Location of Superconducting Fault Current Limiters for the Smart Grid with 30 MVA wind farm

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Abstract: A smart grid delivers electricity from suppliers to consumers using two-way digital technology to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency. It improves the power quality of the grid. A fault current limiter is used to superconductors to instantaneously limit or reduce unanticipated electrical surges that may occur on utility distribution and transmission networks. One of the most important application of superconducting fault current limiters (SFCL) for upcoming smart grid is related to its possible effect on the reduction of abnormal fault current and the suitable location in the micro grids. Due to the grid connection of the micro grids with the current power grids, excessive fault current is a serious problem to be solved for successful implementation of micro grids. Superconducting fault current limiter (SFCL) is innovative electric equipment which has the capability to reduce fault current level within the first cycle of fault current. The first-cycle suppression of fault current by a SFCL results in an increased transient stability of the power system carrying higher power with greater stability. Four scenarios of SFCL's possible locations were analyzed for three different fault occurring points in the power system has been discussed. Here 10 MVA wind farm was considered for the simulation. In this proposed scheme we are considering 30 MVA wind-farms and it is comparing with the 10 MVA Wind farm. 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 and voltage is evaluated.

Keywords: Fault current, micro grid, smart grid, superconducting fault current limiter, wind farm(10 MVA&30 MVA).

I. INTRODUCTION

Conventional protection devices installed for protection of excessive fault current in electric power systems, especially at the high voltage substation level, are the circuit breakers tripped by over-current protection relay which has a response-time delay that allows initial two or three fault current cycles to pass through before getting activated. But, superconducting fault current limiter (SFCL) is innovative electric equipment which has the capability to reduce fault current level within the first cycle of fault current. The first-cycle suppression of fault current by a SFCL results in an increased transient stability of the power system carrying higher power with greater stability. A smart grid delivers electricity from suppliers to consumers using two-way digital technology to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency. The existing transmission and distribution systems use techniques and strategies that are old and there is limited use of digital communication and control technology. To achieve improved, reliable and economical power delivery information flow and secure integrated communication is proposed.

The Smart Grid with intelligent functions is expected to provide self-correction, reconfiguration and restoration, and able to handle randomness of loads and market participants in real time, while creating more complex interaction behavior with intelligent devices, communication protocols, standard and smart algorithms to achieve complex interaction with smart communication and transportation systems. One of the key elements of the smart grid is decentralization of the power grid network into smaller grids, which are known as micro grids, having distributed generation sources (DG) connected with them. These micro grids may or may not be connected with conventional power grid, but the need to integrate various kinds of DGs and loads with safety should be satisfied. However, newly emerging problems due to these integrations are also of severe nature and needs to be taken care of. Two major challenges expected by direct connection of DGs with the power grid are the excessive increase in fault current and the islanding issue which is caused when, despite a fault in the power grid, DG keeps on providing power to fault-state network.

Up to now, there were some research activities discussing the fault current issues of smart grid. But the applicability of a SFCL into micro grid was not found yet. Hence, solving the problem of increasing fault current in micro grids by using SFCL technology is the main concern of this work. 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. As for a dispersed energy resource, 10 MVA wind farm was considered for the simulation. In this we are considering 30 MVA wind farm and comparing with the 10 MVA. 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 and voltage is evaluated.

II. SUPERCONDUCTING FAULT CURRENT LIMITERS (SFCL)

SFCL is a new power device to automatically limit a fault current to a safe level with the superconducting property. When superconductor is cooled down temperature (about -186℃) or less, the resistance becomes zero. However, superconductor looses superconductivity and resistance occurs rapidly (quench), when excessive current flows and exceeds certain value (critical current). SFCL device uses this property to critical. A variety of FCL technologies that utilize unique and novel approaches for limiting the magnitude of fault currents are now in the prototype stage of development and, if successful, will soon be ready for grid deployment. The focus is on superconducting technologies, but several FCLs based on other technologies are described for completeness. Basically there are three configurations of superconductor based fault current limiting devices. In each case the superconductor element is placed parallel with the impedance element. The three types of devices based on the superconductor element are superconductive shunt with a resistive bypass element, superconducting shunt with an inductive bypass element and transformer coupled superconductor shunt.

