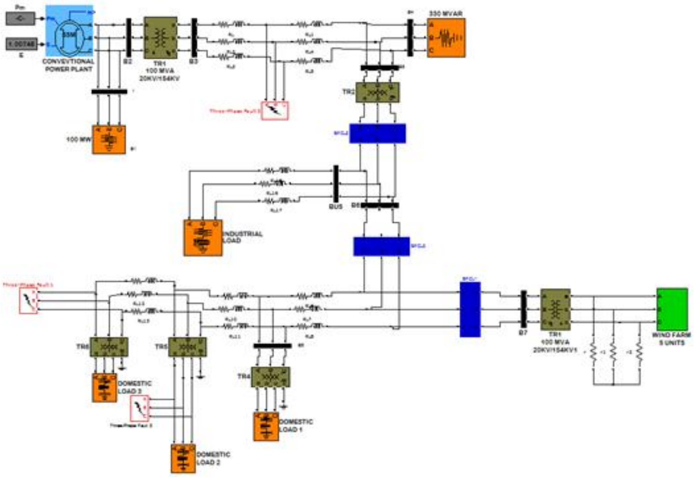


Figure 1 Power system model designed in Simulink. Fault (Red) and SFCL (Blue) locations are indicated in the diagram.

The output current of wind farm at TR3 in Figure.1 for various SFCL locations have been measured and analyzed in section III.

B. Resistive SFCL Parameters & Locations

The three phase resistive type SFCL was modeled considering fundamental parameters of a resistive type SFCL. These parameters and their selected values are (i) Minimum impedance=0.01ohms (ii) Maximum impedance=20ohms and (iii) Triggering current=550A (iv) Response time=2msec (v) Recovery time=10msec (vi) Working voltage = 22.9 kV.

Four prospective locations for SFCL installation are marked at Substation (Location 1), Branch Network (Location 2), Wind farm integration point with the grid (Locations 3) and Wind Farm (Location 4).

Generally, conventional fault current protection devices are located in Location 1 and Location 2.

The SFCL model works as follows: First, SFCL model calculates the RMS value of the passing current and then compares it with the pre-defined value. 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.

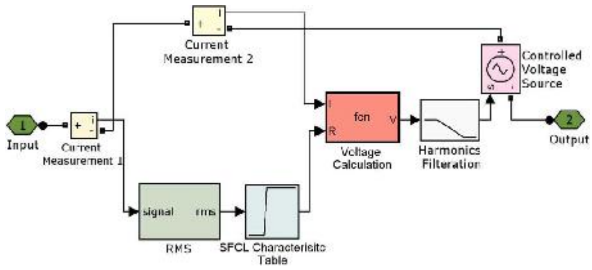


Figure 2 Single phase SFCL model

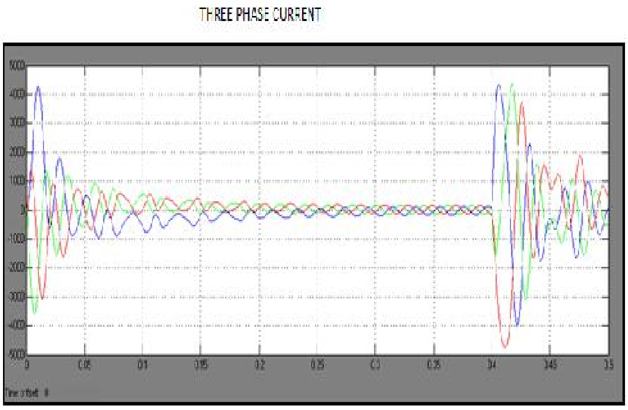
III. RESULTs ANALAYASIS

Four scenarios of SFCL's possible locations were analyzed for three different fault occurring points in the power system depicted in Figure. 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). Finally, in order to clarify the usefulness of dual SFCL installed together for different locations, SFCLs were located at Location 1 and Location 4 respectively. Any kind of fault can be simulated with the three-phase SFCL model developed. However, due to the space limitation, results are given here for the three-phase to ground faults only. Three-phase-to-ground-Fault transition time=0.4secs

A. Fault in the Distribution Grid (Fault 1)

SFCL located at Location 1 or Location 2, fault current contribution from the wind farm has increased and the magnitude of fault current is higher than no SFCL case. These 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 impedance. The SFCL at these locations 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 this case, when SFCL is installed at the integration point of wind farm with the distribution grid, marked as Location 3 in Figure. 1, fault current in the wind farm has been successfully reduced.

With dual SFCL installed at Location 1 and Location 4, 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 Location 1 and Location 4 is economically and technically not feasible.



