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An Enhanced PI Controlled STATCOM for Voltage Regulation

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ABSTRACT

Distributed Generation Resources are increasingly used in distribution systems due to their great advantages. The presence of DG, however, can cause various problems such as miss-coordination, false tripping, blinding and reduction of reach of protective devices. Using superconducting fault current limiters (SFCLs) is one of the best methods to minimize these problems comparing to the other conventional methods. The active SFCL can as well suppress the short-circuit current induced by a three-phase grounded fault effectively, and the power system's safety and reliability can be improved and it is composed of an air-core superconducting transformer and a PWM converter. The magnetic field in the air-core can be controlled by adjusting the converters output current, and then the active SFCLs equivalent impedance can be regulated for current limitation and possible overvoltage suppression. During the study process, in view of the changes in the locations of the DG units connected to the system, the DG units injection capacities and the fault positions, the active SFCLs current-limiting and over voltages suppressing characteristics are presented by using Matlab/Simulink software.

Keywords:— *Wind Energy, PI Controller, STATCOM, Distributed generation. Voltage Regulation.*

I. INTRODUCTION

In response to ever growing needs for electricity, power producers have been expanding the power grids continually, particularly with the proliferation of independent power producers (IPP's). Technical advancements and promotions of various types of renewable energy generation have also led to a large number of distributed generators (DG's) connected to the power grids.

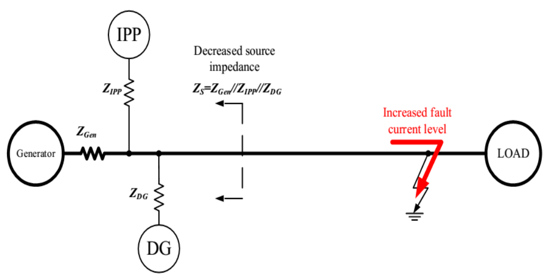

Figure 1. Diagram of Added Electricity Generations to a Power Grid.

Parallel IPP and DG decrease source impedance and increase potential fault current level on the power system.

However, this fast expansion of generation capacity obscures a hidden issue, which must be resolved the potential fault current levels keep increasing as the source impedances are lowered due to the paralleled connections of the growing number of generators. As a result, the potential short-circuit current levels increase substantially, approaching the limits of the devices in existing power systems, including the cables, switchgears, protection devices, and loads. Specifically, if the fault current levels exceed the interruption ratings of existing protection devices, such as fuses and circuit breakers, the equipment will suffer serious damage. In extreme cases, failure to interrupt fault current may destroy insulation of conductors and oil-filled equipment, causing fire or explosion.

Moreover, many of the existing protective devices need several cycles to interrupt the fault current. Within this period of time, several high peaks of fault current are introduced to the system, posing large thermal and mechanical stresses to the protection devices and other equipment in the system.

Various techniques have been proposed to mitigate the increasing fault current issues. The most straightforward way would be upgrading all the conductors, switchgears, and protection devices in existing power systems to raise their fault current ratings and interrupting speed. However, the process of replacing equipment is expensive, complicated, and time consuming. In many cases, given the scale of the existing power systems, system upgrades remain unviable for the foreseeable future. Unfortunately, faults will not wait, so alternative means should be taken in order to safeguard against the increased fault currents, in order to ensure the robustness and safe operation of the power system.

Bus splitting (or network splitting) is one of the practical strategies being used in the power industry against large fault current. By reconfiguring the network topology, the sources of the fault currents are separated into different buses, thereby reducing the available fault current.

However, this strategy leads to the permanent increase of system impedance during normal operation, which contradicts the demand for more efficient and stable power grids. Also, bus splitting reduces the number of power sources that can connect to the buses under normal conditions, sacrificing the power system's flexibility in supplying and dispatching power.