A. Superconductive shunt with a resistive bypass element

The superconductive shunt with resistive bypass is shown in figure1. In this case the bypass element limits the current during fault. The fault current is limited when it is more than the critical current of the superconductor element and it operates in high resistance state which limits the fault current. Superconductor material of high resistivity in its non-superconductor state is preferred as it will limit the current during fault. During normal operation the R2 is zero and when there is fault, resistance R2 becomes very high which limits the current during fault. The resistance R is the bypass resistance. During fault the fault current is transferred from resistance R2 to R.

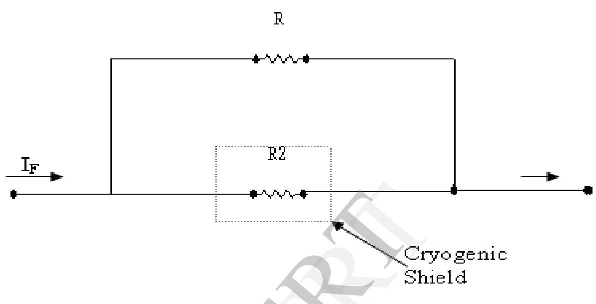

Fig 1: Superconductor Fault Current Limiter, Resistive Shunt type

An external source or magnetic field is needed to bring the superconductor into its off-state. The superconducting device takes a long time to recover from its fault current limiting properties as the coolant must be cooled back to its pre fault temperature. The main disadvantage of this approach is the cost as well as the reliability of the cooling system for the superconductor, as it has to be cooled to the temperature of helium and the cooling system requires maintenance from time to time.

B. Superconductor FCL with an inductive by pass element.

Figure 2. shows the circuit for a superconductor FCL with inductive bypass element. The trigger coil is wrapped over the other coil with low inductance design. During normal operation the current is very low and the superconductor element remains in superconductor state and the voltage drop is also very low.

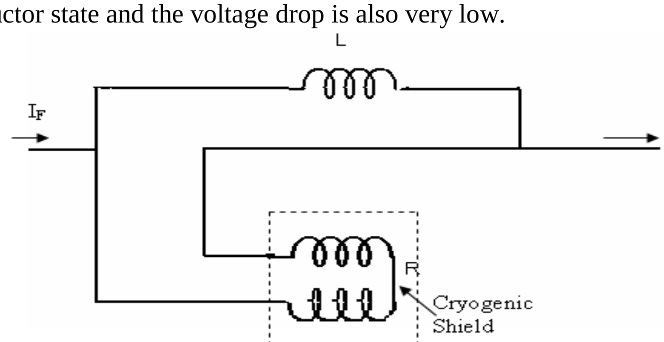

Fig2: Superconductor FCL with inductive bypass element

During fault large amount of fault current is transferred to the bypass element. The ratio of the bypass coil impedance and the non superconducting element impedance determine the current level in the trigger coil during the fault.

C. Transformer coupled superconductor FCL

Figure 3. Shows the transformer coupled superconductor FCL. During normal operation there is no interaction of the field due to current within the interior of the inner coil. Due to very small air gap between the inner and the outer coil, results in a low inductance design. During fault the current becomes greater than the critical current of the superconductor

FCL, the effective inductance increases to a high value because the flux links with the centre of coil. During fault the current is transferred to the bypass element and due to high impedance the fault current is limited.

