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Improved Performance Of Micro Grid By Resistive Type SFCL with PMSM

A.Yamuna
M-tech Scholar
Department of Electrical & Electronics Engineering,
Teegala krishna reddy Engineering College,meerpet;
hyderabad (Dt); Telangana, India.
Email:yamuacha@gmail.com

Dr.P.krishna
Assistant Professor
Department of Electrical & Electronics Engineering,
Teegala krishna reddy Engineering College, meerpet;
Hyderabad(Dt); Telangana, India.
Email:pagidimarrik@gmail.com

Abstract: This paper tests and analyzes the working capability of a resistive superconducting fault current limiter (SFCL) in a micro grid. The micro grid is a test-bed, consisting of a conventional power plant, two renewable energy sources in the form of wind-farm and solar-farm as two distributed generation (DG) units and five loads (i.e., industrial and domestic). Utilization of DG in mainstream is increasing and hence, various consequences that arise from DG penetration are to be considered accordingly. It is observed that DG penetration in existing distribution alters the fault current during a grid disturbance and hence imbalances the system. Based on this, the research work focuses on contribution of fault current from renewable energy sources in a micro grid, and how resistive SFCL offers positive result in minimizing the fault levels. Permanent magnet synchronous motors (PMSM) are typically used for high-performance and high-efficiency motor drives. High-performance motor control is characterized by smooth rotation over the entire speed range of the motor, full torque control at zero speed, and fast acceleration and deceleration. To achieve such control, vector control techniques are used for PM synchronous motors. The analysis of improved performance of resistive SFCL applied in PMSM driveThe proposed concept can be implemented to resistive type SFCL applied to PMSM drive using MATLAB / SIMULINK software.

Key words-transient performance, distributed generation (DG), Superconducting fault current limiters (SFCL), fault current limiter (FCL).

I INTRODUCTION

Application of fault current limiters (FCLs) based on high temperature superconductors is one of the promising solutions of the fault current problem in power electric systems. Several power prototypes of the FCLs have been successfully tested [1]. The achieved characteristics of some of them could allow applying them in the distribution networks. At present there are developments directed to design superconducting FCL for application in high voltage lines. The intense interest in these FCLs is explained by achievements of the technology of high temperature superconductors and expected advantage from their application in power systems. The requirements for FCL parameters and for properties of superconductors are discussed in many publications (for examples see [2], and reverences noted in them). The requirements for FCLs can be separated according to their influence on electromagnetic processes in the system and influence on stability of parallel operation of electrical machines. It was shown that FCLs based on high temperature superconductors meet to the first type requirements: they have low impedance under the normal operation regime of the protected circuit; under a fault their impedance rapidly increases limiting the first peak of a fault current and its steady state value without appearance of dangerous overvoltage; FCLs quickly return into the initial low impedance state after the limitation of fault currents. Usually parameters and installation places of FCLs are chosen to ensure the required current limitation [3].

An FCL application has not to lead to worsening the static and transient stability of the power system. An ideal limiter has zero impedance under the normal conditions of the circuit to be protected. In reality, it is enough that the voltage drop across an FCL under the normal conditions of a circuit is less than several percents (usually 5%) of the rated circuit voltage. In this case the FCL does not disturb the static stability of the power system operation and does not influence handling properties of the lines [4].

There are several studies devoted to analysis of the transient stability of a power system wheresuperconducting FCLs are installed. In these investigations the attention is given to two FCL designs, resistive and inductive, installedin one of the parallel transmission lines. It has been shownthat the FCLs not only limit a fault current but also can increasethe stability of the synchronic operation of the electricmachines [5].

In this paper, we analyze in detail the influence of superconducting inductive FCLs on the transient stability of the power system. The FCL influence on the transient stability was analyzedusing the law of equal areas. On the one hand this approachclearly shows how the installation place of a device and its parameters change the transient stability of power systems [6].

The fault current limiters (FCL) are regarded as the suitable solution to solve excessive fault current problems. Active superconducting fault current limiter (ASFCL) voltage compensation type is a novel topology of FCL. This type SFCL not only preserves the merits of bridge type SFCL such as the automatic switch to the current limiting mode and without the quench of the superconductor, but also has the particular abilities of controlling the steady fault current and compensating active and reactive power for AC main circuit in the normal state [8]. 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 over voltages. We have proposed a voltage compensation type active SFCL. In previous work and analyzed the active SFCL's control strategy and itsInfluence on relay protection [9].

