Application of Superconducting Fault Current Limiters in Distributed Generation with Solar Energy System

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***Abstract*- Increasing demand for Electrical Energy results in periodic increase in power generation and Power system network up-gradation. As a result many public and private power generating utilities are coming forward to fulfil this energy crisis. Renewable energy is one among such utilities where solar energy system plays a crucial role. Integrating solar network to the grid leads to higher levels of abnormalities resulting in malfunctioning or damage to the system and the equipment associated. Existing protection devices become under-duty for protection against these higher abnormalities. This paper discusses the application of superconducting fault current limiter which is necessarily to be installed in the solar power network to minimize the level of fault currents thereby protecting the power network and the equipment. Superconducting fault current limiter introduces the necessary impedance under abnormal conditions and gives near zero impedance under normal conditions.**

Keywords- Superconducting fault current limiter, solar energy system.

I. INTRODUCTION

Renewable energy, now days, is becoming the most important technology for electrical power generation. Solar power generation has become the fastest growing energy solution in many countries like India, USA, Spain, Germany, United Kingdom, China etc.,

By the end of 2014, cumulative solar energy capacity increased by more than 40GW and reached 178GW. This is equivalent to supply 1% of world's electricity consumption of currently 18400TWh. Germany bags the top position in solar power supply in the world having an installed capacity of 38.2GW. Fig I
gives the cumulative global capacity of solar energy from 2001 to 2015.

In future we can witness a drastic increase in the solar power generation which is going to be connected to the countries power grids. With this increase and integration of solar energy system increases the fault levels and makes the existing electrical protection devices under-duty. Higher levels of fault currents creates major disturbances in the power network and the system is subjected to tripping by respective protective relays interrupting the power flow between utilities and consumers. Therefore power system goes to unbalanced state collapsing the power network and damaging the equipment associated with it.

Superconducting fault current limiter is a technological and economical solution for these higher levels of ambiguities that occur in the power system where upgradation of existing and installation of new protective devices is uneconomical and time consuming process. Superconducting fault current limiter is an active research worldwide. There are different types of Fault Current Limiters. Active Fault Current Limiters are those which introduce fast source impedance in the circuit and Passive Fault Current Limiters are the devices use the high source impedance [3].

This paper discusses about the applications of Superconducting fault current limiter for the fast growing solar energy system that are integrated with the country's electrical grids. Superconducting fault current limiter is aimed to reduce the intensity of fault currents making the existing protection devices to operate safely.

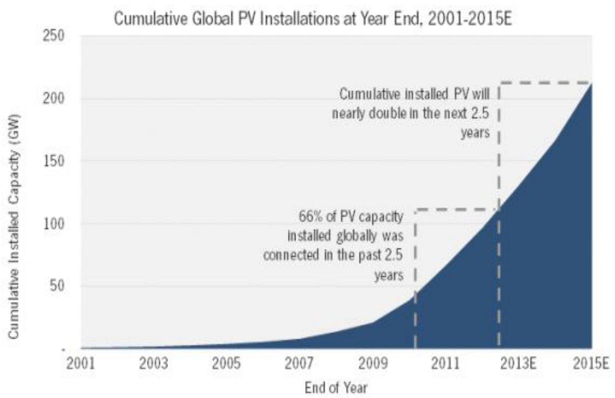

Fig I: Cumulative global capacity of solar energy from 2001 to 2015

II. EXISTING SOLUTIONS

Earlier, research has been done on how to clear the fault and isolate the system from being effected. Recent day research is directed towards limiting the unpredictable intensity of fault currents which include usage of circuit breaker with ultra-high fault current rating, air-core reactors, limiting fuses, bus splitting methods etc., [1] unfortunately, because of their inefficiency, inflexibility in limiting fault current and uneconomical in nature they did not come into existence. Construction of new substations requires up-gradation of existing and installation of new circuit breakers which involves high costs. A typical 15kV substation installation would be around $40000-$60000 per breaker. Therefore the use of conventional methods to protect the system and its equipment involves huge costs.

Bus splitting involves the separation of sources that feed the fault current by opening the bus ties. This method have an advantage of reducing the number of sources that feed the fault and also have disadvantage of reducing the number of sources that are connected to the load causing a discontinuity in the power flow even in normal conditions until the disconnected sources are brought back to the system again.