1.1 The Fault Current Limiter (FCL) Solution:

Because of the urgency of the increasing fault current problem and the issues with the other solutions discussed above, Fault Current Limiters (FCL's) are becoming the preferred option to address the over-rating issue and permit the bypass postponing of costly system upgrades. The merits of FCL technology are:

1. FCLs can be used to mitigate the effect of high fault current levels on a distribution system, permitting the use of lower rated protection devices and avoiding costly device replacements.
2. Since many FCLs can limit the fault current within the first quarter-cycle, they can protect existing devices from the first large peak during a fault.
3. Short circuit faults are often the origin of voltage sags at a point of common coupling (PCC) in a power network. Since the extent of the voltage sag is proportional to the

short circuit current level, reducing the fault current level within the networks can reduce voltage sags during faults and protect sensitive loads that are connected to the same PCC.

Figure 2 shows that in fault conditions, an FCL increases the source impedance in the system and limits the fault current Figure 2 demonstrates the typical operation of an FCL and its effect on fault current limiting.

Figure 3 shows the principle of operation shared by most FCL technologies. An FCL maintains low impedance in normal conditions; when a fault occurs, it quickly inserts high impedance to power line quickly, so as to limit the fault current presented on the system. Therefore, an ideal FCL should meet the following requirements:

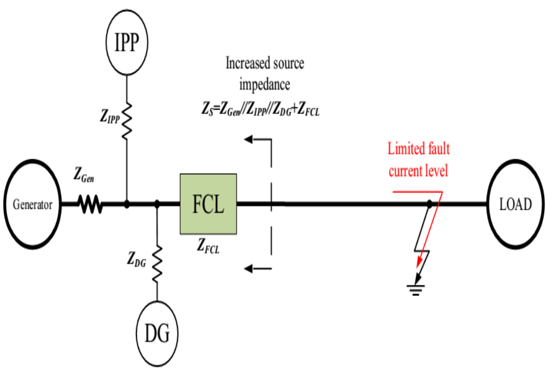

Figure 2. FCL increases source impedance and limits fault current during fault conditions

1. ***Efficient and non-intrusive:*** During normal operation, the FCL should be as "invisible" as possible to the power line, meaning that the power loss, voltage drop, and harmonic injection to both current and voltage waveforms should be minimized;

2. ***Fast action:*** Like all protection devices, the FCL's response (pick up and action) speed to a short-circuit fault is vital. For FCL's, action must be taken within the first half cycle upon fault occurrence;

3. ***Fast recovery:*** Fast recovery capability is favored for FCL's in order to handle sequential fault events or to coordinate with the reclosing actions in many relaying protection applications;

4. ***Low cost:*** As an intermediate device to be added into systems to prevent expensive system upgrades, an FCL should provide reasonable economic benefits compared to a higher rated protection device.

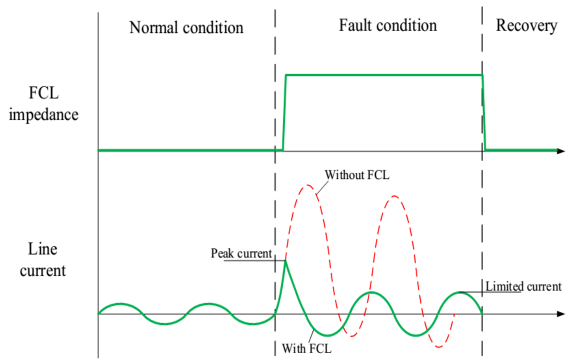

Figure 3. Fault Current Limitation Effects of FCL in Fault Conditions

II. Fault Current Limiters

Before technologies can be considered for the application of limiting a distributed generator's fault current contribution, the operating conditions and requirements of such a limiter must first be established. The existing technologies can then be evaluated for their suitability for such an application by ensuring that any proposed device meets the requirements. The first requirement for the FCL is that it must operate at the distribution voltage level. According to a utility survey in [13] in which utilities were asked to describe their present distribution systems and predicted future system, utilities responded that the most prevalent voltage class is at 15kV. A typical radial distribution system.