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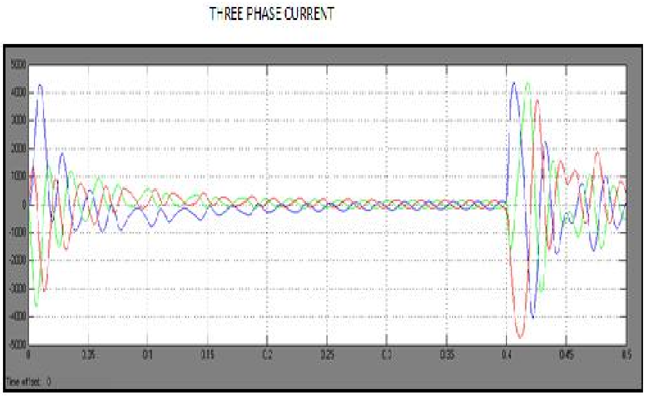

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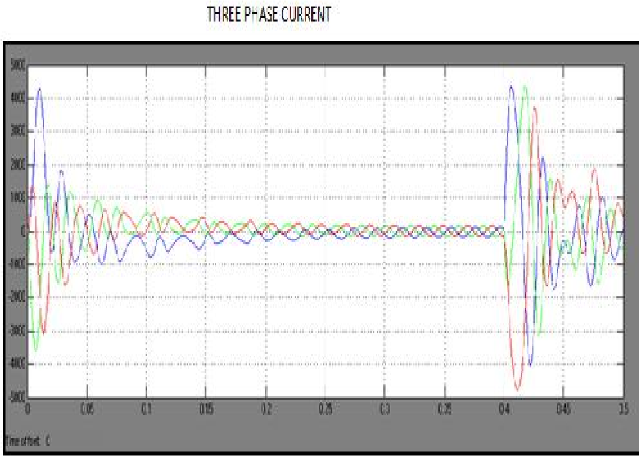

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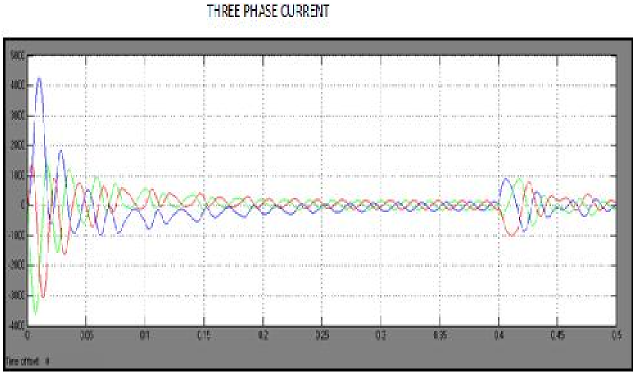

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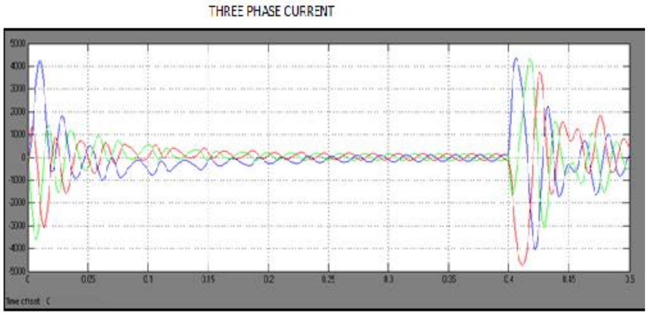
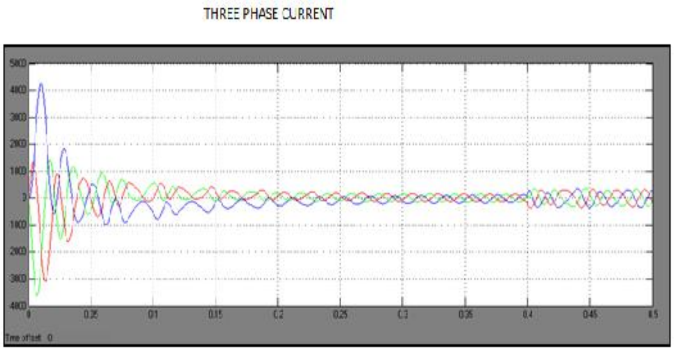


(e)

Figure 3 Wind farm fault currents respectively for SFCL at locations (a) Without SFCL (b) SFCL at location 1 (c) SFCL at location 2 (d) SFCL at location 3 (e) SFCL at locations 1&4.

B. Fault in Customer Grid (Fault 2)

Figure 4 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 Figure 1. Fault 2 is comparatively a small fault as it occurred in low voltage customer side distribution network.