So it is necessary to install, in the system, these current limiting devices at selected places which reduce the level of abnormalities in the system and make the existing protective devices capable for operation.

III. OPERATION OF FAULT CURRENT LIMITER

Fault current limiter is a parallel combination of copper bar and the current limiting fuse. Under normal conditions the current flows through the copper bar. When short circuit occurs the current through the copper bar must be interrupted and forced to flow through the current limiting fuse. This is done with a fast triggering device because the fault current must be limited before reaching its peak value.

IV. SUPERCONDUCTING FAULT CURRENT LIMITER

Superconducting Fault Current Limiter (SFCL) regulates the amount of current from the solar system under abnormal conditions. The use of SFCL reduces fault current levels at the generating side and improves the fault ride through capability of the system. When a fault is occurred in the system SFCL transits from low impedance state to high impedance state at the time of faults. That means it offers near zero impedance under normal conditions and high resistance during the faults. SFCL has a switching speed of several milliseconds that would be fast enough to prevent building up of large fault currents. Typical diagram of a system with SFCL is show in Fig. 2.

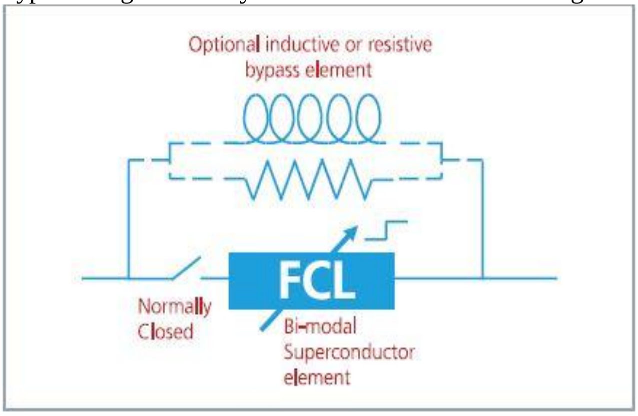

Fig 2: Typical diagram of a system with SFCL

SFCL responds before the first cycle peak and provides effective means to limit excessive fault currents to manageable limits without the disadvantages of the conventional methods. This is shown in fig-3. The superconducting element undergoes step function transition from low impedance to high impedance before the first cycle peak.

The time for the transition is less than 2 milliseconds. The current is controlled for a pre-defined interval consistent with the power rating of the system equipment that enables fault identification before the circuit breaker operation. SFCL offers very low voltage distortion while limiting fault currents and does not require any external controls to reset after the fault.

Voltage sag caused by the fault, system security and reliability etc., depend on the number of SFCL used and locations they are placed. Placing of SFCL for best operating conditions is an important issue and when comes to ring main system it is highly complicated. However, in literature, there are methods to determine the number and locations for installing SFCL's

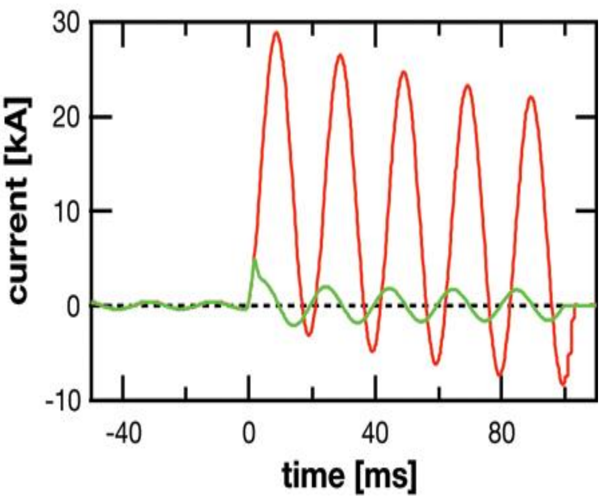

Fig 3: Limiting the short circuit current before reaching its peak.

V. APPLICATION OF SFCL IN SOLAR ENERGY SYSTEM

When an unpredictable fault occurs in the system the amount of current flow is restricted by the generator internal impedance and the line impedance between the generator and the fault. The internal impedance is very low and so the magnitude of fault current is high. Inter connection of solar power plants to the grid results in breaker over duty problems on multiple breakers.

