Selection of Optimal Positioning of Superconducting Fault Current Limiter (SFCL) in Smart Grid Application

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Abstract - The devices in electronics and electrical circuits are sensitive to disturbance and any disturbance or fault may damage the device permanently so that it must be replaced. The cost of equipment like circuit breakers and transformers in power grids is very expensive. Moreover, replacing damaged equipment is a time and labour consuming process, which also affects the reliability of power systems. It is not possible completely eliminate the faults but it is possible to limit the current during fault in order to save the equipment and devices in the circuits or systems. Superconducting Fault Current Limiter (SFCL) is optimal equipment which has the capability to reduce fault current level in power system. The application of superconducting fault current limiters (SFCL) for smart grid is reduction of abnormal fault current and the suitable location in the micro grids. In this work, a resistive type SFCL model was proposed using Simulink tool. 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.

Keywords - Fault current, micro grid, smart grid, superconducting fault current limiter, wind farm.

I. INTRODUCTION

In recent year, electrical energy is the most versatile and universally available. Electricity is available every field like homes, industry, businesses, and transportation. With increase in this, consumption of electrical energy is increased. As a result there is increase in the generating station and the interconnected networks called power grids. Due to increase in the grids and generating this also increases the possibility of abnormal operation in the system. There may be sudden decreases in the impedance of the power systems network, which lead to an increase in current, known as fault current.

Often generating stations are located far away from urban areas and the electrical energy is transmitted from generating station through long overhead transmission lines. These transmission lines are naked and exposed to the atmosphere. Wind may blow down electric poles and ground the wires or lightning may cause severe faults in the system resulting in the flow of large fault currents in the system which can damage the equipment installed at the power grids and generating station. The increase in the electrical energy consumption necessitates a large power system, resulting in considerable increase in the system fault levels. These large fault current generate large mechanical forces which endanger the mechanical integrity of the power system hardware, transformers and other equipment may overheat. As the equipment in the power networks is very expensive, their protection from large fault current is needed. The reliability of the power systems is the most important factor for their efficient operation. It is not possible to completely eliminate the faults in the system but it is possible to lower the harmful effects of the fault on the systems by decreasing the current during fault.

The electrical and electronic industry flourishing 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 needed to limit to a lower value. Hence for solving the problem of fault current in the power system using superconducting fault current limiter (SFCL) is the important work presented here. In this paper, the effect of SFCL and its position was investigated considering power system model integrated with wind farm [3].

II. POWER SYSTEM MODEL

The power system with fault current limiter located at different position shown in figure 1. In figure 1 different artificial fault are indicated at different position and SFCL are installed at different position. 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) [3].

The power system is composed of a 100 MVA, 20KV conventional power plant, connected by 200 km long 154 KV distributed parameters transmission line [2] 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 farm 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.

III. SFCL

FCLs utilizing superconducting materials which are capable of providing instantaneous (sub cycle) current limitation abilities, can prevent the buildup of fault currents and have been studied for years. In particular, a superconducting fault current limiter (SFCL) will be operating in a superconducting state and is basically invisible to the power grid because no major energy loss and voltage drop will be developed across the device during normal operation. In the event of a fault, the SFCL will produce a certain value of impedance within a few milliseconds due to the loss of superconductivity, and insert it into the circuit, thus reducing the fault currents to levels that circuit breakers can handle. Being a promising application of superconductors, the SFCL is considered to be one of the innovative devices of FACTS in electric power systems.

The application of the SFCL would not only decrease the stresses on the devices but also offer a higher interconnection to secure the network. This is a very effective means to enhance the system stability and power quality in terms of availability and voltage drop, which is a real need today. Several types of SFCL have been considered which are based on different superconducting materials and designs. From the point of view of power systems, the resistive SFCL is preferable because it increases the decay speed of the fault current by reducing the time constant of the decay component of the fault currents, and can also make system less inductive.
R-SFCL

SFCLs utilize the superconducting material as the main current carrying conductor under normal grid operation. The principle of their operation is to suppress the fault current within the first cycle of fault current [1]. It consists of a shunt resistor and variable resistor. The current passing through the shunt resistor is denoted as Ishunt. At present, for HTS materials, the convention is to define “critical current” as the current at which a voltage drop of 1.0iV/cm is observed along the conductor. An R-SFCL directly exploits the transition from superconducting to normal state that a material exhibits when the transport current exceeds the critical value [1].