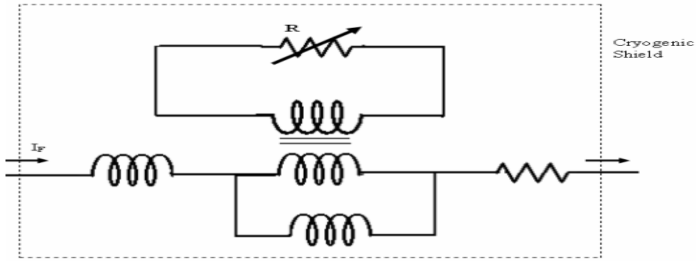

Fig 3: Transformer coupled Superconductor FCL

III. CIRCUIT DIAGRAM OF A GRID CONNECTED SYSTEM WITH SFCL

Figure 4.shows a complete smart grid power net work including generation, transmission, and distribution with an integrated wind farm model. Smart grid is a term used for future power grid which integrates the modern communication technology and renewable energy resources for the 21 st century power grid in order to supply electric power which is cleaner, reliable, It is responsive than conventional power systems. Smart grid is based on the principle of decentralization of the power grid network into smaller grids (micro grids) having distributed generation sources(DO) connected with them, One critical problem due to these integrations is excessive increase in fault current due to the presence of DO within a micro grid, 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 .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. SFCL achieves this function by losing its superconductivity and generating impedance in the circuit.