A 3MW solar power plant of kolar in Karnataka state of India is considered for the study purpose. The plant is divided into three segments of one MW each. Each segment is coupled with four inverters of 250kW each and grouped together to form a LT panel as shown in fig-4. The power generated by each PV Panel is 0.415kV, is stepped up to 11kV, and connected to 11kV lines. The full load rating of the transformer is 1.25MVA.

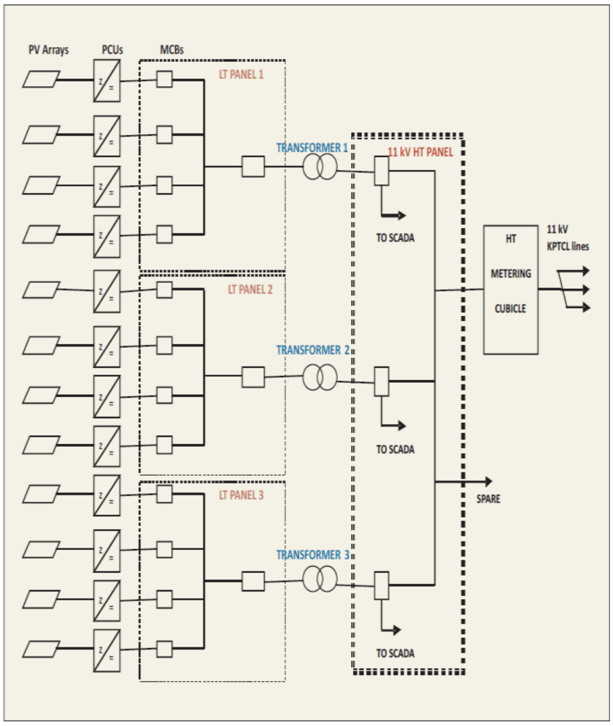

fig-4: Block diagram of the solar Plant of kolar, Karnataka.

Depending on the mix of 225 & 240 Wp modules, 45 to 46 PV arrays are connected in parallel to each single inverter, and each array consists of 24 modules connected in series.

Fig 5 shows the example for application of super conducting fault current limiter to reduce the level of fault currents and maintaining the breaker in healthy state without experiencing the high electrical stresses. The system shown here may experience prolonged outages and solar plants has huge installation and maintenance costs which is uneconomical to upgrade the existing protection devices.

Installing SFCL in series with the breaker gives a challenging solution when the system is experiencing higher levels of abnormalities.

Under normal conditions SFCL is invisible in the system and offers zero impedance in the network. The plants peak value of the output current is always below the critical value of the superconductor. So there is no voltage drop across the device and the subsequent I^2R losses are also minimum. When there is a fault in the system, the fault current value exceeds the critical value of the superconductor creating a quenching condition in the device. Now the transition takes place in the superconductor to its high resistive state and the time of transition is less than 2 milliseconds. Resistance that is given by SFCL also decreases the X/R ratio of the system at particular point, reducing the DC offset in the fault current. The fault current is been shunted into the parallel inductor to introduce the limiting impedance to the grid for limiting fault current. The system below shown is modeled in PSCAD.

