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A Study on Application of Superconducting Fault Current Limiter (SFCL) in Smart Grid

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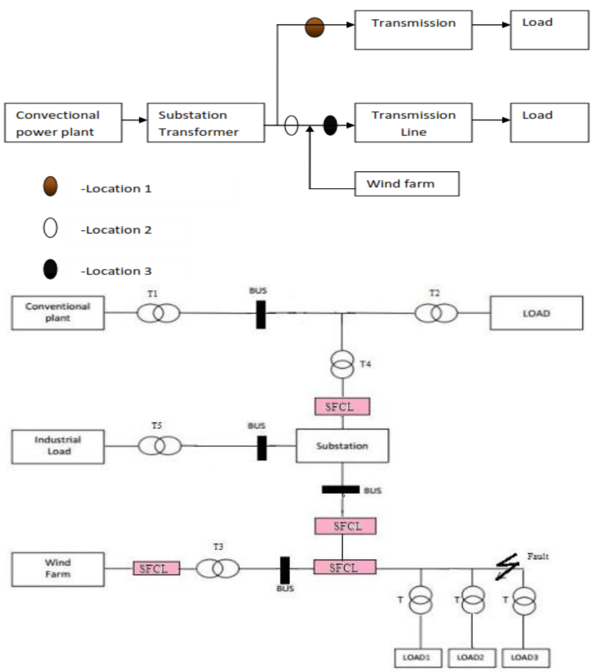
Abstract: Nowadays, the main energy supplier of the worldwide economy is fossil fuel. However has led to many problems such as global warming and air pollution. Therefore, with regard to the worldwide trend of green energy, solar power technology has become one of the most promising energy resources. Smart grid will integrate modern communication technologies and renewable energy resources into the future power grid, in order to supply more efficient, reliable, resilient and responsive electric power. In this paper, an application of superconducting fault current limiter (SFCL) is proposed to limit the fault current that occurs in power system, SFCL is a device that uses superconductors to instantaneously limit or reduce unanticipated electrical surges that may occur on utility distribution and transmission networks. 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.Three phase faults have been simulated at different locations in smart grid and the effect of the SFCL and its location on the wind farm fault current was evaluated. Smart grid with combination of PV cell and Wind farm is also considered and the performance of PV cell with three phase faults at different locations is also evaluated. Consequently, the optimum arrangement of the SFCL location in Smart Grid with renewable resources has been proposed and its remarkable performance has been suggested.

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

I. INTRODUCTION

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 ofdecentralization of the power grid network into smaller grids (microgrid) 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 [1].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 [2]. 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 [2].Up to now, there were some research activities discussing the fault current issues of smart grid [4].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 [3]. 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.



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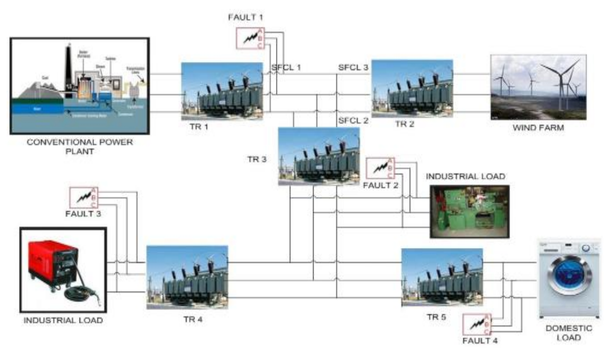

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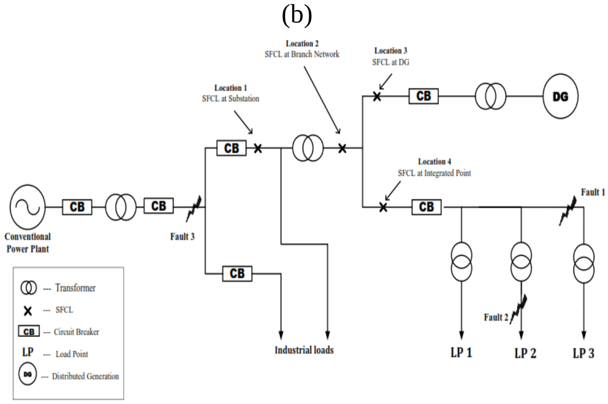

