A New Micro grid Fault Current Limiter for Transient Performance Improvement

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ABSTRACT: **In this work, super conducting Fault Current Limiter is proposed to protect the energy storage system in a micro grid. Energy storage systems (ESSs) are enabling technologies for well-established and new applications such as power peak shaving, stability purpose, integration of renewable energies. The possible advantages of resistive Superconducting Fault Current Limiter (SFCL) as a means to limit the adverse effect of DG on distribution system protection and their effectiveness will be demonstrated. When a short-circuit fault happens at the connecting line, the resistive SFCL will be send the signal to Energy storage systems (ESSs) the included in the micro-grid. Accordingly, the switching between the master DG's two control patterns can be flexibly performed, and further the micro-grid system is expected to achieve a smooth transition between its grid-connected and islanded modes. The resistive SFCL has been noticed as the best solution to limit fault current effectively. However, the application of the resistive SFCL in the power system affects the protective coordination of the existing protective devices and can deviate their operation time from the original one. The simulation results are obtained using MATLAB/SIMULINK software.**

Index Terms- **Distributed generation, micro-grid, resistive superconducting fault current limiter, transient performance.**

I.INTRODUCTION

The resistive type superconducting fault current limiters (SFCLs) have attracted more attention around the world, and their applications in existing and future electrical distribution systems can theoretically solve some kinds of technical issues. In a sense, current-limiting devices are becoming increasingly important because of the connection of distributed generation (DG), whose access capacity can result in a higher fault-current level. A micro-grid system can be designed to accommodate high penetration of DG units and improve the energy efficiency, and it is crucial to ensure the micro-grid system's power quality and service reliability during a fault. Typically, a micro-grid system has two modes of operation, called as grid-connected and islanded. When a short-circuit fault occurs in the main network, the micro-grid may be tripped off.

According to, reasonably controlling the master DG is a basic method of guaranteeing the micro-grid's transient behaviors under the islanded condition. Nevertheless, in the case that the resistive type SFCL's rapid quenching characteristic and its potential effects on inhibiting current rush are taken into account, the micro-grid may achieve a more smooth transition and stable operation. In this paper, the application of a resistive type SFCL in a typical micro-grid system is assessed. The article is organized in the following manner presents the SFCL's working principle as well as influence mechanism to the micro-grid's transient performance, and also discusses some technical issues about the device design. In section the model of the micro-grid integrated with the SFCL is built in MATLAB/SIMULINK, and the simulation analysis on different cases is conducted. The conclusions are summarized and next steps are suggested.

II. THEORITICAL ANALYSIS

A. Modelling of the Resistive SFCL

Based on the experimental studies for a resistive SFCL being applied in the actual power distribution system. An SFCL is one of the most promising current limiters to prevent the short-circuit current from increasing in magnitude owing to its rapid current limiting ability. Many models for an SFCL have been developed, such as resistive type, reactive type, transformer type, and hybrid type SFCLs. Among the various types of SFCLs, the resistive type SFCL is preferred because of its simple principle and compact structure of small size. In this paper, we have modelled a resistive type SFCL using mathematical expressive equations the time evolution of the SFCL impedance RSFCL as a function of time t is given by

$$R_{sfcl}(t) = R_n\,[1 - \exp(-\frac{(t-t_0)}{T_f})]^{\frac{1}{2}}\; t_0 \le t < t_1 \qquad (1)$$

$$R_{sfcl}(t) = a_1(t - t_1) + b_1 \qquad (2)$$

$$R_{sfcl}(t) = a_2(t - t_2) + b_2 \qquad (3)$$

Where R_n and τ represent the impedance being saturated at normal temperature and time constant, respectively. In $t0$, $t1$, and $t2$ denote the quench-starting time, first starting time of recovery, and second starting time of recovery, respectively. In addition, $a1$, $a2$, $b1$, and $b2$ are the coefficients

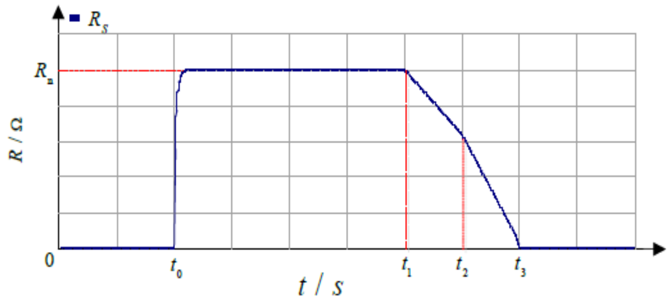

Fig.1. Characteristics of a resistance type SFCL.