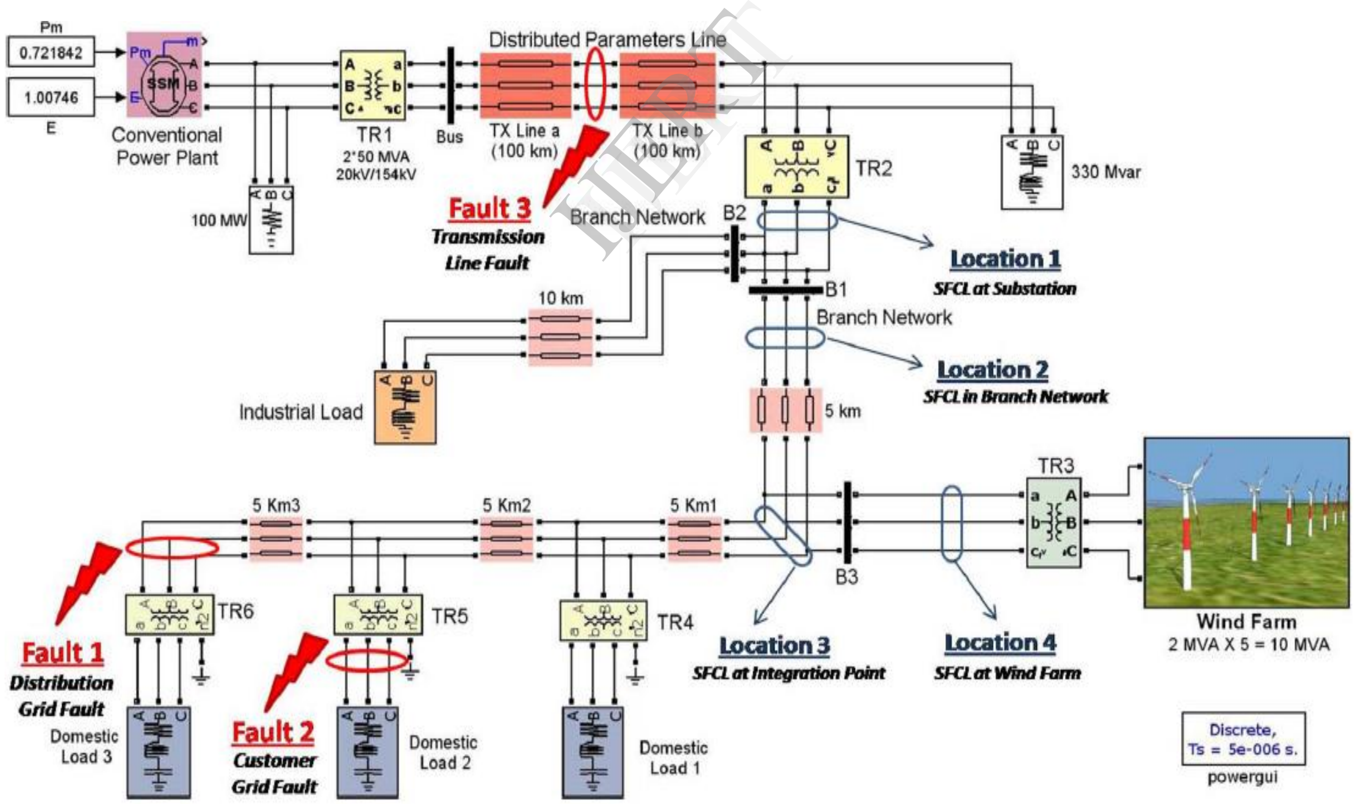

Fig 4:power system model designed in simulink fault are indicated in the diagram

SFCL does not only suppress the amplitudes of fault currents but also enhance the transient stability of power system .Up to now, there were some research activities discussing the fault current issues of smart grid .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 the most effective way to limit the fault current and results inconsiderable saving from not having to utilize high capacity circuit breakers.

SFCL for upcoming smart grid is related to its possible effect on the reduction of abnormal fault current and the suitable location in the micro grid. Due to the grid connection of the micro grids with the current power grid excessive fault current is a serious problem to be solved for the successive implementation of the microgrids.sfl model is easily utilized for determining for an impedance level of SFCL according to the grid FCL requirements of various kinds of the smart grid system.

B. Resistive SFCL Model

The three phase resistive type SFCL was modeled considering Three fundamental parameters of a resistive type SFCL [9].

These parameters and their selected values are: 1) transition or response time = 2 msec, 2) minimum impedance = 0.01 Ohms and maximum impedance = 20 Ohms, 3) triggering current = 550 A and 4) recovery time = 10 msec. Its working voltage is 22.9 kV.

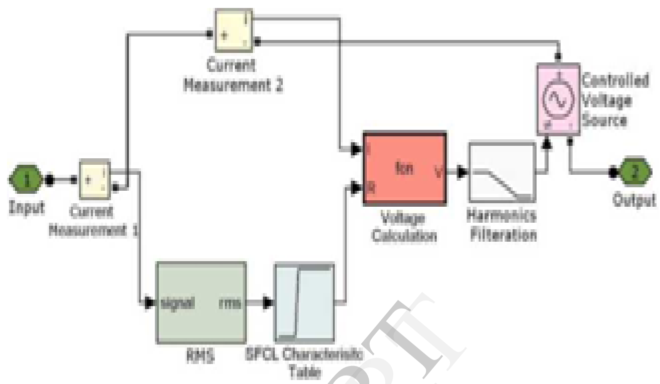

Fig 5:Single phase SFCL model developed in simulink/sim power system

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. 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.

IV. RESULTS AND DISCUSSION

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

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. These critical observations imply that the installation of SFCL in Location 1 and Location 2, instead of reducing, has increased the DG fault current. This sudden increase 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, 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 Fig. 4, the wind farm fault current has been successfully reduced. SFCL gives more 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. With dual SFCL installed at Location 1 and Location 4, reduction in fault current is also observed. However, even though two SFCLs were installed, wind farm fault current reduction is lower than what is achieved by the single SFCL installed at location 3.From the simulation results ,it was known that the installation of two SFCLs (location 1 and location 4) is economically and technically feasible. Fig 3 shows Simulation Circuit Of A Grid Connected System With SFCL Location In Case Of Distribution Grid (Fault1).

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figure 7, 8,9 and 10 shows the simulation results of wind farm current and voltages SFCL location in case of distribution grid feasible 1 at 10 MVA wind farm . figure 11,12,13,and 14 shows the simulation results of wind farm current and voltages SFCL location in case of distribution grid feasible 1 at 30 MVA at wind farm. From the comparisons table 1 it clearly shows that the axis of the wind farm is changed then automatically voltage is changed i.e. increased. . At location 3 the wind farm fault current has been reduced.