II THEORETICAL ANALYSIS

A) Modeling of the Resistive SFCL

Based on the experimental studies for a resistive SFCL being applied in the actual power distribution system [7], its mathematical model can be expressed as:

$$R(t) = \begin{cases} 0 & (t < t_0) \\ R_n\left[1 - \exp\left(-\frac{t-t_0}{\tau}\right)\right]^{\frac{1}{2}} & (t_0 \le t < t_1) \\ a_1(t - t_1) + b_1 & (t_1 \le t < t_2) \\ a_2(t - t_2) + b_2 & (t_2 \le t < t_3) \\ 0 & (t \ge t_3) \end{cases} \quad (1)$$

Where Rn and τ represent the impedance being saturated atnormal temperature and time constant, respectively. In addition, t0, t1, and t2 represent quench-starting time, the first recoverystarting time, and the secondary recovery-starting time, respectively. In the case of properly adjusting the thermal environmentand setting the system parameters, the SFCL's recovery timemay be less than 0.5 s [8], so as to match up the auto-reclosing'soperation. As shown in Fig.1, it indicates the detailed quenching and recovery characteristics.

B) Influence of the Resistive SFCL on a Micro-Grid'sTransient Performance:

The schematic diagram of a typical micro-grid integrated with the resistive SFCL is shown in Fig.2, where the SFCLis installed at the point of common coupling (PCC) between the micro-grid and the main network.

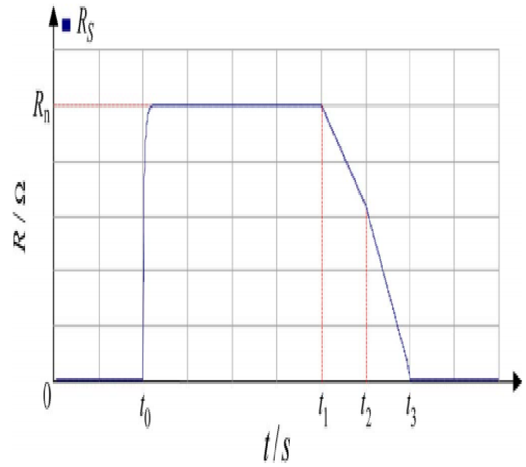


Fig.1.Quenching and recovery characteristics of a resistance-type SFCL

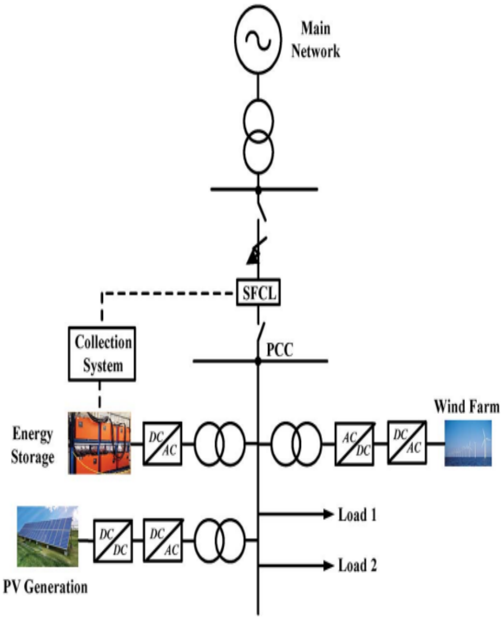


Fig.2. Schematic of a typical microgrid integrated with the SFCL.

In regards to the energystorage device, photovoltaic (PV) plant and wind farm, all of these DG units are accessed to the micro-grid through theinverters [9]. Note that, the energy storage device willbe served as a master DG, which is used for stabilizing themicro-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, eachof the DG units will use the P–Q control. In the case that ashort-circuit fault happens in the main network, the micro-gridmay be operated to work in the islanded state. The master DG'sobjective is to maintain the micro-grid's frequency and voltagestability as far as possible, and its control pattern will switchto the V-f control from the original P–Q control. As reasonablycontrolling the master DG is a basic method of ensuring thetransient performance, employing the resistive type SFCL isexpected to affect the control mechanism more actively andmake the transition process be more smooth. Due to the SFCL'srapid quenching characteristics, it can be conducted as a controltrigger since the fault current is timely detected to be larger thanits critical value. That is to say, the SFCL's trigger signal causedby the superconducting-normal (S-N) transition will be sent toa collection system, and then be used for activating the masterDG's control switching.