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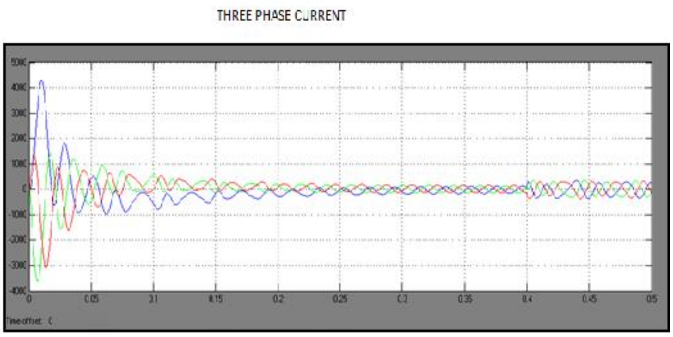

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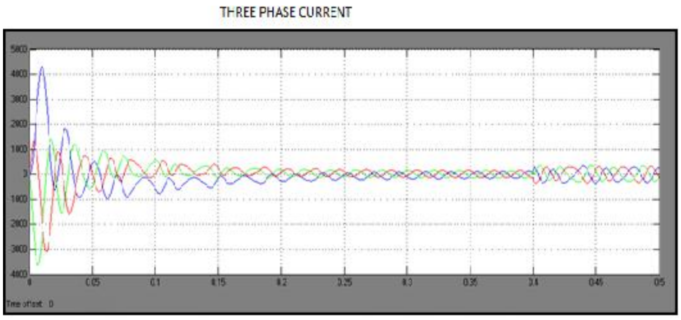

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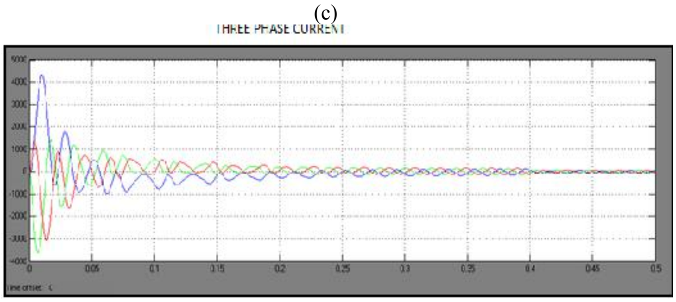

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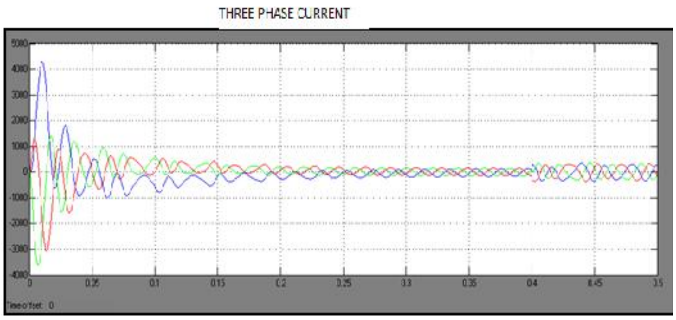

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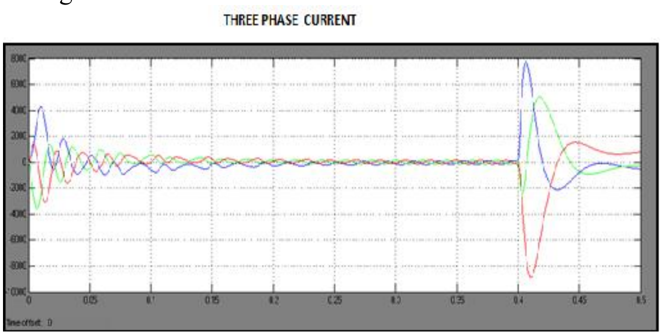
Figure 4 Wind farm fault current respectively for SFCL at locations (a) Without SFCL (b) SFCL at location 1 (c) SFCL at location 2 (d) SFCL at location 3 (e) SFCL at locations 1&4.

C. Fault in Transmission Line (F3)

The Fault 3 in Figure 1 indicates the rarely occurring transmission line fault which results in very large fault currents. Figure 5 shows fault current from the wind farm measured at output of TR3 in Figure 1 for different SFCL locations in this case. 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.