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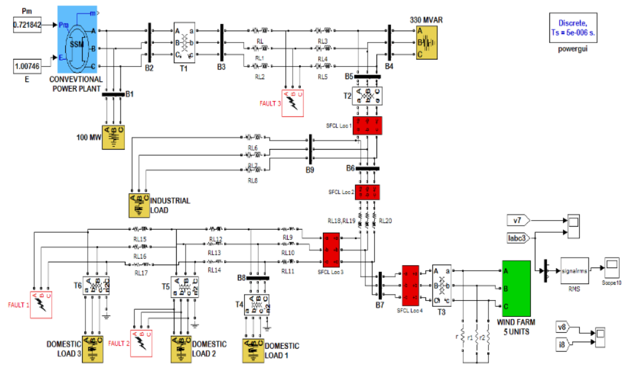

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Fig. 1. Power System Model Designed in Simulink/SimPower System. Fault and SFCL Locations are Indicated in the Diagram

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. Simulation Set-up

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.

A. System Model:

Newly developed micro grid model was designed by integrating a 10 MVA wind farm with the distribution network. Fig. 1 shows the power system model designed in Simulink/SimPowerSystem.

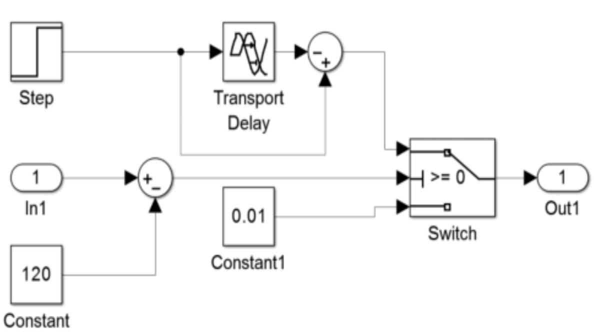
The power system is composed of a 100 MVA conventional Power plant, composed of 3-phase synchronous machine, connected with 200 km long 154 kV distributed-parameters transmission line through a step-up transformer TR1. At the substation (TR2), voltage is stepped down to 22.9 kV from 154 kV. High power 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.

In Fig. 1 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 Location2.The output current of wind farm (the output of TR3 in Fig. 1) for various SFCL locations have been measured andanalyzed in Section IV 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 [5-8]. 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. 2 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.



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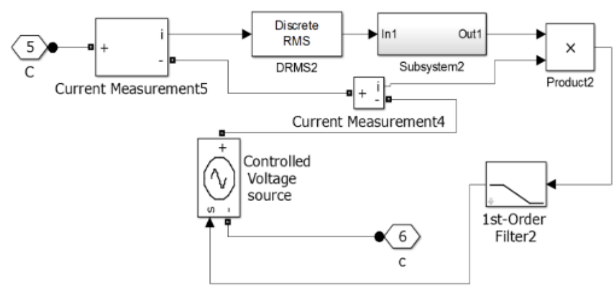

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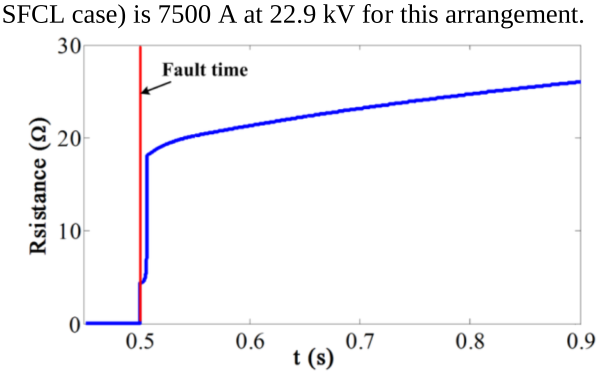
Fig. 2. Single phase SFCL model developed in Simulink/Sim-PowerSystem

Fig. 3 shows the result of verification test of SFCL model conducted on power network model depicted in Fig. 1. 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.



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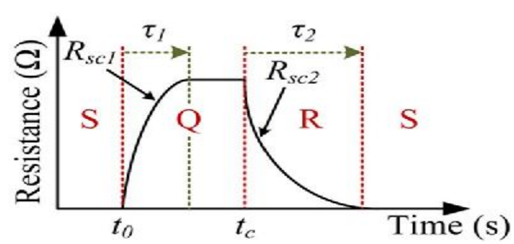

(b)

Fig. 3. SFCL Performance Evaluation Graph Indicating the Relationship between SFCL Impedance and Reduction in Fault Current

III. PHOTOVOLTAIC SYSTEM WITH GRID

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices.

