Study of position of SFCL for maximum fault current limiter for power systems protection

Sachin Trankatwar[1], Dr.S.L.Nalbalwar[2], Dr. A.B.Nandgaonkar[3]
[1]PG student Department of electronics and Telecommunications Dr. Babasaheb Ambedkar echnological University
[2]Associate Professor Department of electronics and Telecommunications Dr. Babasaheb Ambedkar Technological University.
[3] Associate Professor Department of electronics and Telecommunications Dr. Babasaheb Ambedkar Technological University.
[1]strankatwar@gmail.com
[2]nalbalwar_sanjayan@yahoo.com
[3]abnandgaonkar@yahoo.com

ABSTRACT: In this paper the fault current reduction using Superconducting fault current limiter (SFCL) due to integration of wind power with power system is investigated. Fault current plays very important role in strengthening power system security due to the increase in the integration of wind power in recent year. To prevent, optimal position of SFCL is focused. The typical power system model including generation, transmission and distribution network with distributed energy resource was modeled to determine optimal position of the SFCL. In this work, a resistive type SFCL model was implemented by integrating Simulink and SimPowerSystem blocks in Matlab. As for a distributed energy resource, 10 MVA wind farm was considered for the simulation.

***Index Terms* —** Fault current, micro grid, smart grid, supercon- ducting fault current limiter, wind farm.

1. INTRODUCTION

As we know the electrical energy is the most useful, versatile energy. Electrical energy used in industry, homes, transportation and business i.e. everywhere used. With increase in demand of electrical energy, consumption of electrical energy is increased. As the result demand of generation station increase and hence size of generating station and interconnection networks increase. Due to increase in size of generating station and interconnection network this increase the possibility of abnormal operation in the systems. There may possibility of sudden change in the impedance of the power system, which lead to increase in current, known as fault current. The equipment installed at power station and at generating station is very expensive and costly. To save this expensive equipment from fault current the current limiters are required. The electrical and electronic industry is rapidly increasing due to which the demand for as well as the power quality of the electricity is increasing. To have continuous and reliable operation of the power systems the fault current in the system need to be limit to lower value[5].

The circuit breakers has large response-time delay that allows initial two or three fault current cycles to pass through before getting activated. Sometime circuit breakers cannot handle the intense level of faults' so they fail to interrupt the fault current. Also the less expensive current limiter reactors may have unwanted side effects, such as increasing system losses, voltage regulation problems or system stability. Thus the Superconducting fault current limiter (SFCL) is one of the attractive solution to solve the fault current problem. Hence, SFCL technology is the main concern for solving the problem of increasing fault current in power grids. In this paper, the effect of SFCL and its position was investigated by considering one of typical configurations of the smart grid. Here wind farm integrated with a distribution grid model.