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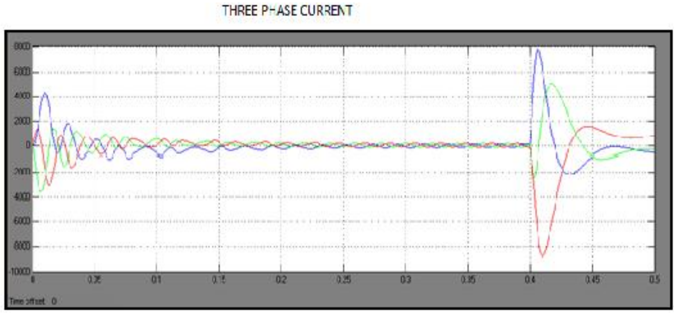

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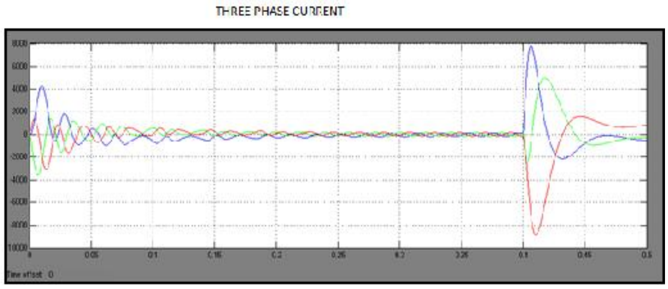

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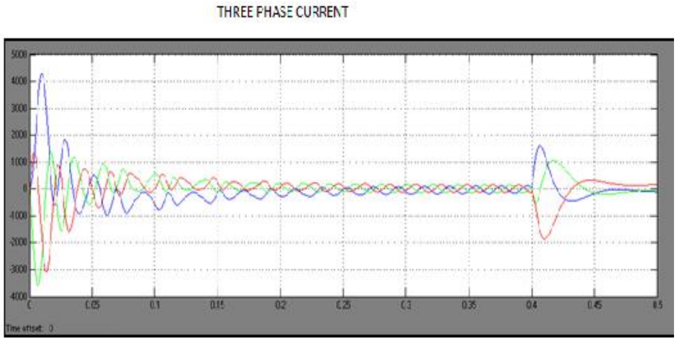

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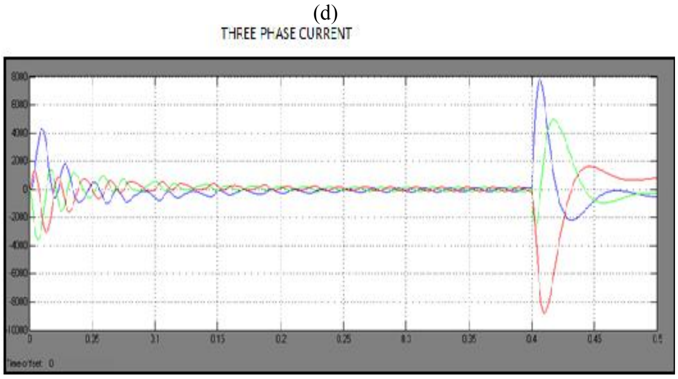

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Figure 5 Wind farm fault current respectively for SFCL at locations (a) Without SFCL (b) SFCL at location 1 (c) SFCL at location 2 (d) SFCL at location 3 (e) SFCL at locations 1& 4.

The majority of faults in a power system occur in the distribution grid and the SFCL designed to protect micro grid should not be expected to cater for the transmission line faults. 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, the highest fault current reduction was achieved and it is shown in the waveforms.

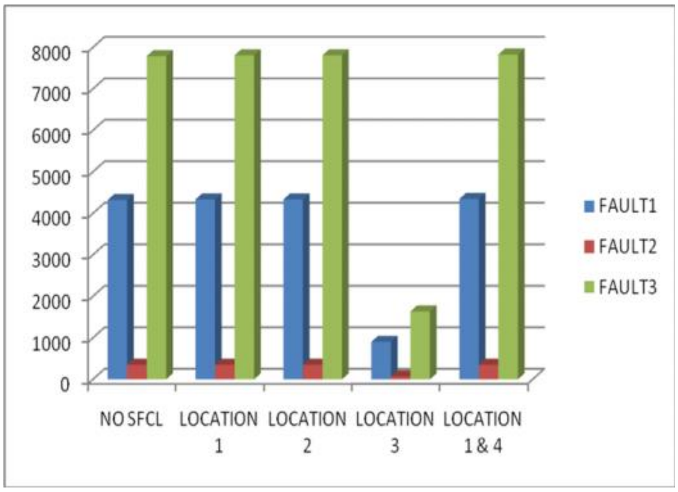

Figure 6 Comparison of the reduction in wind farm fault current magnitude in Three Phase to Ground Fault Case.