The SFCL's recovery time may be less than 0.5 s [8], so as to match up the auto-reclosing operation. As shown in Fig. 1, it indicates the detailed quenching and recovery characteristics. The schematic diagram of a typical micro-grid integrated with the resistive SFCL is shown in Fig. 2,

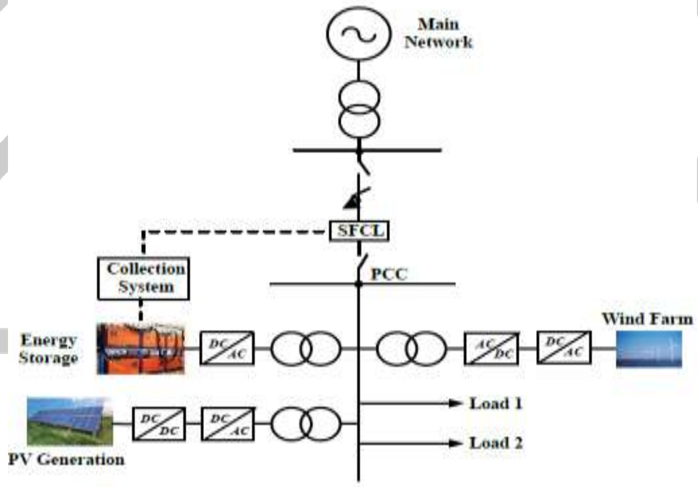

Fig.2. Schematic diagram of a typical micro-grid integrated with the SFCL

Where the SFCL is installed at the point of common coupling (PCC) between the micro-grid and the main network. In regards to the energy storage device, photovoltaic (PV) plant and wind farm, all of these DG units are accessed to the micro-grid through the inverters. Note that, the energy storage device will be served as a master DG, which is used for stabilizing the micro-grid. In general, the maser DG has two control patterns, so called as the P-Q control and the V-f control. When the micro-grid is under the grid-connected state, each of the DG units will use the P-Q control. In the case that a short-circuit fault happens in the main network, the micro-grid may be operated to work in the islanded state. The master DG's objective is to maintain the micro-grid's frequency and voltage stability as far as possible, and its control pattern will switch to the V-f control from the original P-Q control. As reasonably controlling the master DG is a basic method of ensuring the transient performance, employing the resistive type SFCL is expected to affect the control mechanism more actively and make the transition process be smoother. Due to the SFCL's rapid quenching characteristics, it can be conducted as a control trigger since the fault current istimely detected to be larger than its critical value. That is to say, the SFCL's trigger signal caused by the superconducting-normal (S-N) transition will be sent to a collection system, and then be used for activating the master DG's control switching.

B. Description of Faults

Electrical powers system is growing in size and complexity in all sectors such as generation, transmission, distribution and load systems. Types of faults like short circuit condition in power system network results in severe economic losses and reduces the reliability of the electrical system. Electrical fault is an abnormal condition, caused by equipment failures such as transformers and rotating machines, human errors and environmental conditions. Theses faults cause interruption to electric flows, equipment damages and even cause death of humans, birds and animals.