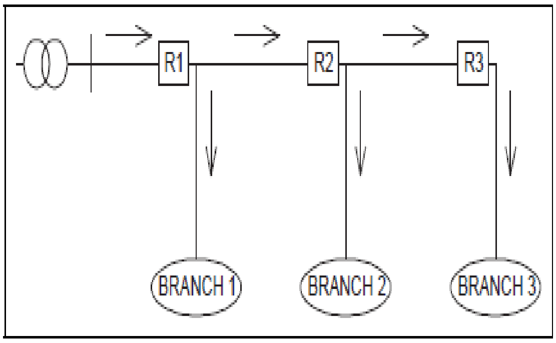

Figure 4. Typical radial distribution system with relay protection

The distribution system shown in Figure 5 is an example in which the addition of DG to the system in Figure 4 would impact the existing relay coordination. If a fault were to occur in *Branch 1* or *Branch 3*, the DG would likely contribute to the fault current, with the current flowing from the DG back onto the main feeder, towards the fault. The current that flows through relay *R2* would then be different than if the DG had not been added, so that the coordination between the 3 relays, *R1, R2,* and *R3*, would be affected.

To prevent the DG from supplying fault current onto the main feeder, the FCL should be placed between the DG and the main feeder, along the distribution line off of the main feeder leading to the DG and *Branch 2* as shown by the **X** in Figure 5. The fault current limiter's operation must follow specific guidelines in such a placement. When there is no fault in the system, the FCL must not affect the system. If a fault occurs in the system outside of *Branch 2*, the FCL must limit the current that will flow from the DG to the fault. In the last mode of operation, for faults inside Branch 2, the FCL must not operate, preserving the fault current seen by the relay, *R2*. To be able to operate in the manner described, limiting the fault current in one direction while having no effect on the other, the fault current limiter needs the ability to be selectively turned on and off based on the direction of the sensed current. Finally, for the FCL to be viable, it will need to introduce almost no losses during the steady-state operation of the system, and be able to sustain repeated operations with low maintenance.

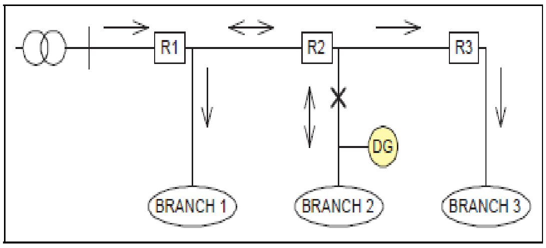

Figure. 5 Radial distribution systems with added DG.

2.1 Fault Current Limiters Application & Benefits:

Due to an FCL's ability to rapidly change the impedance within the system, it mitigates the large potential fault current threats. Also, it brings in additional benefits to the system, such as enabling parallel operation, reducing voltage dips, enhancing system stability, etc.. In general, fault current limiters have been proposed for applications in various system levels, including power generation, transmission and distribution levels of system voltages from 400V to 132kV

1. Reduce or eliminate wide-area blackouts, far fewer localized disruptions, and faster recovery when disruptions do occur

2. Provide protection to T&D equipment, eliminate or reduce replacement of T&D equipment (i.e. circuit breakers)

3. Avoid split buses, opening bus-tie breakers

4. Higher system reliability

5. Reduce voltage dips

6. Enhance grid stability. Enables the creation of a safer, more reliable, more efficient, and affordable power delivery system

2.1.1 Fault Current Limiters:

1. Passive limiters
2. Solid state limiters
3. Solid-state switch hybrid current limiter

III. Distributed Generation Coupling

Figure 6 shows an FCL application that couples a DG to the existing substation, which is described in [15]. As stated above, adding this DG increases the potential fault current level on the substation bus. In fact, connecting more and more DG's to the power grid greatly limits the short-circuit current margins in some stations. Due to this effect, short-circuit current level should be limited when a new DG is being connected to the station. One existing solution is to install an additional generator transformer, which is expensive. However, if an FCL is installed between the DG and the distribution grid, the additional generator transformer is no longer needed since the FCL can limit the fault current level to within the safety margin of the substation's short-circuit current allowance.