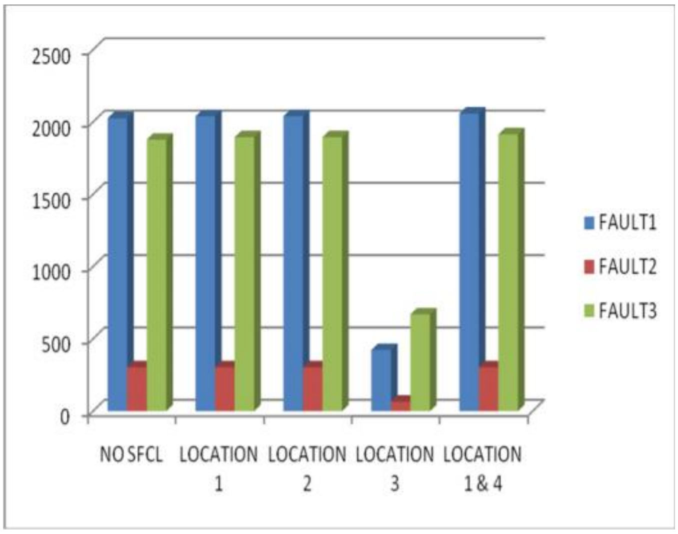

Figure 7 Comparison of the reduction in wind farm fault current magnitude Single Phase to Ground Fault Case.

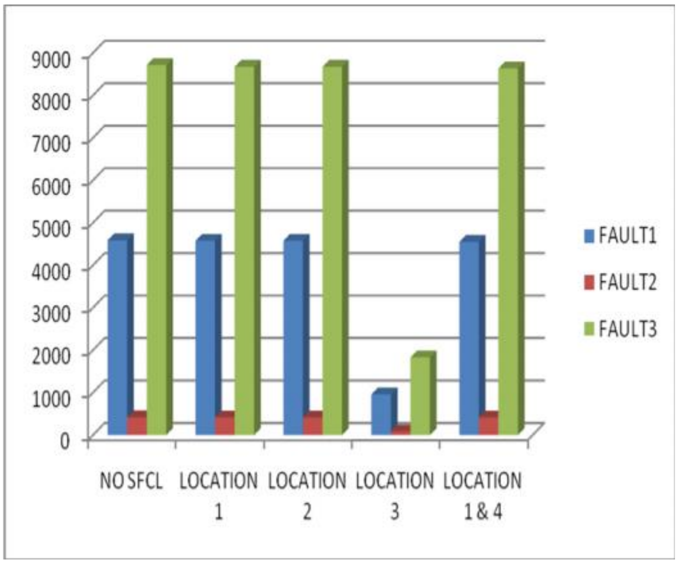

Figure 8 Comparison of the reduction in wind farm fault current magnitude Phase to Phase Fault Case.

IV. CONCLUSION

SFCL optimal location evaluated from the above results & discussions in the considered wind farm integrated power system model & it is the integration point of conventional power plant with a wind farm. When the SFCL was strategically located at the point of integration of the wind farm with grid, the highest fault current reduction was achieved & it is shown in bar charts. Performance of SFCL at this location was even better than dual SFCL located at location 1 & location 4.

Thus the multiple SFCLs in a micro-grid are not only costly but also less efficient than strategically located SFCL. Finally paper concludes, SFCL at location 3 fault current coming from the Transmission lines, Distributed grid, Customer grid was successfully limited.

V. REFERENCES

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VI. BIOGRAPHIES

CH.Srinivas was born in Machilipatnam, Andhra pradhesh, India. He received the B.Tech degree in Electrical & Electronics Engineering from the D.M.S.S.V.H. College of Engineering, Machilipatnam, in the year 2011 and the M.Tech degree in Power System Control & Automation Engineering from SRI VASAVI ENGINEERING COLLEGE, Tadepalligudem, in year 2013.

He is currently working as a Assistant Professor in D.M.S.S.V.H. College of Engineering, Machilipatnam. His area of interest is Distributed Power Generation. He published one international journal & presented a paper in national conference.

M.Bharathi was born in Machilipatnam, Andhra pradhesh, India. She received the B.Tech degree in Electrical & Electronics Engineering from the D.M.S.S.V.H. College of Engineering, Machilipatnam, in the year 2010 and the M.Tech degree in Power Electronics & Drives from LAKIREDDY BALIREDDY COLLEGE OF ENGINEERING Mylavaram in the year 2013.

She is currently working as a Assistant Professor in D.M.S.S.V.H. College of Engineering, Machilipatnam. Her area of interest is power electronic devices for power quality improvement & Distributed Generation interfaces. She presented a paper in national conference.