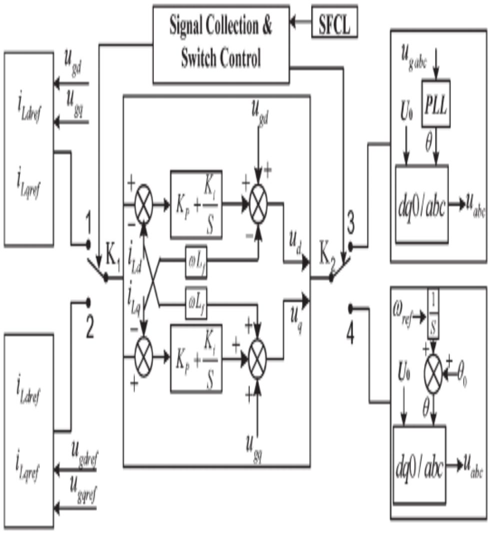


Fig.3. Control strategy of the energy storage device in consideration of theresistive SFCL's trigger signal.

Concerning how to effectively implement the master DG'scontrol switching, a feasible way is presented as follows. Fig.3.shows the control strategy of the energy storage device inconsideration of the resistive SFCL's trigger signal, from thisfigure, specialized current-input and voltage-output channelsare arranged for controlling the master DG. The channels 1and 3 are used for realizing the master DG's P–Q control, and the current-input references (i_{Ldref}, i_{Lqref}) can beexpressed as:

$$\begin{cases} i_{Ldref} = \frac{2}{3}\frac{P_{gref}u_{gd}+Q_{gref}u_{gq}}{u_{gd}^2+u_{gq}^2} \\ i_{Lqref} = \frac{2}{3}\frac{P_{gref}u_{gq}-Q_{gref}U_{gd}}{u_{gd}^2+u_{gq}^2} \end{cases} \tag{2}$$

Where P_{gref} and $Q_{gref}$are the given power references; ugd andugq are respectively the d-axis and q-axis components of thenetwork-side voltage.According to the control block diagram as demonstratedin Fig. 3, the P–Q control's output-voltage signals (ud,uq)can be obtained. From the figure, the following variables aredefined. ω is the fundamental angular frequency; Lf is the filterinductance; i_{Ld} and i_{Lq} are the d-axis and q-axis componentsof the energy storage converter's output current.On the other side, the channels 2 and 4 are used to achievethe master DG's V-f control. Based on the given network-sidevoltage references (u_{gdref},u_{gqref}), the V-f control's currentinput references (i_{Ldref},i_{Lqref}) can be expressed as:

$$\begin{cases} i_{Ldref} = \left(K_{P1}+\frac{K_{i1}}{s}\right)\left(u_{gdref}-u_{gd}\right)-\omega C_f u_{gq}+i_{gd} \\ i_{Lqref} = \left(K_{P1}+\frac{K_{i1}}{s}\right)\left(u_{gqref}-u_{gq}\right)+\omega C_f u_{gd}+i_{gq} \end{cases} \tag{3}$$

Where C_f is the filter capacitance; K_{p1}, K_{i1} are the proportional and integral parameters of the voltage regulator; $i_{gd}$and i_{gq} are the d-axis and q-axis components of the networkside current. In a similar way, the V-f control's output-voltages(u_d,u_q) can be obtained.

In accordance to the resistive SFCL's quenching trigger,using the logical switches K1 and K2 can precisely implementthe control switching for the master DG. It should be pointedout that, the resistive SFCL also has the responsibility oflimiting the fault current from the micro-grid to the short-circuitlocation. Before the static-state switch equipped at the PCC isoperated to make the micro-grid be disconnected from the mainnetwork, the current fluctuations can be suppressed within anacceptable level, and thus the micro-grid's transient behaviorscan be ensured more effectively.

C) Technical Discussion on the Design of the SFCL

1) Superconducting Material: Currently, the bulk Bi seriesand YBa2Cu3Ox(YBCO) second-generation (2G) are the mainhigh temperature superconducting (HTS) materials for electricpower applications. Considering that the commercialYBCO 2G tapes may have the high resistivity matrix with alinear resistance of 0.354 Ω/m, the transition to the normalconducting state may occur from 2 ms up to 4 ms after the startof fault current. Besides, the YBCO 2G tapes with stainlesssteel reinforcement can provide good mechanical properties,such as tensile strength above 250 MPa at room temperature.Since the YBCO 2G components may actuate faster thanthe Bi-2212 components, and the expected currentlimitation is higher for the YBCO 2G components after theS-N transition, the YBCO 2G tapes may be more suitable formaking the resistive SFCL.