C. Technical Discussion on the Design of the SFCL

•**Superconducting material.** Currently, the bulk Bi series and YBa2Cu3Ox (YBCO) second-generation (2G) are the main high temperature superconducting (HTS) materials for electric power application. Considering that the commercial YBCO 2G tapes may have the high resistivity matrix with a linear resistance of 0.354 Ω/m, the transition to the normal-conducting state may occur from 2 ms up to 4 ms after the start of fault current. Besides, the YBCO 2G tapes with stainless steel reinforcement can provide good mechanical properties, such as tensile strength above 250 MP a at room temperature. Since the YBCO 2G components may actuate faster than the Bi-2212 component, and the expected current-limitation is higher for the YBCO 2G components after the S-N transition, the YBCO 2G tapes may be more suitable for making the resistive SFCL.

•**AC loss.** In a sense, the AC loss will be an important factor affecting the SFCL's engineering application. Its AC loss can be measured with a standard electrical technique, and also be calculated by finite-element simulations. Theoretically, the superconductor's electrical properties may be modelled with a nonlinear power law where voltage varies as (*J*/*J*c) n. *J* and *J*c are respectively the current and critical current density. The critical current density *J*c and the power index *n* can be derived from the measured DC current-voltage characteristics. Accordingly, the AC loss can be computed in:

$$P = f\int_0^{1/f}\int_S \mathbf{J}\cdot\mathbf{E}\,dSdt \qquad (\mathrm{W/m}) \qquad (4)$$

Where *f* is the frequency, *S* is the superconductor's cross-section, and **J** and **E** are the current density and the electric field at each example finite element method (FEM) node. From the simulation and experimental results in, the AC loss will be reduced in the presence of externally applied AC magnetic field, but be increased in the presence of AC transport current. To reduce the SFCL's AC loss as much as possible, the coupling transformer with the superconducting limiting coil may be properly considered.

•**Electrical Insulation.**
In the case of that the sub-cooled liquid nitrogen is used to be the SFCL's cooling system, the dielectric strength and bubble suppression effect as the electrical insulation design's factors in the cryostat can be enhanced by increased pressure. Through injecting the non-condensable gas such as gaseous helium (GHe) or gaseous-neon (GNe) into the cryostat, the pressure of the cooling system can be controlled. In addition, the gap distance between a cryostat and superconducting tapes is one of the emphasis factors of the SFCL's insulation design. According to, the shield ring attached to the copper current lead can reduce the gap distance between the cryostat and the SFCL. And based on the request of AC withstand voltage and shield ring's diameter, the gap distance can be designed. preliminary conclusions can be obtained, and the detailed engineering design of the SFCL for an actual micro-grid system will be performed in the near future.

Table I: Main simulation parameters of the system model

Micro-grid System	
Energy Storage	(800 V / 1000 Ah) ×5
PV Plant	100 kW ×10
Wind Farm	260 kW × 10
Load 1	0.2 MW
Load 2	0.1 MW+j0.05 Mvar
Voltage/Frequency	3 kV / 50 Hz
Resistive type SFCL	
Normal-state Resistance	1 Ω

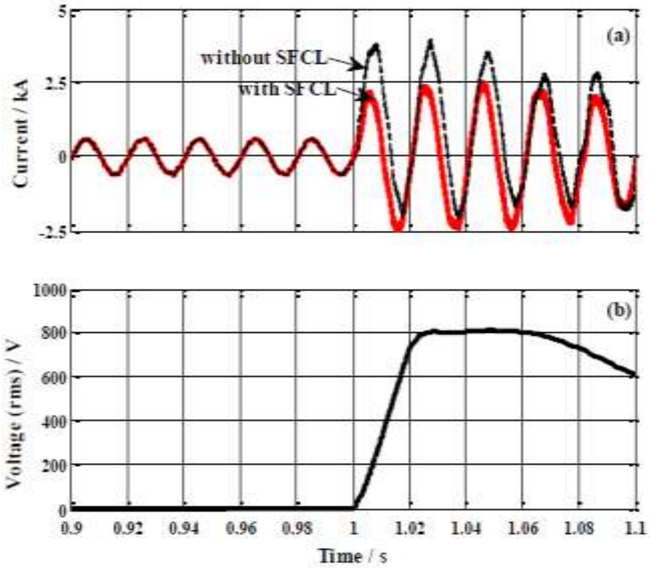

Fig 3 Operating characteristics of the suggested resistive type SFCL. (a) fault current at the PCC and (b) RMS voltage across the SFCL's two terminals.