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2. MODEL

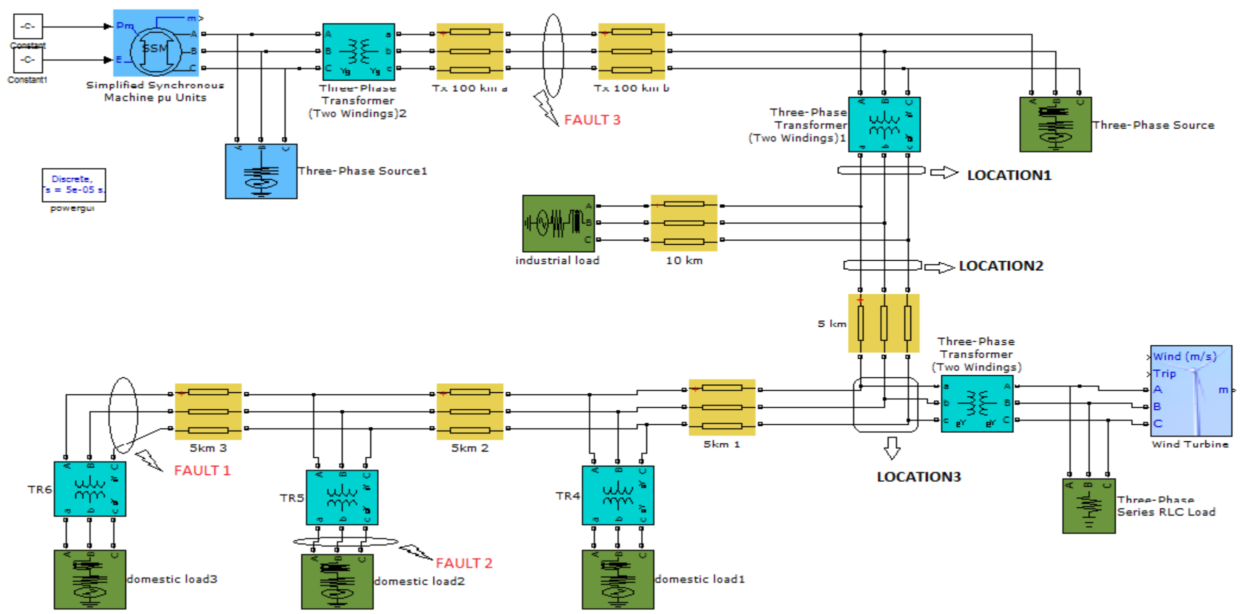

Fig.1: Power system model designed in Simulink. Fault and SFCL location are indicated in the diagram

The above figure shows typical power system for simulation in the Simulink and SimPowerSystem in Matlab. The system is composed of conventional power plant which is 100 MVA,20KV, composed of 3-phase synchronous machine which is connected by 200 km long 154 KV distributed-parameters transmission line through a step-up transformer of 20/154KV(TR1). At the substation (TR2), the voltage is stepped down to 22.9 kV from 154KV. High power industrial loads of 6MW and 330MVAR loads are connected to the conventional source. The 10 MVA wind farms is composed of three fixed-speed induction-type wind turbines each having a rating of 3.33MVA. The wind farm is operating at 20KV, and is this voltage is stepped up to branch network voltages of 22.9KV through a 20KV/22.9KV transformer (TR3). The wind farm directly connects with the branch network (B1) through a transformer (TR3) and is providing power to the domestic loads. The 10MVA wind farm supplied to the
customer loads at 400V, through distribution transformers of 22.9KV/400V. Three domestically loads are separated by each 5KM transmission line and at each end of 5KM transmission line a domestically load is connected through a distribution transformer, as shown in Figure 1[3].

Artificial faults 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 as shown in the Figure 1 and for each and every fault the wind farm fault current observed. To reduce this wind farm fault current the Superconducting fault current limiter used. Superconducting fault current limiter is placed at three scenarios for three different faults in the power system[3]. First, we assumed that single SFCL was located at Location 1 (Substation). Second, single SFCL was located at Location 2 (Branch Network). Third, single SFCL was located at Location 3 (Wind farm integration point with the grid). Finally, dual SFCL installed together for different locations, SFCLs were located at Location 1 (Substation) and Location 4 (Wind Farm) respectively.
In this paper, we study SFCL technologies, device performance and analyze the effects of SFCL devices at different location on power system network.

3. SFCL

The superconducting fault current limiter uses the unique relationship between resistance and temperature in superconductor to limit the current after fault has occurred. The materials like Bi-2222, Bi2223 and YBCO are used as superconductor materials. This materials are perfect conductors of electricity, having zero resistance when they cooled below critical temperature. The primary advantage of the SFCLs is that it offers an optimal solution to the problem of fault current because it automatically limited as the superconductor makes the transition from a superconducting state to a normal state. SFCLs have low impedance in its superconducting state but it increases to a high value during fault[5].

The superconductors discovered in 1911 are called low temperature superconductors as they need to be cooled to the temperature of liquid Helium to have zero resistance. The SFCLs discovered in late 1980s are called high temperature superconductors, which has wide range of applications for power systems. The development of the high temperature superconductor enabled the development of the economical fault current limiters. Early ones were designed using low temperature superconductors. They were cooled with liquid helium, a substance very expensive and difficult to handle. The high temperature superconductor operates at high temperature and can cool by liquid Nitrogen, which is less expensive. This increased interest in the High temperature superconductor fault current limiter [5].