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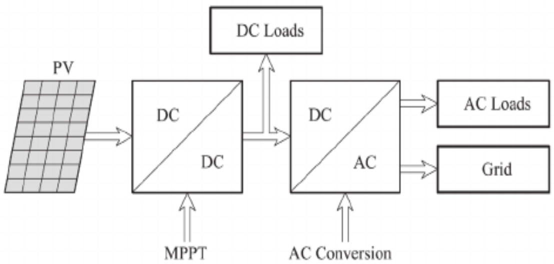
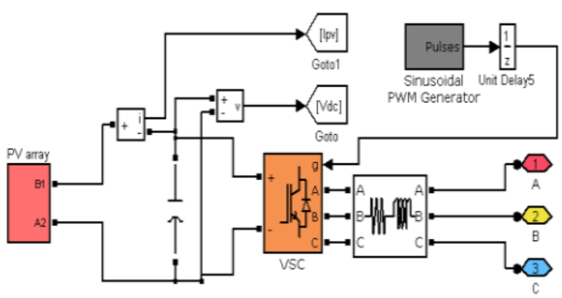


Fig. 4. Block Diagram Representation of Photovoltaic System

This photovoltaic system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The Block diagram of the PV system is shown in Fig.4. A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited1

(a)



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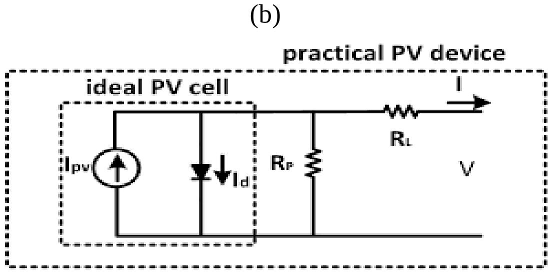

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Fig. 5. Practical PV Device

The equivalent circuit of PV cell is shown in the fig.5. In the above figure the PV cell is represented by a current source in parallel with diode. R_s and R_p represent series and parallel resistance respectively. The output current and voltage form PV cell are represented by I and V

IV. Simulation Results And Disscusion

Feasibility analysis of the micro grid with wind farm and PV cell as the distribution generators are analyzed by considering the different fault locations in power system such as distribution grid, customer grid and transmission grid. From these, we found out the optimal location of SFCL in the power system to protect the wind farm and PV cell from high fault currents.

CASE 1: Wind Farm Alone:

A: Fault at Distribution Side:

When fault occurred at distribution grid, most of the fault current is shared by the wind farm and then by the conventional power source. When considering the SFCL location at 1 and 2, we can observe that the fault current from wind farm increased rather than decreased. It is because of the abrupt change in the network impedance and the current from the conventional source is decreased at the SFCL location, so very less current is shared to the fault and the remaining total current is shared by Wind farm only. For SFCL at location 3, we can observe the very good results and wind farm current is reduced significantly. Though the same results are obtained at location 1 and 4 also, it is not feasible to place to SFCLs economically and technically.

B. Fault at Customer Side:

It is small fault comparatively with the other faults. The results obtained at this fault location are similar to the results discussed for fault at distribution grid. Best results are obtained for SFCL location 3 that is at integration point.

C. Fault at Transmission Side:

It is very rare fault in power systems. For this fault, wind farm current flows in reverse direction towards the fault point through substation. So, when SFCL placed at location 1 and 2 also, wind farm fault current is reduced this is in contradictory for previous cases. Also the SFCL locations at 3 and 1 and 4 give the best results for this scenario.

Case 2: Wind Farm and PV Cell

A. Fault at Distribution Side:

When fault occurs at distribution grid, most of the current is shared by the conventional source and wind farm. As PV cell is introduced at the industrial load, current from

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conventional power source to the industrial load decreased and the same amount is shared towards distribution grid. Hence, load on the wind farm also reduced significantly. For this fault point at distribution grid wind farm and PV cell are not affected as most of the fault current is sharing by the conventional power source. Hence No SFCL is required for protection.

B. Fault at Substation:

When fault occurred at substation, fault current from wind farm flows in reverse direction towards substation and conventional power source shares the fault current. Here PV cell is not affected as there is no change in the output load connected to it. So protection is required only for wind farm and SFCL can be placed at location 2 or 3 or 1 and 4.