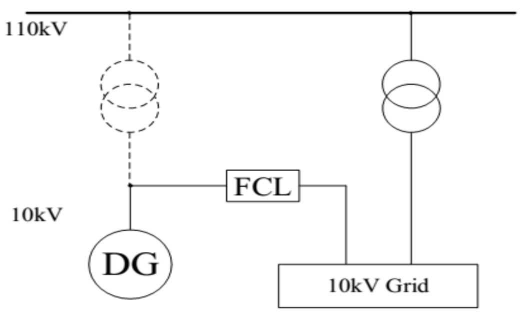

Figure 6. Application of FCL in DG coupling

Due to increased consumption demand and high cost of natural gas and oil, distributed generation (DG), which generates electricity from many small energy sources, is becoming one of main components in distribution systems to feed electrical loads [1]–[3]. The introduction of DG into a distribution network may bring lots of advantages, such as emergency backup and peak shaving. However, the presence of these sources will lead the distribution network to lose its radial nature, and the fault current level will increase. Besides, when a single-phase grounded fault happens in a distribution system with isolated neutral, over voltages will be induced on the other two health phases, and in consideration of the installation of multiple DG units, the impacts of the induced over voltages on the distribution network's insulation stability and operation safety should be taken into account seriously. Aiming at the mentioned technical problems, applying superconducting fault current limiter (SFCL) may be a feasible solution. For the application of some type of SFCL into a distribution network with DG units, a few works have been carried out, and their research scopes mainly focus on current-limitation and improvement of protection coordination of protective devices [4]–[6]. Nevertheless, with regard to using a SFCL for suppressing the induced overvoltage, the study about it is relatively less. In view of that the introduction of a SFCL can impact the coefficient of grounding, which is a significant contributor to control the induced overvoltage's amplitude; the change of the coefficient may bring positive effects on restraining overvoltage. We have proposed voltage compensation type active SFCL in previous work, and analyzed the active SFCL's control strategy and its influence on relay protection. In addition, a 800 V/30 A laboratory prototype was made, and its working performances were confirmed well.

In this project, taking the active SFCL as an evaluation object, its effects on the fault current and overvoltage in a distribution network with multiple DG units are studied. In view of the changes in the locations of the DG units connected into the distribution system, the DG units' injection capacities and the fault positions, the current limiting and overvoltage-suppressing characteristics of the active SFCL are investigated in detail.

IV. Application of FCL and SFCL in Distributed Generated System

Now a days with the trend of growing electric power systems and their interconnections, fault current levels are increased and these fault levels may exceed the current rating of system equipments. In this condition, the realization of a fault current limiter (FCL) is going to be expected strongly. FCL structures not only are used for effective suppression of faults in power system, but also are applied to variety of applications such as power quality and transient stability improvement. Many types of FCLs are introduced in literature, such as superconducting FCLs (resistive or inductive types), solid state FCLs, flux lock type FCLs and resonance type FCLs.

Previously presented resonance type FCLs are used a capacitor in series or parallel with superconducting inductors and limited fault currents by this way. However, these structures have two problems. Firstly, because of high technology and costs (construction and maintenance costs) of superconductors, there are not commercially available. Secondly, by using these structures, peak of current is not constant during the fault and has increasing variation. So, for the faults that last more time, it may be harmful for utility equipments, even considering high speed breakers. In addition, by increasing manner of fault current, selecting the power rating of breakers will be a problem.

In this paper a new series resonance type FCL is introduced. Using non-superconducting inductor in this topology leads to low construction and maintenance costs. Also, by the proposed FCL, fault current's peak will be constant. In addition, capacitor of this structure can be used as series compensator in normal operation, that it is not possible in previously introduced series resonance type FCLs; because, in those structures inductor and capacitor are in resonance condition in normal operation of power system. Analytical analysis is performed and simulations are presented using MATLAB software to show the effectiveness of this structure.

4.1 Circuit of Proposed FCL and Operation

Figure 7 Shows single phase power circuit topology of the proposed FCL. It is necessary to use a similar circuit for each phase in a three -phase power system. This structure is composed of two main parts which are described as follows:

1. ***Bridge part:*** This part consists of a semi-conductor rectifier (SCR) bridge containing D_1 to D_4 diodes, a small dc limiting reactor (L_{dc}), a self turn off switch (such as GTO, IGBT, etc) and a freewheeling diode (D_f).
2. ***Resonance part:*** This part consists of a series LC resonant circuit (L_{sh} and C) that is tuned on 50 Hz network frequency and an arrester in parallel with the capacitor. Note that the natural resistance of inductor (R_{sh}) is considered too.