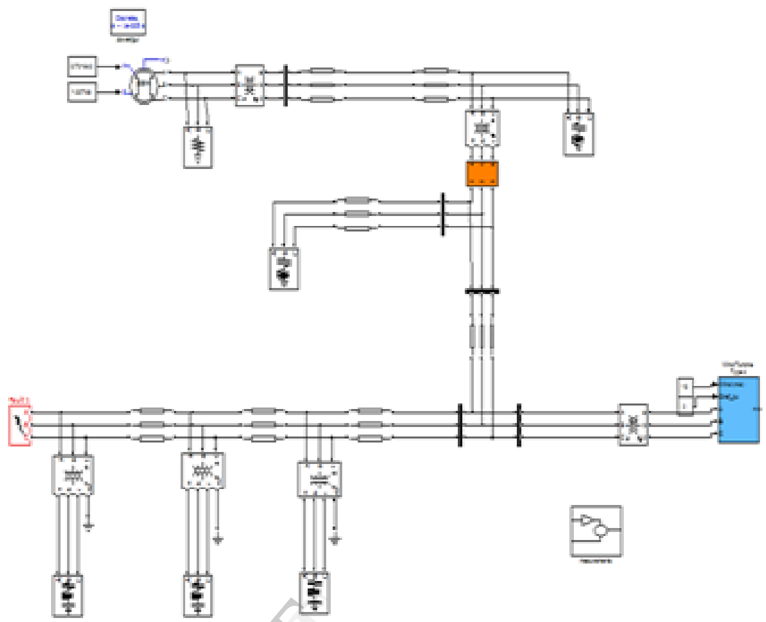

Fig 6: Simulation Circuit Of A Grid Connected System With SFCL Location In Case Of Distribution Grid (Fault1)

A. Wind Farm Rating At 10MVA Voltage & Current Waveforms

Wind farm (2*5=10MVA)

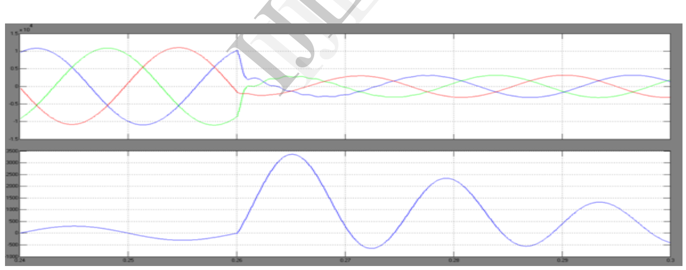

Fig 7: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault1) feasible 1 location 1 with wind farm rating (2*5=10MVA)

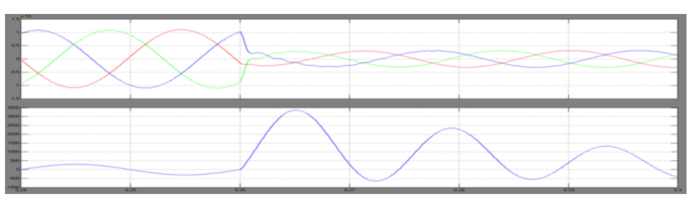

Fig 8: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 2 with wind farm rating (2*5=10MVA)

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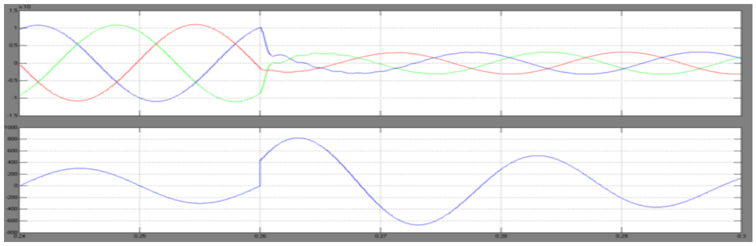

Fig 9: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 3 with wind farm rating (2*5=10MVA)