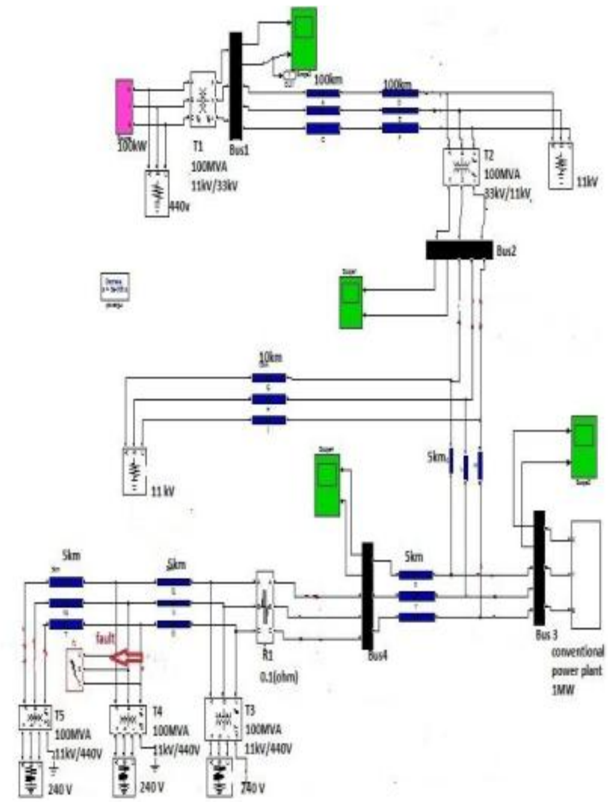
C. Fault at Transmission:

When fault occurred at transmission line, fault current from wind farm flows in reverse direction through substation and conventional power source shares the fault current. Here PV cell is not affected as there is no change in the output load connected to it. So protection is required only for wind farm and SFCL can be placed at location 1 or 2 or 3 or 1 and 4.

D. Fault at Industrial Side:

When fault occurred industrial load, PV cell output current is raised to a very high value as its output is short circuited. So most of the fault current is shared by the PV cell. Here, Wind farm is not affected. So, protection is required only for the PV cell and SFCL can be placed at the location suggested in the fig 1.

Majority of faults in power system occur in the distribution grid. Hence, from above observations, for the protection of Wind farm and PV cell from high fault currents SFCL can be placed at the integration point that is location 3. We can observe that PV cell will be affected only by the fault at industrial load and it can be protected from that as suggested. For remaining all the conditions, location 3 is the best position for SFCL in power system in both technically and economically.



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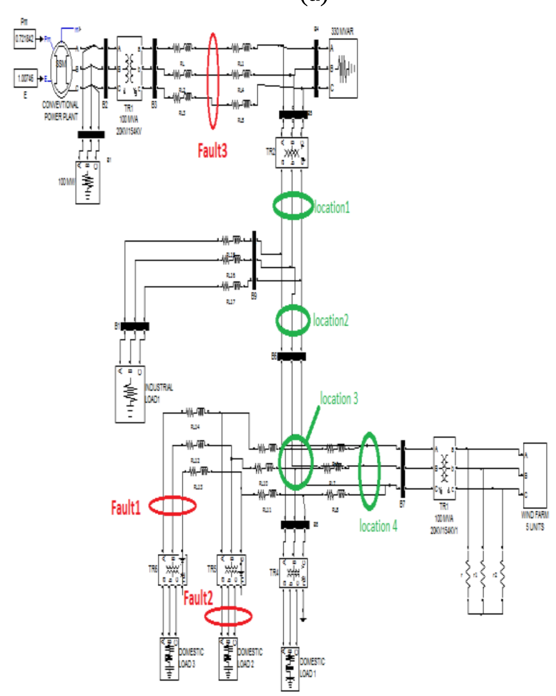

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Fig. 6. Shows the MATLAB Modeling of Proposed Network

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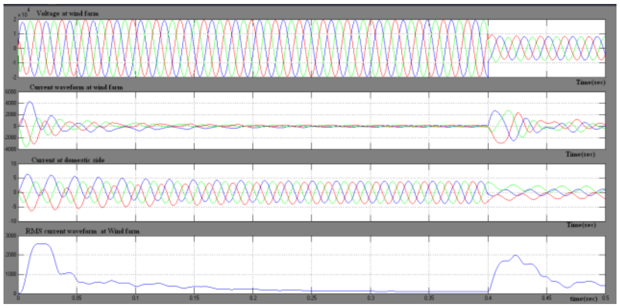

