Analysis of Optimal Location of Superconducting Fault current limiters in Transmission Network

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***Abstract*—**In an endeavor to avert harm existing power system apparatus and to diminish customer downtime, protection engineers and utility planners have enlarged intricate schemes to perceive fault currents and trigger segregation devices that interrupt the over-current adequately briskly to evade spoil to parts of power grid. Fault current limiters (FCLs) with capability of hastily increasing their impedance, and thus limiting high fault currents are being expanded. In this study, an application of superconducting fault current limiter (SFCL) is conversed to limit the fault current that happens in power system.

The exploitation of fault current limiters (FCLs) in power arrangement affording an effective way to suppress fault currents and results in substantial saving in the speculation of high capacity circuit breakers. In this work, a feasibility analysis of positioning of a superconducting fault current limiter in a power system has been presented.

Keywords*—Distributed generations, protection methods, Current limiters, SFCL, MFCL etc.*

I. INTRODUCTION

In smart grid, transmission and distribution infrastructure should handle potential bi-direction energy gushes, permitting for distributed generation such as wind turbines, photovoltaic (PV) farms and other power resources. However, one critical dilemma of these incorporations is the unnecessary amplification in a fault current due to the existence of distributed generation within a smart grid By the manifold courses from power plant to conventional grid, AC and DC micro-grid, the unwarranted fault current in one micro-grid could impinge on the neighbouring micro-grid and it could be able to cause a domino effect which guides a blackout concluding stage. Therefore, smart power mechanisms which could defend smart grid from the increasing fault current are entailed for the reliability and the safety of power systems

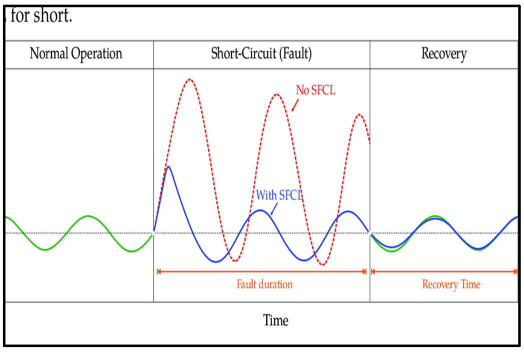

Fig.1. Characteristics of Fault Current Limiters into three operating modes

Superconducting fault current limiters (SFCLs) exploits superconducting substances to limit the current unswervingly or to supply a DC bias current that influences the level of magnetization of saturated iron core. These appliances have the pledges of controlling fault currents to levels where conventional protection equipment can operate safely. A significant advantage of proposed FCL technologies is the ability to remain virtually invisible to the grid under nominal operation, introducing negligible impedance in the power system until a fault event occurs. Ideally, once the limiting action is no longer needed, an FCL quickly returns to its nominal low impedance state.

II. BASICS OF SFCL

The SFCL is symbolized by a High Temperature Superconductor element revealed as variable resistance in parallel with reactor. Under normal functioning circumstances, peak of the AC current level of the power transmission network is always below the critical current level of the superconductor, therefore there is essentially not voltage drop across the device and there are no I^2R losses.

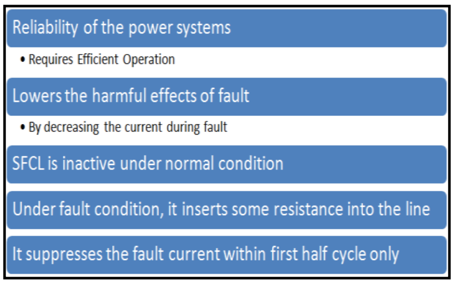

Fig-2 Basic of SFCL operation

For the grid, the device virtually doesn't exist unless fault comes in picture.

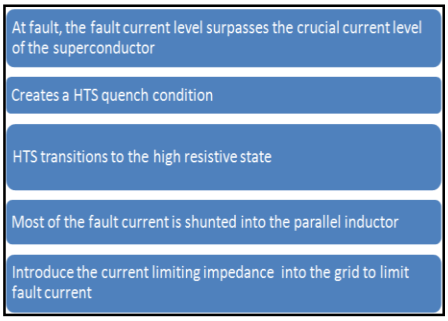

Fig-3 SFCL operation

The relevance of superconducting fault current limiters in the utility network requires new integration issues to be addressed. As these apparatus comes closer to business reality, these matters are being mulled over by various industries.