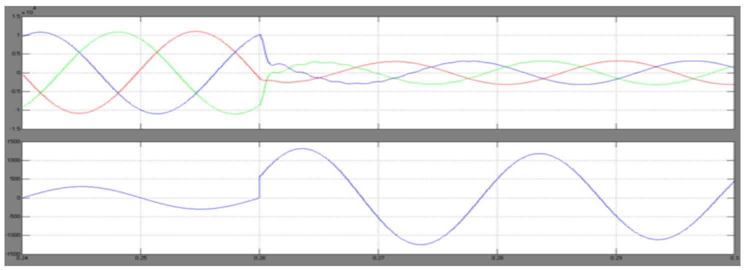

Fig 10: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 1&4 with wind farm rating (2*5=10MVA)

B. Wind Farm Rating At 30 MVA Voltage & Current Waveforms
Wind farm (6*5=30 MVA)

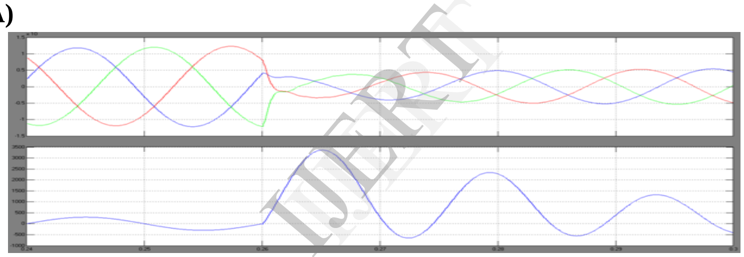

Fig 11 : Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 1 with wind farm rating (6*5)=30MVA

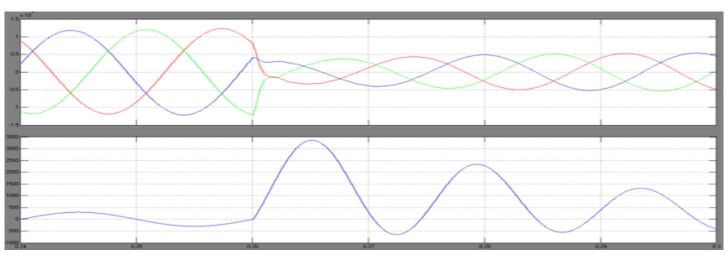

Fig 12: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 2 with wind farm rating (6*5)=30MVA

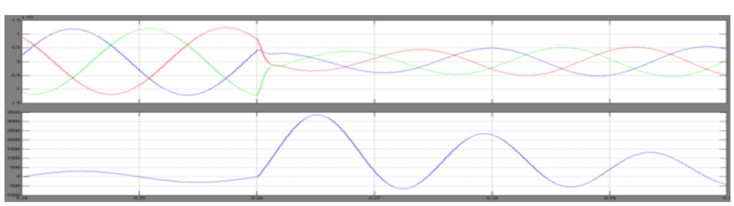

Fig 13: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 3 with wind farm rating (6*5)=30MVA

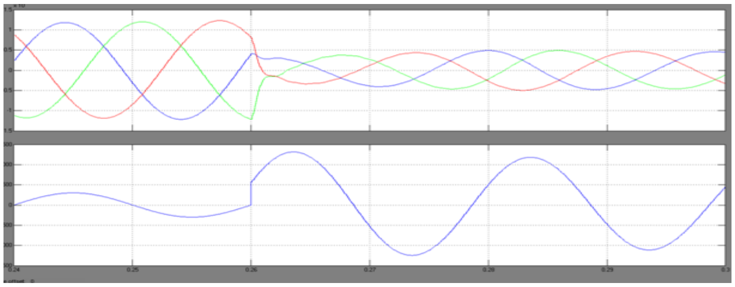

Fig 14: Simulation result of wind farm fault current and voltages SFCL location in case of distribution grid (fault 1) feasible 1 location 1&4 with wind farm rating (6*5)=30MVA