SFCL MODEL

Simulink/SimPowerSystem was selected in order to design and implement the SFCL model for both single phase andthree phase systems. The control systems designed inSimulink for the proposed SFCL model can be directlyintegrated with SimPowerSystem models. Fig.1 Simulink model of Single phase SFCL. The resistive type SFCL was modeled considering four fundamental parameters of a resistive type SFCL. These parameters and their selected values are: 1) Transition or response time = 2 msec 2) Minimum impedanc = 0.01Ω & Maximum impedance = 20Ω 3) Triggering current and = 550A 4) Recovery time = 10msec The SFCL working voltage is 22.9kV. The maximum impedance value can be varied from 20 ohms to 27 ohms. The SFCL model developed in Simulink/SimPowerSystem is shown in Figure 2. 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 predefined 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.

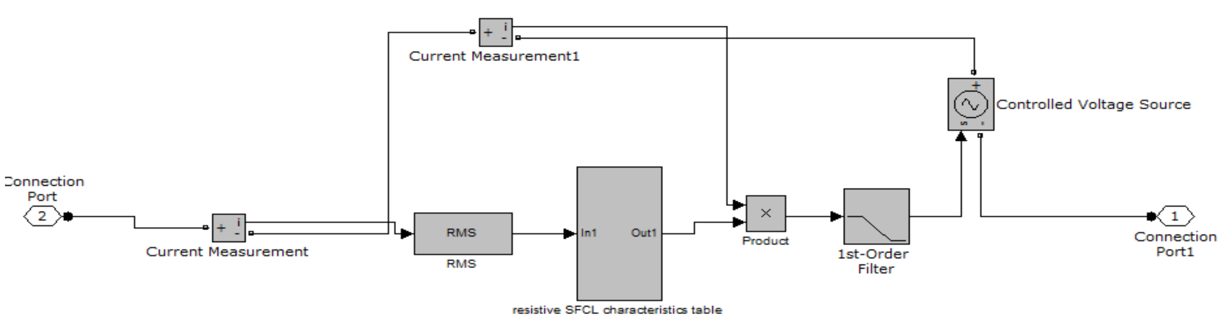

Fig.2: Simulink model of single phase SFCL

4. RESULT

We are place SFCL's module at four different position to find out the excellent performance of the system as shown in figure 1. First, we placed SFCL at location 1 (substation). Second, single SFCL placed at Location 2 (Branch Network). Third, single SFCL placed at Location 3 (Wind farm integration point with the grid). Finally, dual SFCL placed together for different locations, SFCLs were located at Location 1 (Substation) and Location 4 (Wind Farm) respectively.

Four scenarios of SFCL's possible locations were analyzed for three different fault occurring points in the power system depicted in Figure 1.

CASE I: Fault in Distribution Grid(Fault 1)

This distribution grid fault is most frequent fault in the power system. Three phases to ground is applied at distributed grid for 0.4s - 0.44s.

I.I SFCL at substation (Location1)

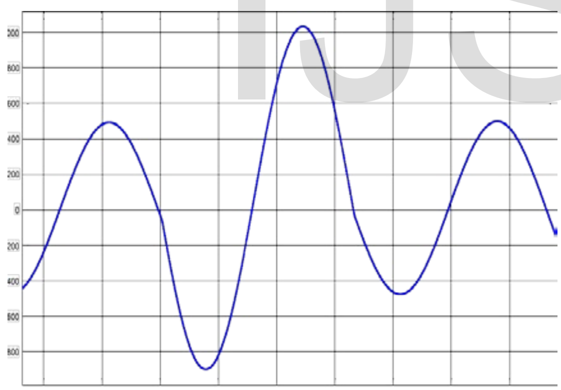

Fig.3: Fault current for location 1 in distribution grid

In the case of SFCL located at Substation (location 1), fault current contribution from the wind farm was increased to 1025 and the magnitude of fault current is higher than 'No FCL' situation shown in figure 3.These observation shows that the placement of SFCL in Location 1, has increased the DG fault current, instead of reducing. This rapid increase of fault current from the wind farm is caused by the abrupt change of power system's impedance.

I.II SFCL at Branch network (Location2)

In the case of SFCL located at Branch network (location 2), fault current contribution from the wind farm was increased to 1025 and the magnitude of fault current is higher than 'No FCL' situation. These observation shows that the placement of SFCL in Location 1, has increased the DG fault current, instead of reducing. This rapid increase of fault current from the wind farm is caused by the abrupt change of power system's impedance similar to case of SFCL at substation.