Bridge part of FCL operates as a high speed switch that changes the fault current path to resonance part, when fault occurs. Obviously, as a conventional method, it is possible to substitute this part with an anti parallel connection of two semiconductor switches. In this case, it is necessary to use a series inductor with each switch for limiting the di / dt . These inductors make a voltage drop on FCL in normal operation of power system. But, using diode rectifier bridge and placing a self turn off switch inside the bridge has two advantages compared to two anti-parallel switches as follows:

1. This structure uses only one controllable semiconductor device which operates at dc side, instead of two switches that operate at ac current. So, control circuit is simpler because of no need to

switching ON/OFF at normal operation case. In addition, there is not switching losses.

2. It is possible to placing a small reactor in series with the self turn off switch at dc side. This reactor plays two roles; Snubber for self turn off switch to protect it and current limiter at first moments of fault that will be discussed in detail.

In normal operation of power system, self turn off switch is ON and small dc reactor is charged to the peak of line current and behaves as short circuit. Neglecting small voltage drop on diodes and self turn off switch, total voltage drop on FCL becomes almost zero and therefore, FCL does not affect normal operation of power system. As fault occurs, dc reactor limits increasing rate of short circuit current and starts to charge. When the line current reaches to the pre-defined value that can be set by system operator, control system turns off the self turn off switch. So, the bridge retreats from utility. At this moment, freewheeling diode turns on and provides free path for discharging the dc reactor. When the bridge turns off, fault current passes through the resonance part of the proposed FCL.

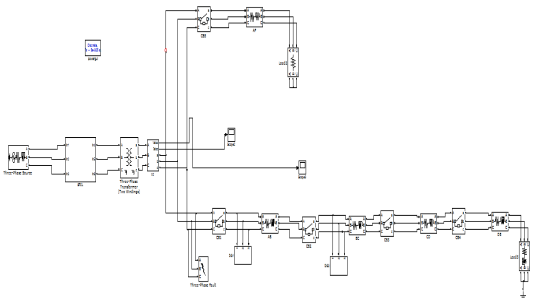

Figure 7.Simulation Diagram of Application of FCL in a Distributed Generated System

Without using arrester in the proposed topology, only series LC resonance circuit will be in fault current path. As will be shown in analytical analysis section, in such condition, fault current will has increasing variations. But, by using arrester fault current can be limited to a constant value. In addition, it is possible to protect the capacitor from over voltages that can be harmful By removal of fault, self turn off switch turns on again and system returns to the normal state.

Some previous structures have AC power losses in resonant circuit during no-fault condition, because of placing large inductor in line current path. But, this structure has very lower losses at normal condition. Total power loss of the as will be shown in analytical analysis section, in such condition, fault current will has increasing variations. But, by using arrester fault current can be limited to a constant value. In addition, it is possible to protect the proposed structure is made by semiconducting devices and small resistance of dc reactor. It is very small percentage of the transmitted power of feeder and can be ignored for most of practical applications.

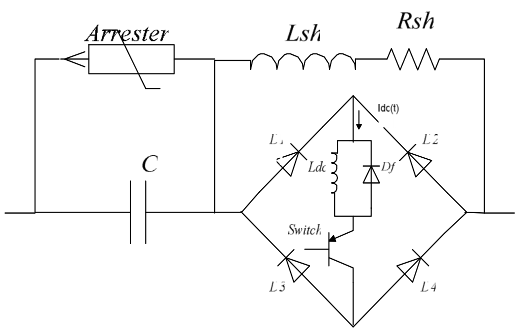

Figure 8. Power Circuit Topology of the Proposed FCL

V. Simulation Models & Results:

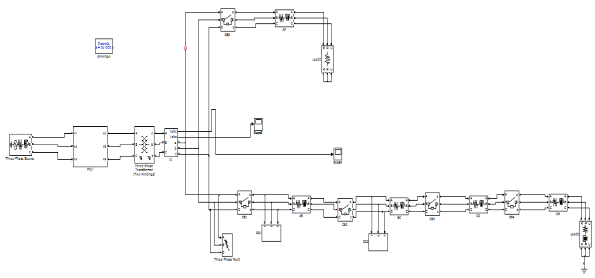

Figure 9. Simulation Diagram of Application of SFCL in a Distributed Generated System