Fig. 7. Fault 1 with No SFCL

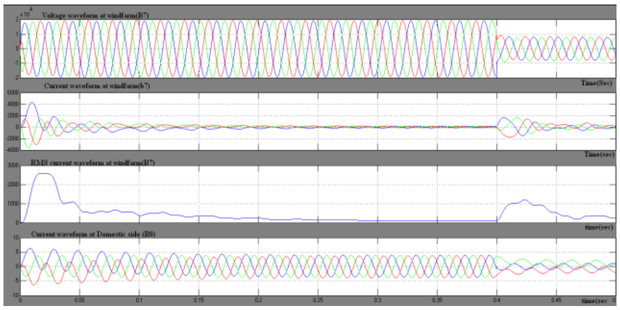

Fig. 8. Fault 1 with SFCL at 1and 4 Locations

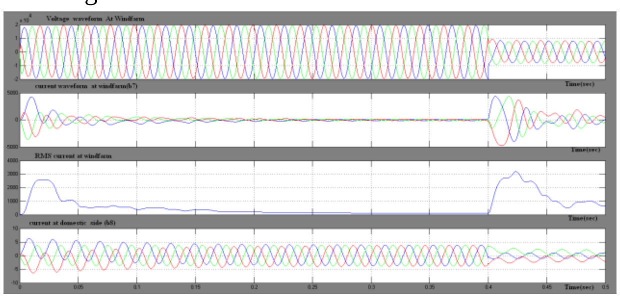

Fig. 9. Fault1 with SFCL at Location 2

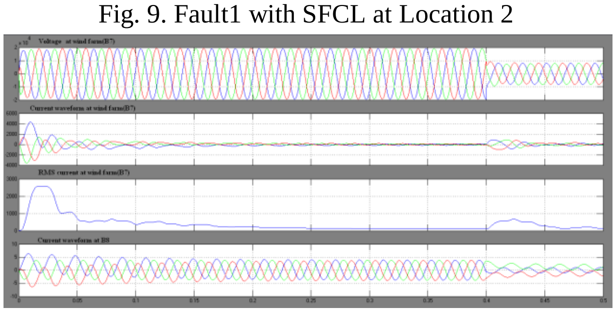

Fig. 10. Fault1 with SFCL at Location 3

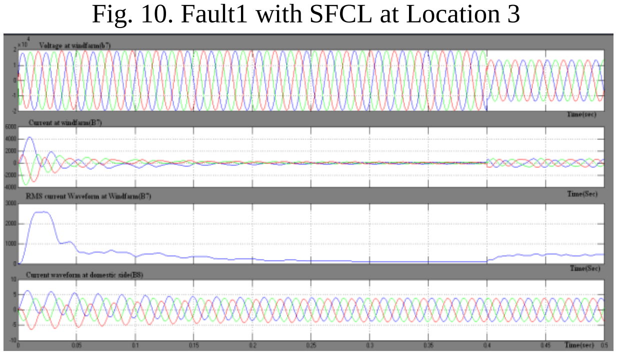

Fig. 11. Fault 2 No SFCL

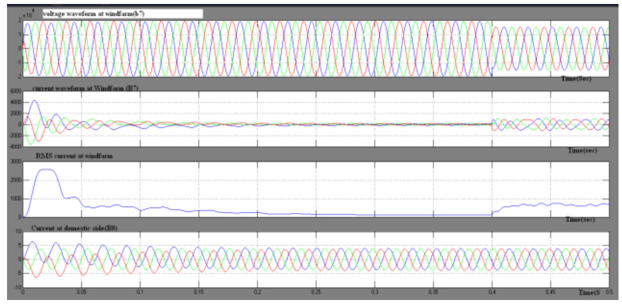

Fig. 12. Fault2 with SFCL at Location 2