Table 1:Comparison of wind farm current and voltages at fault 1(Distribution grid)s at Wind farm 10&30 MVA

WIND FARM(2*5=10MVA) AT FAULT 1(DISTRIBUTION GRID)						
S.No	**SFCL location**	**Wind turbine axes**	**Wind turbine rating (MVA)**	**Wind farm fault current (A)**	**fault voltage (KV)**	**Steady state Fault current (A)**
1	Location 1	5	2	3450	7	1450
2	Location 2	5	2	3451	8	1550
3	Location 3	5	2	810	6	400
4	Location1&4	5	2	1251	7	1600
WIND FARM(1.66*6=10MVA)						
1	Location 1	6	1.66	3450	6.5	1450
2	Location 2	6	1.66	3451	7	1550
3	Location 3	6	1.66	810	6.5	450
4	Location1&4	6	1.66	1251	5	1600
WIND FARM(1.43*7=10MVA)						
1	Location 1	7	1.43	3450	4.5	1450
2	Location 2	7	1.43	3451	4	1550
3	Location 3	7	1.43	810	5	450
4	Location1&4	7	1.43	1251	5.4	1600
WIND FARM(5*6=30MVA) AT FAULT 1 DISTRIBUTION GRID)						
S.No	**SFCL location**	**Wind turbine axes**	**Wind turbine rating (MVA)**	**Wind farm fault current (A)**	**fault voltage (kv)**	**Steady state Fault current (A)**
1	Location 1	5	6	3450	9	1550
2	Location 2	5	6	3451	10	1560
3	Location 3	5	6	810	3	450

4	Location1&4	5	6	1251	9	1600
WIND FARM(6*5=30MVA)						
1	Location 1	6	5	3450	10	1450
2	Location 2	6	5	3451	11	1550
3	Location 3	6	5	810	5	450
4	Location1&4	6	5	1251	9	1600
WIND FARM(4.33*7=30MVA)						
1	Location 1	7	4.3	3450	10	1450
2	Location 2	7	4.3	3451	11	1550
3	Location 3	7	4.3	810	3	450
4	Location1&4	7	4.3	1251	9	1600

The fault occurs on distributed grid, the above table has been discussed the fault voltage, wind farm fault current and steady state fault current variations according to the SFCL placed at different locations. the table 1 discussion has been done for the 10MVA & 30 MVA with different wind axis and rating. From the above comparisons it clearly shows that the axis of the wind farm is changed then automatically voltage is changed i.e. increased. At location 3 the wind farm fault current has been successfully reduced. Similarly in case of customer grid and transmission line .

V. CONCLUSIONS

This paper mainly concentrates on feasibility analysis of positioning of the SFCL in rapidly changing modern power grid. The proposed topology SFCL is used to limit the fault current that occurs in power system. In this single phase resistive type SFCL is used. As for a dispersed energy source, in the proposed system 30 MVA wind farm with three units connected and the system is simulated wind farm current and voltage is calculated and it is comparing with 10 MVA wind farm. 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. Six wind farms were considered and their performance is also evaluated. Because of SFCL no negative effect on the DG source is the point of integration of the wind farm with the power grid. The simulation model of a grid connected system with SFCL is shown in this. The simulation results of the wind farm fault current of SFCL location in case of fault in distribution grid (Fault 1) with different locations at wind farm rating 10 MVA & 30 MVA has been discussed here. Compared to location 1 fault current is more. on location 3 fault current is 68% is decreased. Here we are clearly shows that the axis of the wind farm is changed then automatically voltage is changed i.e. increased. At location 3 the wind farm fault current has been successfully reduced. 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 later for the transmission line faults (Fault 3). 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. From this we can conclude that Superconducting fault current limiter (SFCL) is innovative electric equipment which has the capability to reduce fault current level within the first cycle of fault current. The first-cycle suppression of fault current by a SFCL results in an increased transient stability of the power system carrying higher power with greater stability.

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