III. SIMULATION STUDY

To quantitatively evaluate the resistive type SFCL's effects on a micro-grid system's transient performance, the simulation model corresponding to Fig. 2 is built in MATLAB/ SIMULINK, and parts of simulation parameters are indicated as Table I. The access voltage of the demonstrated micro-grid system is selected as 3 kV, and the short-circuit fault is supposed to happen at the middle of the connecting line. During the simulation analysis, it is set that the fault occurs at t_0 = 1 s and lasts for 100 ms. Further, the static-state switch will be operated at t=1.1 s, and the micro-grid system will carry out the transition from its grid-connected mode to islanded mode. Herein two different simulation cases are considered and respectively reordered as case I and case II. For the former, the SFCL is not applied, and the control switching will be implemented after the fault is cleared. Regarding the latter, the resistive SFCL is employed, and this suggested device will be used for current-limitation and control trigger.

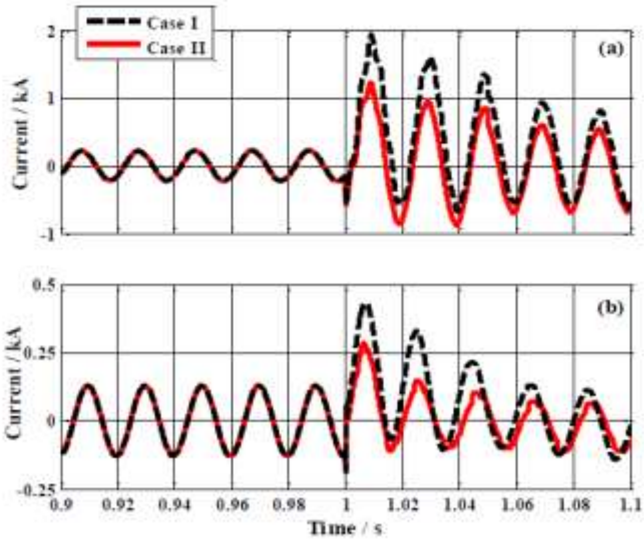

Fig.4. Waveforms of the fault current provided by the DG included in the micro-grid with and without the SFCL . (a) wind farm and (b) PV plant.

TABLE II
FIRST PEAK OF THE FAULT CURRENT AT DIFFERENT LOCATIONS

Measuring point	Without SFCL	With the SFCL	Current-limiting ratio
PCC	3.8 kA	2.1 kA	44.7%
Wind farm	1.9 kA	1.1 kA	42.1%
PV plant	0.4 kA	0.255 kA	36.2%

The DG units included in the micro-grid can not only meet the two local loads' power requirements, but also provide the energy to the accessed main network. After the fault, the resistive SFCL will play its role in time. Fig. 4 shows the operating characteristics of the resistive type SFCL. Owing to the increased fault current, the maximum value (root-mean-square, RMS value) of the SFCL's terminal-voltage can be up to 800 V. In consideration of that the fault current will be quickly detected to be larger than the critical value, it is assumed that once the terminal-voltage is detected to be larger than 200V and can last for 5 ms (a quarter of power-frequency cycle), the master DG's control transition will be activated.
Fig. 5 shows the characteristics of the fault currents provided by the wind farm and the PV plant, and the SFCL's effects are also taken into account. Table II expresses the detailed data results. In terms of Fig. 4 and Fig. 5, the resistive SFCL's current-limiting characteristics can be verified, and the decrease of the over current inrush will have a positive influence on the micro-grid.

IV.BASICS OF SFCL

Superconducting fault current limiter is a promising technique to limit fault current in power system. Normally non-linear characteristic of superconductor is used in SFCL to limit fault current. In a normal operating condition SFCL has no influence on the system due to the virtually zero resistance below its critical current in superconductors. But when system goes to abnormal condition due to the occurrence of a fault, current exceeds the critical value of superconductors resulting in the SFCL to go resistive state. This capability of SFCL to go off a finite resistive value state from zero resistance can be used to limit fault current. Different types of SFCLs have been developed until now. Many models for SFCL have been designed as resistor-type, reactor-type, and transformer-type etc. In this paper a resistive-type SFCL is modelled using simulink. Quench and recovery characteristics are designed on the basis of.