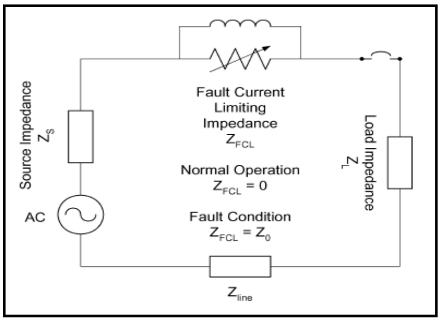

Fig.4. Equivalent circuit of SFCL in a power system

The characteristic of the SFCL impedance materializing only during fault must be considered in the execution of protective relay designs. The enlargement of testing standards and formulas, it is to regard the erratic impedance nature of the device. During the fault, the HTS material heats up and must cool back down to return to a superconducting state before the apparatus is imperceptible to the system again. Parameters effecting cool down period is shown below.

In some applications, the SFCL device will not be carrying any current during the recovery, which will result in the fastest recovery period. In some applications, the apparatus will have to bear nominal load current throughout the recovery, which will provide some constant level of background heat generation in the device that will lengthen the recovery period.

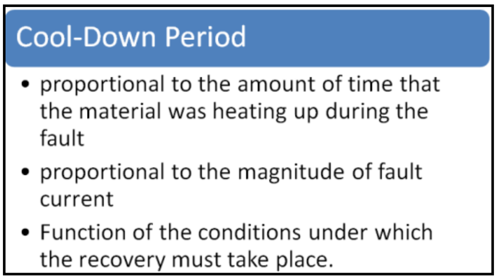

Fig.5- Factors effecting cool down period

III. SIMULATION DETAILS

The 3-phase resistive type SFCL was reproduced by chewing over the following fundamental parameters:

- *Transition time*
- *Minimum impedance*
- *Maximum impedance*
- *Triggering current*
- *Recovery time*

Its working voltage is 22.9 kV

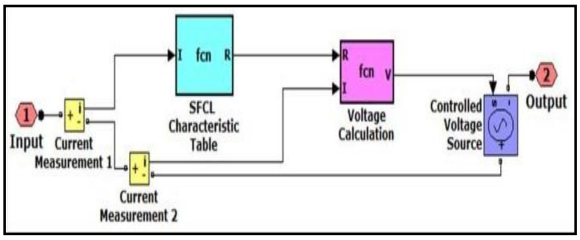

Fig 6a- DC-SFCL model in Simulink

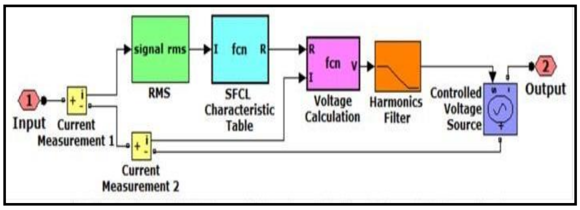

Fig 6b- AC-SFCL model in Simulink

TABLE I: AC/DC-SFCL Model Parameters

Sr.	SFCL Parameters	AC SFCL	DC SFCL
1	Transition/Response Time	2msec	2msec
2	Minimum Impedance	0.01Ohm	0.01Ohm
3	Maximum Impedance	20Ohms	10Ohms
4	Triggering Current	550Amps	1400Amps

SFCL model computes the RMS value of the passing current and subsequently weigh against it with the characteristic table. If outgoing current is outsized than the triggering current level, SFCL's resistance augments to greatest impedance level in a pre-defined response time. When the current level falls below the triggering current level, the system lingers until the recovery time and then goes into normal state.

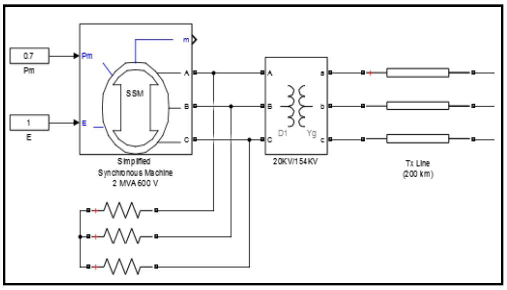

Fig 7a- 3-phase Synchronous machine

The power line modelled in Simulink to imitate the complete power system composed of normal power plant, composed of 3-phase synchronous machine, connected with 200 km long rated at supply voltage of 154kV, through a step-up transformer. Further ahead, the voltage is levelled down to 22.9 kV. Industrial load of 6 MW and domestic loads 1 MW each are being supplied by split distribution branches.