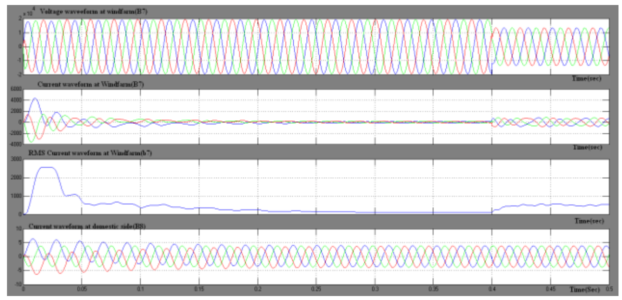

Fig. 13. Fault2 with SFCL at Location1& 4

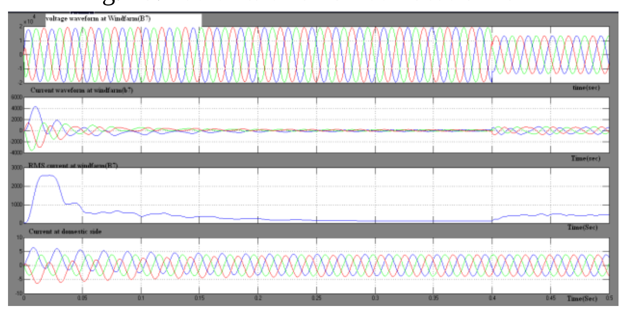

Fig. 14. Fault 2 with SFCL at Location 3

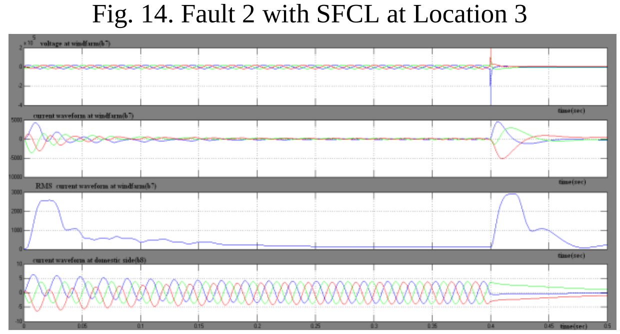

Fig. 15. Fault 3 No SFCL

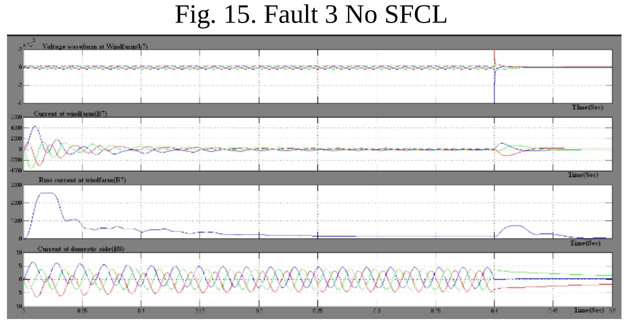

Fig. 16. Fault 3 with SFCL at Location 3

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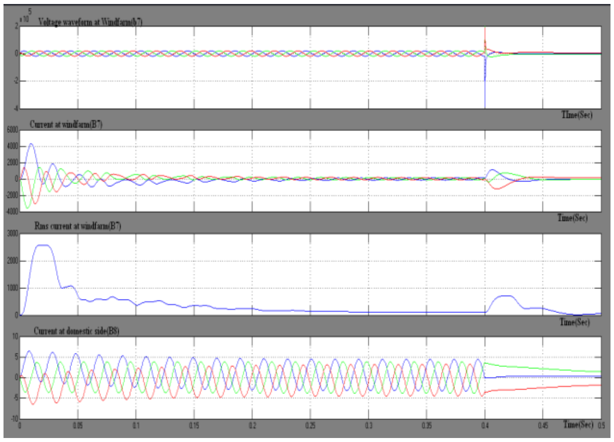