3.1. Simulation Model of SFCL

The SFCL model developed in Simulink/SimPower System is shown in Figure. The parameters for the R-SFCL model and their selected values are: 1) Transition or response time = 2msec 2) Minimum impedance = 0.01Ω. Maximum impedance = 20Ω 3) Triggering current = 550A and 4) Recovery time = 10msec. The SFCL working voltage is 22.9kV. The Simulink model was composed of four major parts: 1. RMS value 2. Characteristic table of SFCL 3. Harmonic Filtration 4. Voltage controlled oscillator (VCO) [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, SFCLs 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. The SFCL characteristic table shown in Figure 2 plays a main role which consists of standard parameter values of SFCL. The current limiting resistance value is calculated and this value is implemented in the simulation model. The important parameter to be given in SFCL is the current limiting resistance value. It is stored in the SFCL characteristic table. In order to avoid harmonics caused by transients, filter is used.

IV. RESULTS AND ANALYSIS

The power system in Figure 1 is studied by considering a wind farm integrated with distribution grid. The fault current reduction depends on the location of SFCL. Four SFCLs possible locations were analyzed for three different fault occurring points in the power system depicted in Figure 1. First, we assumed that single SFCL was located at Location1 (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 (Substation) and Location 4 (Wind Farm) respectively.

4.1 Fault in Distribution Grid

Figure 3 shows a comparison between fault current from the wind farm (measured at output of TR3 in Figure 1) for different SFCL locations in the case when a three-phase-to-ground fault was initiated in the distribution grid (Fault 1 in Figure 1).

In the case of SFCL located at Location 1 (Substation) or Location 2 (Branch Network), fault current contribution from the wind farm was decreased and the magnitude of fault current is 27 % decreased for location 1 and 40 % decreased for location 2. These critical observations imply that the installation of SFCL in Location 1 and Location 2, has decreased the DG fault current. 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, wind farm which is the 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 grid, marked as Location 3 in Figure 1, the wind farm fault current has been successfully reduced. SFCL gives 70% 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.

### 4.2 Fault in Customer Grid

Figure 4 shows a comparison between fault current from the wind farm (measured at output of TR3 in Figure 1) 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).

![Fig 4: DG fault currents in case of fault in customer grid](image)

Fault 2 is comparatively a small fault as it occurred in low voltage customer side distribution network. In the case of SFCL located at Location 1 (Substation) or Location 2 (Branch Network), fault current contribution from the wind farm same as NO SFCL for location 1 and for location 2 was decreased and the magnitude of fault current is 5% decreased. These critical observations imply that the installation of SFCL in Location 2 has decreased the DG fault current. The SFCL at these locations (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, wind farm which is the 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 grid, marked as Location 3 in Figure 1, the wind farm fault current has been successfully reduced. SFCL gives 75% 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. 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.

### 4.3 Fault in Transmission Line

Fault 3 in Figure 1 indicates the rarely occurring transmission line fault which results in very large fault currents. Figure 5 shows a comparison between fault current from the wind farm (measured at output of TR3 in Figure 5) for different SFCL locations in the case when a three-phase-to-ground fault was initiated in the transmission line (Fault 3 in Figure 5).

When a fault in transmission line occurs, fault current for location 1, location 2 and location 3 is same as NO SFCL condition. For this case there is no increased or decreased of current.

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 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. The performance of SFCL at this location was even better than dual SFCL located at Location 1 and Location 4 at a time. Thus, multiple SFCLs in a micro grid are not only costly but also less efficient than strategically located single SFCL. Moreover, at Location 3, fault current coming from the conventional power plant was also successfully limited. Reduction in wind farm fault current for various SFCL locations were summarized in Table 1.
Table 1 Percentage change in Wind Farm Fault Current due to SFCL locations

<table>
<thead>
<tr>
<th>SFCL Locations</th>
<th>Fault 1 Distribution Grid</th>
<th>Fault 2 Customer Grid</th>
<th>Fault 3 Transmission Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>27% Decreased</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Location 2</td>
<td>46% Decreased</td>
<td>9% Decrease</td>
<td>-</td>
</tr>
<tr>
<td>Location 3</td>
<td>3% Decreased</td>
<td>5% Decreased</td>
<td>-</td>
</tr>
</tbody>
</table>

V. CONCLUSION

This project presented a feasibility analysis of positioning of the SFCL in rapidly changing modern power grid. A complete power system along with a micro grid (having a wind farm connected with 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 of the grid. It has been observed that SFCL should not be installed directly at the substation or the branch network feeder. This placement of SFCL results in abnormal fault current contribution from the wind farm. Also multiple SFCLs in micro grid are inefficient both in performance and cost. The strategic 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.

VI. REFERENCES