Sr.No.	Parameters	Value
1	Mechanical Input power	0.7pu
2	Rated Power	2MVA
3	Rated Voltage	600V
4	Generator Connection	Y
5	Frequency	50
6	No.of Pole Pairs	2
7	Internal Resistance	0.0036pu
8	Internal Reactance	0.16pu

Fig 7b- 3-phase Synchronous machine parameters

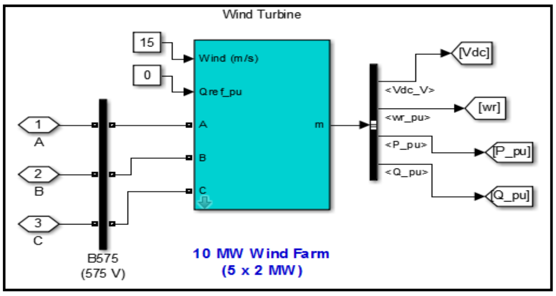

Fig 8a- Wind power generator system

The micro-grid system is simultaneously supported by wind farm, which is directly connected with the network through transformer powering the domestic loads. It is rated at 10 MVA, and composed of five fixed-speed induction-type wind turbines rated at 2 MVA each.

S. No	Parameters	Value
1	No. Of Wind Turbines	5
2	Rated Power	2 MVA
3	Rated Voltage	480 V
4	Grid-side Converter Voltage	575V
5	Max. Grid-side Converter Current	1.1pu
6	Grid side coupling inductor	0.15pu
7	Line Filter Capacitor	150kVAR
8	Nominal DC side voltage	1100V
9	DC bus capacitance	0.9 F

Fig 8b- Wind power generator parameters

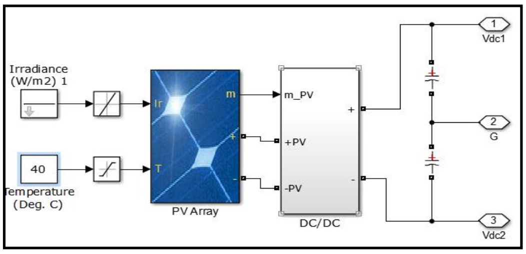

Fig 9a- Solar PV system

S. No	Parameters	Value
1	No. Of Parallel Strings	67
2	Series Modules per String	24
3	Cells per module	96
4.	Maximum Power	315.072 W
5	Open Circuit Voltage	64.6 V
6	Short Circuit Current	6.14 A
7	Voltage at Max. Power point	54.7V
8	Current at Max. Power point	5.76A
9	Light generated current	6.1461A
10	Diode saturation current	6.504pA

Fig 9b- Solar PV system parameters

The microgrid is also strengthened at the DC side of the grid with the power generated by a Solar PV system having a capacity of 500Kw at 1.5Kv voltage level. The power is connected at DC bus which directly serves the four domestic load connected in the grid, which are placed at a distance of 10km from each other. The loads are connected to DC grid through a converter arrangement.

IV. RESULTS AND DISCUSSION

The system designed is tested under 3-phase fault condition with SFCL's positioned in various configurations. We will discuss the cases one by one.

a) Case 1- 3 phase AC bus fault near Wind Farm and impact of AC-SFCL in AC microgrid

Fig. 10 shows the comparison of fault currents for different arrangements measured at the output of wind farm. When SFCLs were installed in Arrangement 1, 2 and 3, the magnitude of fault currents was increased than that of No SFCL condition. This observation implies that SFCLs in Arrangement 1, 2 and 3 has no effect to reduce the fault current supplied from a wind farm. SFCLs installed in Arrangement 4 and 5 have shown the best fault current limiting performance because they are located in the direct path of the fault current occurred in AC microgrid.

It can be easily seen that in the absence of an effective fault current limiter, the fault current values are touching extremely high values.

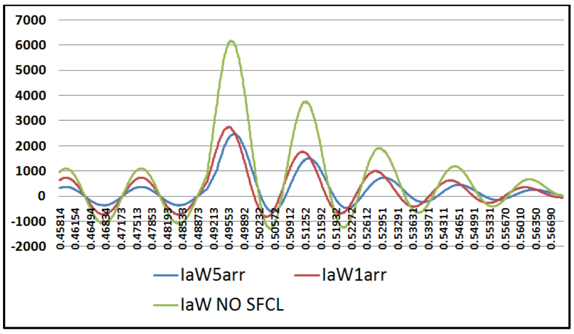

Fig. 10a-Comparison of the wind farm fault currents for different SFCL locations in case of fault in AC microgrid