Fig. 17. Fault 3 with SFCL at 1 and 4 Locations

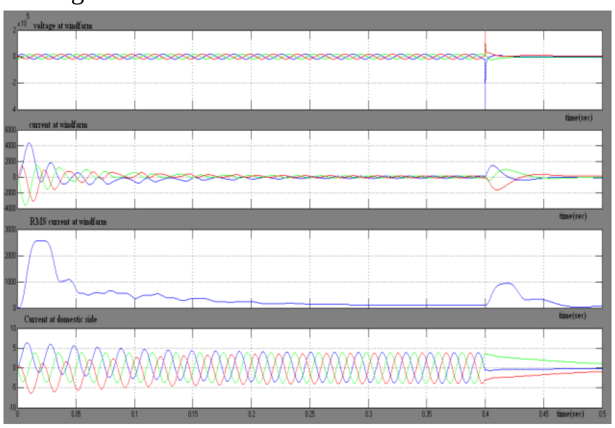
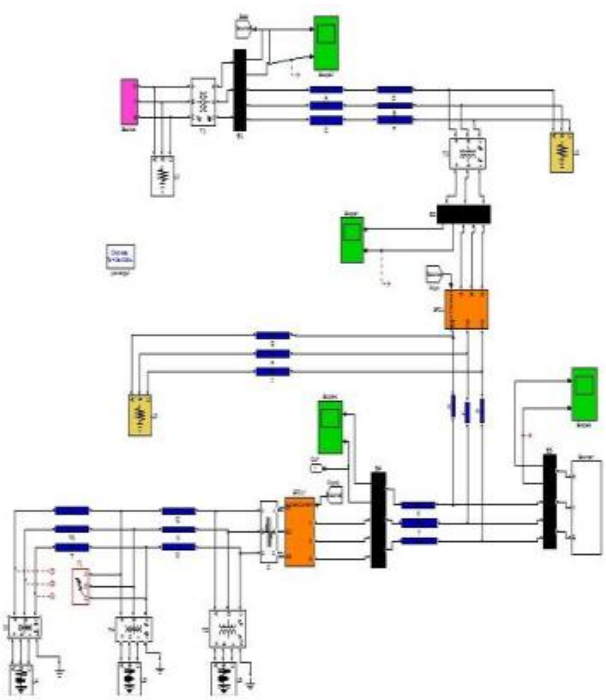


Fig. 18. Fault3 with SFCL at Location 2



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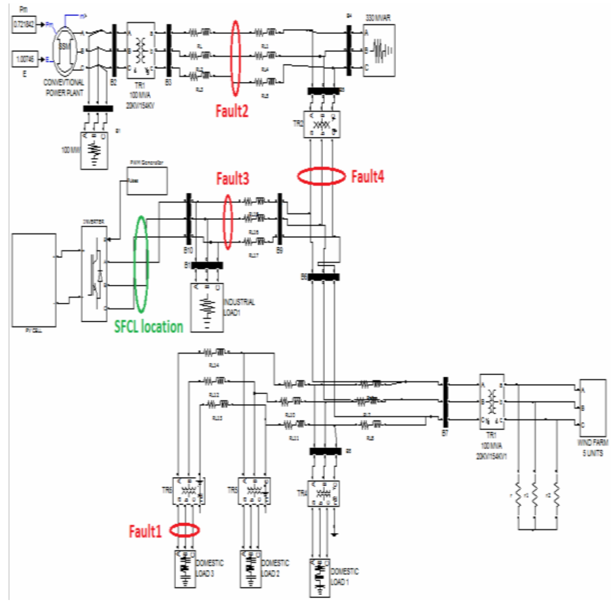

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Fig. 19. Shows the MATLAB Modeling of Both wind Farm and PV Cell Circuit