I.III SFCL at Integration point (Location3)

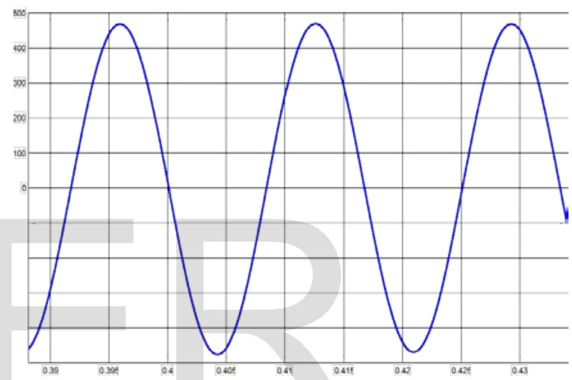

Fig.4: Fault current for location 3 in distribution grid

In the case of SFCL located at Integration point (location 3), the wind farm fault current has been successfully reduced to 450A shown in figure 4.SFCL gives reduction of fault current from wind farm and also reduce the fault current coming from conventional power plant because SFCL located in the direct path of any fault current flowing towards Fault 1.

I.IV Dual SFCL at Substation and at Wind farm (Location4)

With dual SFCL installed at Location 1 and Location 4, 45% reduction in fault current is also observed. However, even though two SFCLs were installed, wind farm fault current reduction is lower than what was achieved by the single SFCL installed at Location 3. From the simulation results, it was known that the installation of two SFCLs

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(Location 1 and Location 4) is economically and technically not feasible.

CASE II: Fault in Customer Grid (Fault 2)

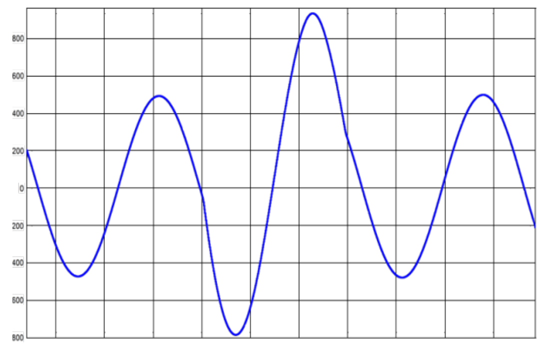

Fig.5: Fault current for location 1 in customer grid

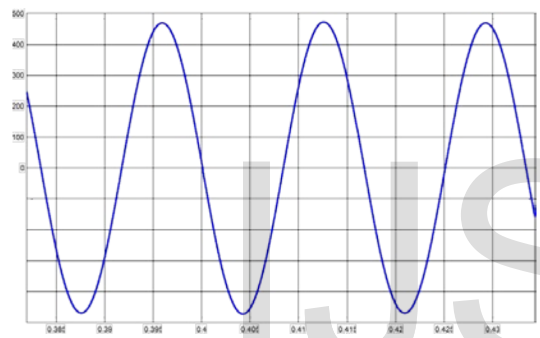

Fig.6: Fault current for location 3 in customer grid

Fault 2 is comparatively a small fault as it occurred in low voltage customer side distribution network. The results obtained are similar to what were observed in the case of distribution grid (Fault 1) as explained in CASE I. Once again the best results are obtained when a single SFCL is located at Location 3, which is the integration point of the wind farm with the Distribution grid.

CASE III: Fault in Transmission Line (Fault 3)

Fault 3 in Figure 1 indicates the rarely occurring transmission line fault which results in very large fault currents.

When a fault in transmission line occurs, fault current from the conventional power plant as well as the wind farm would flow towards fault point. In case of wind farm, fault current would flow in reverse direction through the substation and into the transmission line to fault point. Thus, on the contrary to the previous results obtained in CASE I & II, SFCL positioned at Location 1(Substation) or Location 2 (Branch Network) reduces the wind farm fault current. 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.

5. CONCLUSION

The majority of faults in a power system might occur in the distribution grid. Transmission line fault is not serious problem because it is rarely occurring fault in the system. Thus the Result only for fault 1 and fault 2 shown here.

The optimal location of SFCL is at integration point of two generating sources, for both distribution and customer grid faults. This location of SFCL in a power grid wich 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 for both distribution and customer grid faults. Even though multiple SFCLs in micro grid can reduce the wind farm current due to faults but dual SFCL‟s are inefficient both in performance and cost.

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