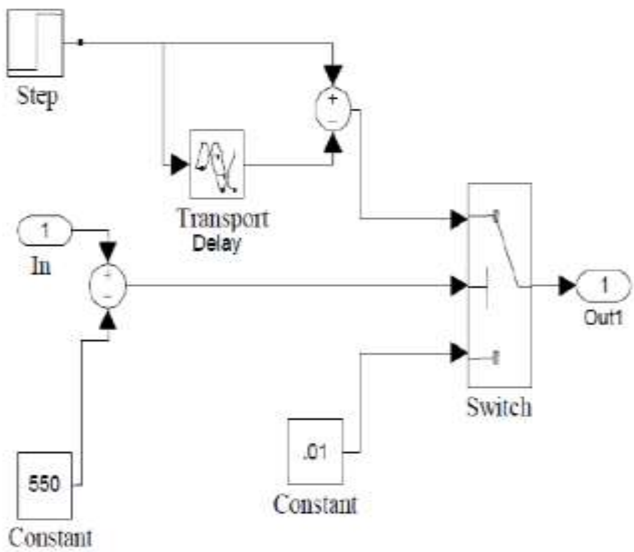

Fig.5. Implementation of resistive SFCL characteristics in simulink.

These parameters are used for implementing resistive SFCL characteristic is shown in Fig. 2. Quenching and recovery time of SFCL are specified using step and transport block respectively. A Switch block is used to give minimum or maximum impedance in output which is determined considering the incoming current. The simulation model of SFCL for a single phase system is shown in Fig.5
Case 1: Single Line to Ground Fault without an SFCL

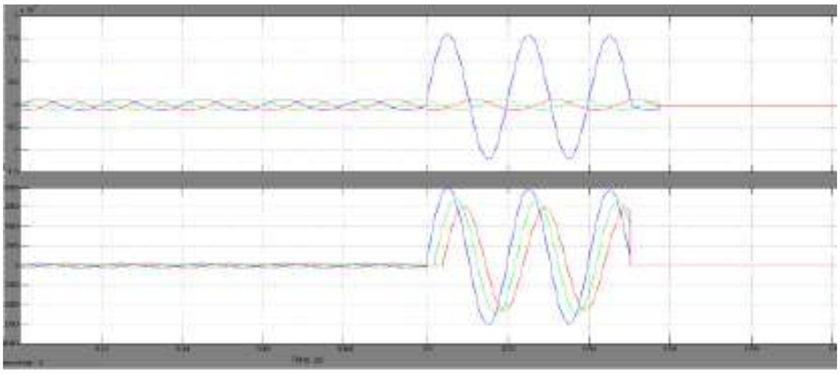

Fig.6. Simulation waveform currents caused by the single line-to ground fault without SFCL

Case 2: Single Line to Ground Fault With SFCL

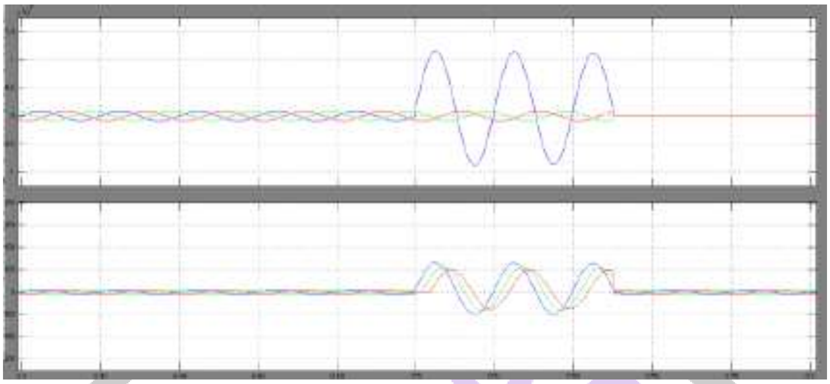

Fig.7. Simulation waveform currents caused by the single line-to ground fault with SFCL