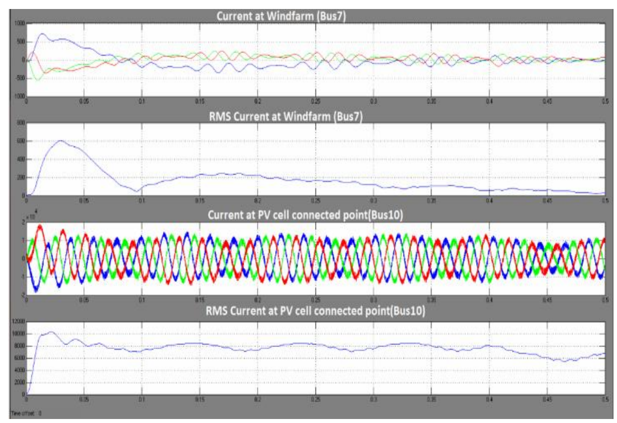

Fig. 20. Fault 1 No SFCL

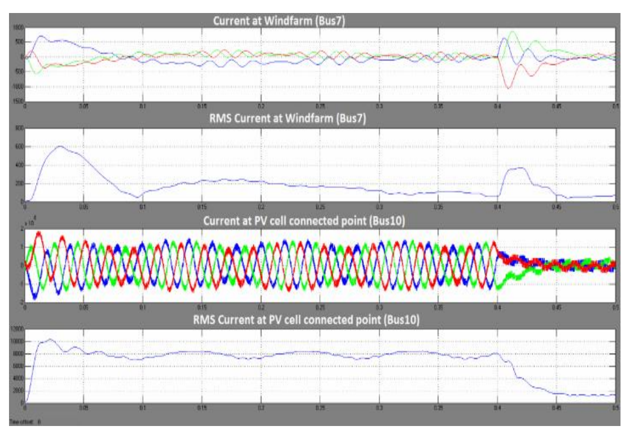

Fig. 21. Fault 2 without SFCL

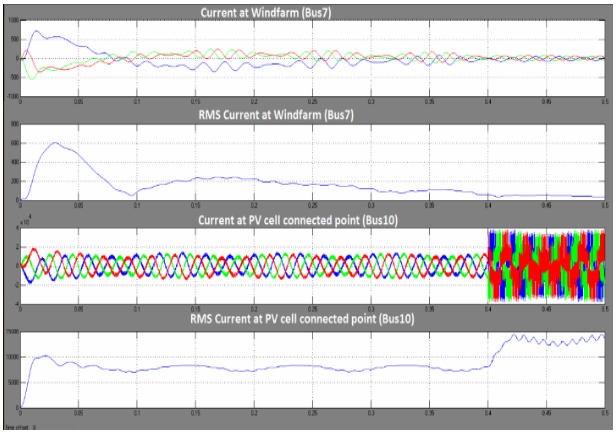

Fig. 22. Fault 3 without SFCL

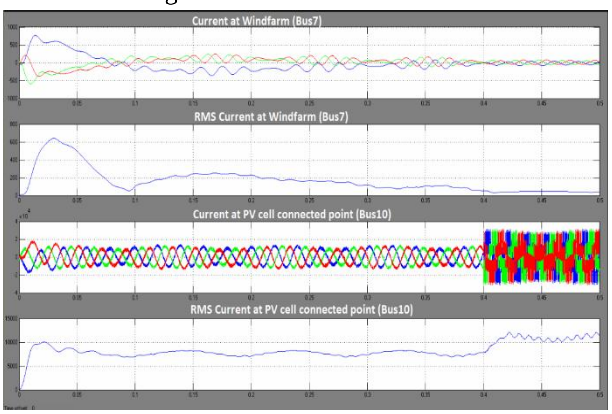

Fig. 23. Fault 3 with SFCL 3 Location

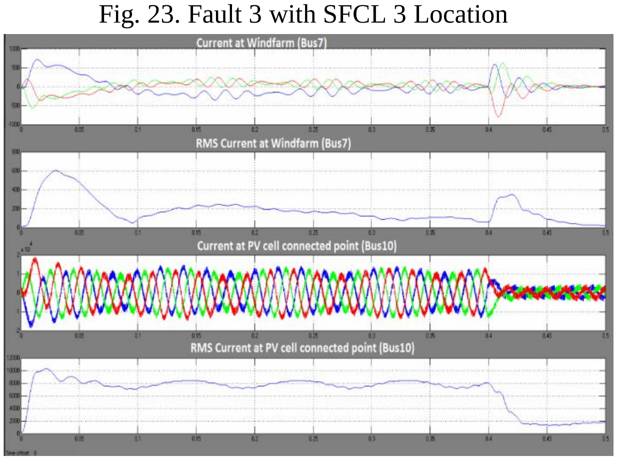

Fig. 24. Fault 4 without SFCL

V. CONCLUSION

As a kind of clean energy technique, the photovoltaic (PV) power generation offers the advantages of low emission, renewable energy source and independence of mechanical devices. However, the high cost and relatively low efficiency of the PV modules have limited the use of PV power generation in the past compared to other energy sources such as oil, gas, hydro and wind. This paper presented a feasibility analysis of a modern power grid with micro grids such as wind farm and PV cell connected with the grid. Also power system is analyzed for positioning of the SFCL in the grid. A complete power system with Wind farm and PV cell was designed and analyzed for different locations of three phase to ground fault. By this optimal location of SFCL was found for protection of wind farm and PV cell from high fault currents. It has been observed that PV cell is affected only when the fault occurred at industrial load side and SFCL should be placed at the output of PV cell for its protection. For wind farm protection, SFCL should be placed at location 3 that is integration point of wind farm with grid for best results.

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