As shown in Figure 8 it indicates the application of SFCL in distributed generated system with multiple DG units. It multiple DG units are inserted on feeder line in order to meet the load demand, circuit breakers also inserted just before the DG units. SFCL is inserted before the three phase two winding transformer; when a three fault occurs in the feeder line 1 SFCL automatically trigger the fault current rising rate.

5.1 Voltage waveform with the application of SFCL

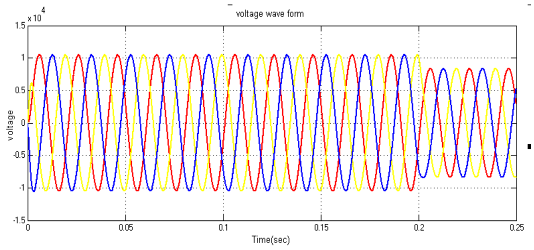

Figure 10. Voltage waveform with the application of SFCL

5.2 Voltage Waveform with Proposed FCL

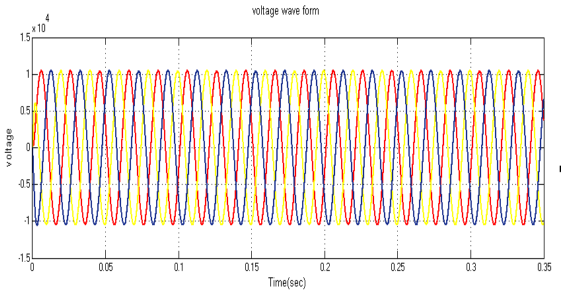

Figure 11. Voltage waveform with proposed FCL

5.3 Current waveform with the application of SFCL

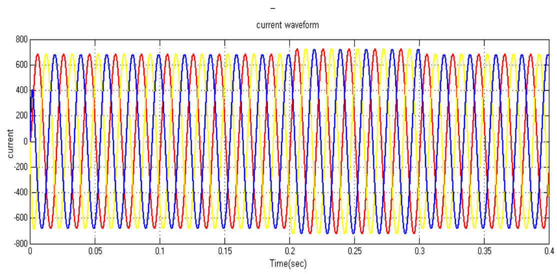

Figure 12. Current waveform with the application of SFCL

5.4 Current Waveform with Proposed FCL

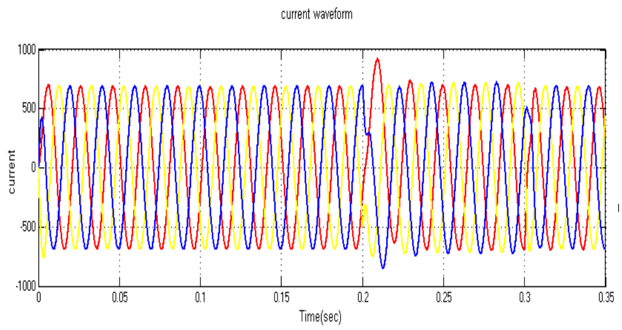

Figure 13. Current waveform with proposed FCL

VI. CONCLUSION

This paper is the quick review of Distributed Generation in India, its need, importance in near future. This paper provides how Traditional Generation is differing from Distributed Generation. In this paper, the application of the active SFCL and FCL into in a power distribution network with DG units is investigated. For the power frequency overvoltage caused by on the same problem using a DG based operation to enhance the power quality concerns at bus levels using a supportive source with active SFCL and FCL topologies. A single-phase grounded fault, compare to the active type SFCL and active type FCL. Active type FCL is reduces the over voltage's amplitude and avoids damaging the relevant distribution equipment. The active FCL can as well suppress the short-circuit current induced by a three-phase grounded fault effectively, and the power system's safety and reliability can be improved.

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