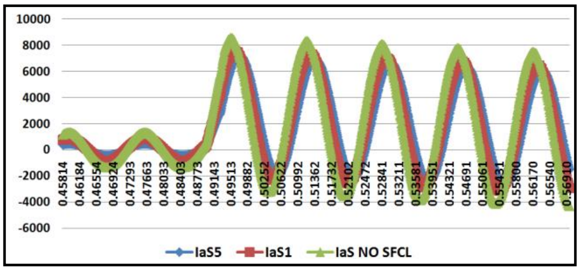

Fig.10b-Comparison of the substation transformer fault currents for different SFCL locations in case of fault in AC microgrid

If we compare the corresponding graphs, it can be seen that the peak current value at 3500A at a time duration of 0.5sec, whereas the maximum peak value of current in case of SFCL is 2500A. The comparative between substation transformer fault current shows that in grid without AC-SFCL, the fault current in transformer peaks to 7000 A, whereas with AC-SFCL the fault current peak goes down to 1800 A. If the same comparison is done in DC grid, it can be seen that effect of fault in AC side can affect current in DC side also.

b) Fault Current at the Output of Photovoltaic Farm When a Fault occurred In DC Microgrid:

Fig.11 shows the comparison of fault currents for different arrangements measured at the output of photovoltaic farm. When SFCLs were installed in Arrangement 1, 2 and 3, there is no big difference with No SFCL. On the other hand, SFCLs placed in Arrangement 4 and 5 could limit the fault current instantly without any negative effect because they are located in direct path of the fault point. Thus, the best performance of SFCLs could be obtained using Arrangement 4 and5.

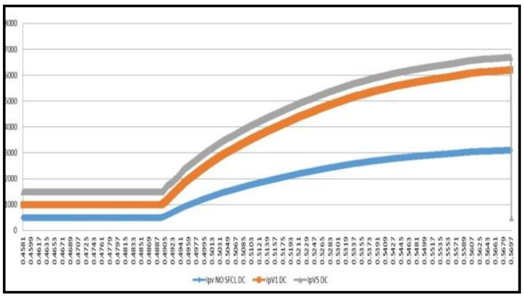

Fig.11 -Comparison of the Photovoltaic Farm fault currents for different SFCL locations in case of fault in DC microgrid.

c) Case 3- Fault Current at the Output of Substation Transformer When a Fault occurred In DC Microgrid:

Fig.12 shows the comparison of fault currents for different arrangements measured at the output of substation transformer. As mentioned above, fault occurred in DC microgrid has no severe effect on AC grid. Therefore, there's no big difference with No SFCL condition regarding all Arrangements.

When SFCLs were placed in Arrangement 4 and 5, the best fault current limiting effect could be obtained. Because of these results, Arrangement 4 and 5 might be strategic location of SFCLs to protect smart grid from increasing fault current. This implies that the SFCL should be located on the direct path of current flowing from distributed generation resources both for AC microgrid and DC microgrid. Actually, Arrangement 4 and 5 have no big difference in fault current limiting capabilities, but considering economic aspects, Arrangement 4, which has less number of SFCLs, would be better solution for a smart grid.

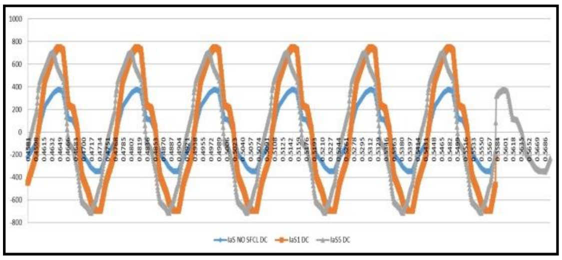

Fig.12-Comparison of the substation transformer fault currents for different SFCL locations in case of fault in DC microgrid.

Measurement in AC grid also shows some changes in current values. The values of current in wind farm terminal oscillate to a value less than +300 A to -300 A. Measurement at substation transformer shows value of peak of current oscillates between +400A to -400A, which concludes the reduction in fault current values, as a direct affect for placing SFCL in grid.

CONCLUSION

The study has established a practicable approach to fault current limiting at transmission level voltage applications. A microgrid was tested under simulation condition on how it responds to the fault conditions with respect to placement of SFCL.

The result shows that the fault current in both AC cases and DC cases got controlled with application of SFCL. The placement of DC-SFCL works best when its located before PV system terminals whereas in case of AC-SFCL, it works best when its placed near substation.

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