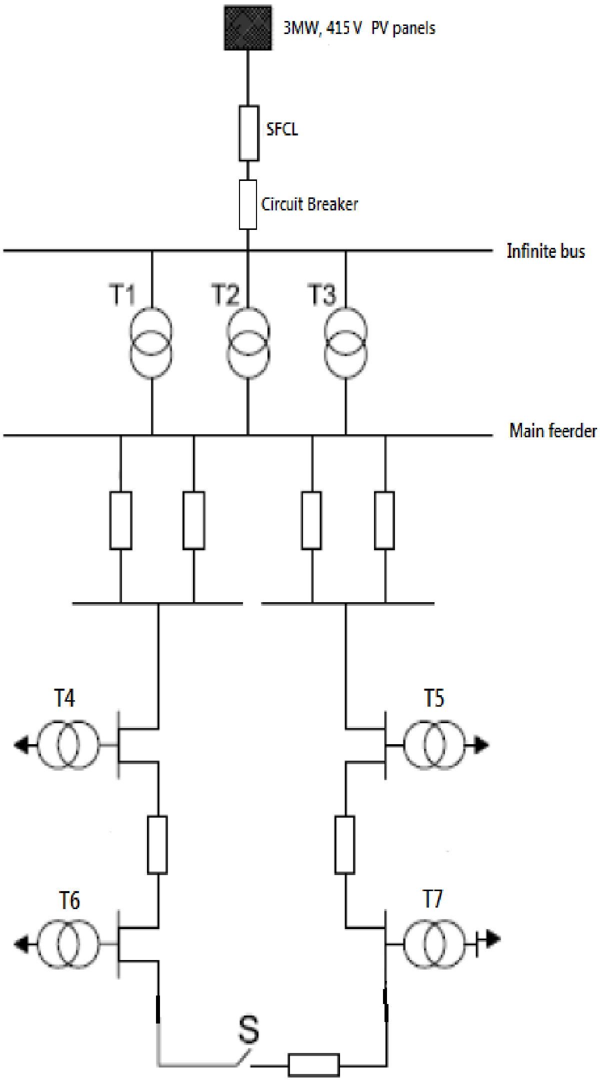

Fig 5: Sample single line diagram of the test system

When there is symmetrical 3-phae fault at the station transformer without the SFCL installed in the system, the peak value of the fault current is 25kA and reaches its steady state at 20kA as shown in the graph (Fig.6)

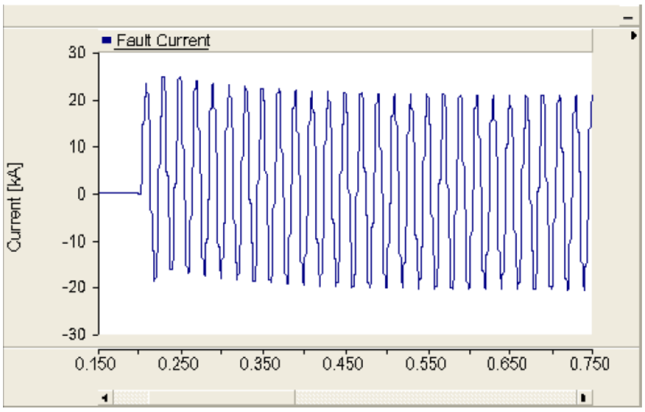

Fig 6: Fault current in the absence of SFCL

Fig.7 gives the results when the solar system is integrated with the grid and if there is a 3-phase VII. symmetrical fault in the system with SFCL installed in series with the system peak value of the fault current drops to 5kA.

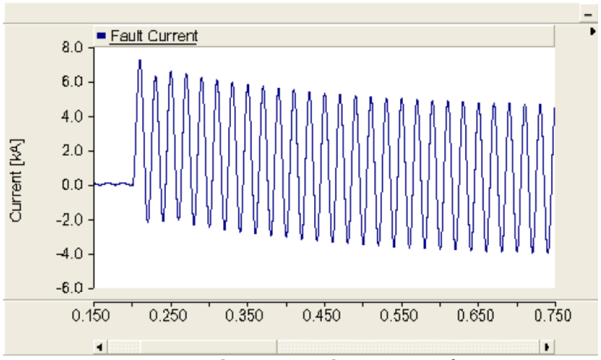

Fig 7: Fault current in the presence of SFCL

We can compare the above results of fault currents without and with the SFCL. In second case there is decrease in fault is reduced value which the breaker sees for safe operation and system protection.

VI. CONCLUSION

Fast growing solar energy system is being connected to the countries electrical grids which also increase the fault current levels imposed on the system. Conventional methods for protecting the system experiences vulnerable electrical and mechanical stresses damaging the equipment. It is highly uneconomical and difficult to upscale or replace the existing protection systems.

Technical and highly economical solution for this problem is installing Superconducting Fault Current Limiter in the solar energy system which high resistance offering device that minimizes the fault current level and does not affect the system under normal conditions. SFCL is wide growing technology that can eliminate the problem of replacing the circuit breakers in the grid, reduce short circuits and increase the system reliability. Due to its economical nature number of SFCL's can be placed where ever necessary for stable operation of the power system.

Form the results we can analyze effect of SFCL in reducing the fault current when it is installed in the network. There is a drastic decrease in peak fault current value when SFCL is present in the system compared to the peak value in its absence. So SFCL is highly useful for solar power plants in maintaining system stable and healthy operation of protective devices.

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