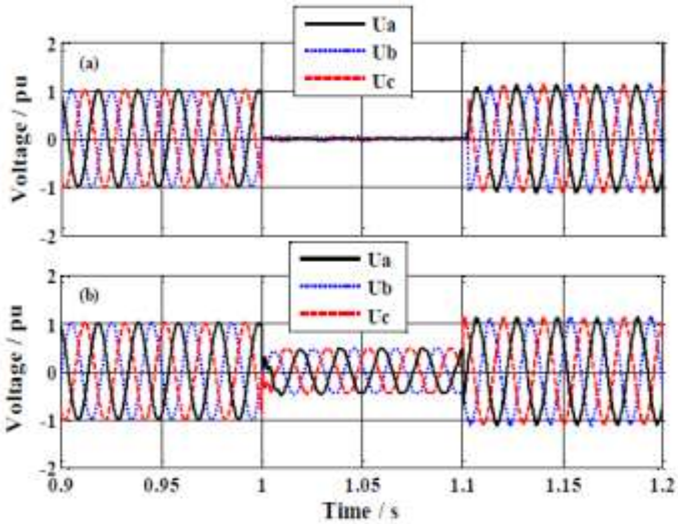

Fig.8. Waveforms of the micro-grid's PCC voltage during the fault. (a) case I and (b) case II.

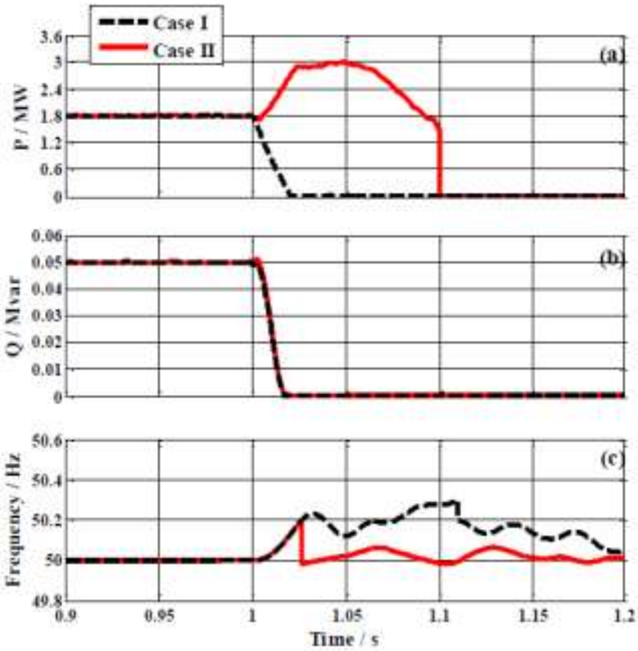

Fig.9 Transient characteristics of the micro-grid system during the fault. (a) active power exchange, (b) reactive power exchange and (c) system frequency.

Figs. 6-7 denote the bus-voltage, exchange power and frequency characteristics of the micro-grid during the control switching. It can be observed that, the application of the resistive SFCL can bring comprehensive contributions to improve the micro-grid's performance. Applying the SFCL can make the micro-grid's PCC voltage be maintained at 0.5 pu, compared to that the PCC voltage will down to 0.08 pu without SFCL, and the expected increasing rate is approximate to 84%. In addition, employing the resistive SFCL can make

IV. CONCLUSION

In this paper, concerning the transient performance enhancement of a micro-grid system during a fault, a resistive type superconducting fault current limiter is suggested to play the role. Related theoretical derivation, technical discussion and simulation analysis are carried out. From the results, applying the resistive SFCL can effectively limit the transient current rush, guarantee the power balance, and improve the micro-grid system's voltage and frequency stability.
In the near future, a small-scale prototype of the resistive type SFCL will be made, and its application in a real micro-grid system will be tested. The research results will be reported in later articles.

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