AC Loss: In a sense, the AC loss will be an important factoraffecting the SFCL's engineering application. Its AC loss canbe measured with a standard electrical technique, and alsobe calculated by finite-element simulations. Theoretically, thesuperconductor's electrical properties may be modeled witha nonlinear power law where voltage varies as (J/Jc)n. Jand Jc are respectively Where f is the frequency, S is the superconductor's crosssection, and J and E are the current density and the electricfield at each example finite element method (FEM) node. Fromthe simulation and experimental results in, the AC loss willbe reduced in the presence of externally applied AC magneticfield, but be increased in the presence of AC transport current.To reduce the SFCL's AC loss as much as possible, the couplingtransformer with the superconducting limiting coil may beproperly considered.

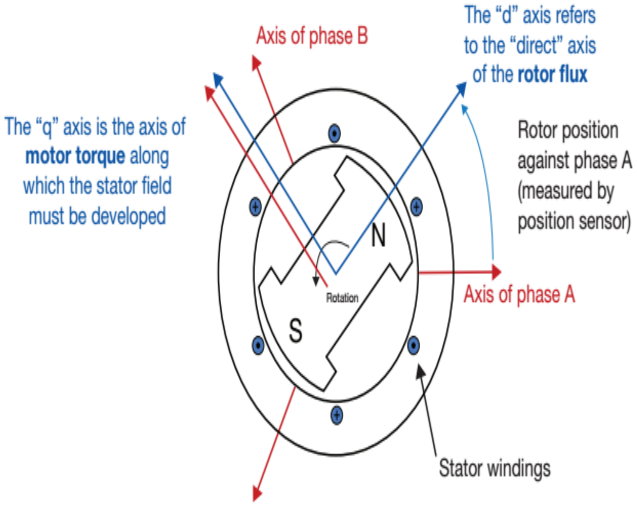
2) Electrical Insulation: In the case of that the sub-cooledliquid nitrogen is used to be the SFCL's cooling system, thedielectric strength and bubble suppression effect as the electrical insulation design's factors in the cryostat can be enhancedby increased pressure. Through injecting the non- condensablegas 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 cryostatand superconducting tapes is one of the emphasis factors ofthe SFCL's insulation design. According to, the shield ringattached to the copper current lead can reduce the gap distancebetween the cryostat and the SFCL. And based on the requestof AC withstand voltage and shield ring's diameter, the gapdistance can be designed.From the aforementioned brief discussions, some preliminary conclusions can be obtained, and the detailed engineeringdesign of the SFCL for an actual micro-grid system will beperformed in the near future.

III PERMANENT MAGNET SYNCHRONOUS MOTORS (PMSM)

Permanent magnet synchronous motors (PMSM) are typically used for high-performance and high-efficiency motor drives. High-performance motor control is characterized by smooth rotation over the entire speed range of the motor, full torque control at zero speed, and fast acceleration and deceleration. To achieve such control, vector control techniques are used for PM synchronous motors. The vector control techniques are usually also referred to as field-oriented control (FOC). The basic idea of the vector control algorithm is to decompose a stator current into a magnetic field-generating part and a torque generating part. Both components can be controlled separately after decomposition. Then, the structure of the motor controller (vector control controller) is almost the same as a separately excited DC motor, which simplifies the control of a permanent magnet synchronous motor. Let's start with some basic FOC principles.

the current and critical current density.The critical current density Jc and the power index n can bederived from the measured DC current-voltage characteristics.Accordingly, the AC loss can be computed in:

$$P = f\int_0^{\frac{1}{f}}\int_s \mathbf{J}\cdot\mathbf{E}\,dS\,dt \qquad (\mathrm{W/m}) \tag{4}$$



Torque Generation

A reactance torque of PMSM is generated by an interaction of two magnetic fields (one on the stator and one on the rotor). The stator magnetic field is represented by the magnetic flux/stator current. The magnetic field of the rotor is represented by the magnetic flux of permanent magnets that is constant, except for the field weakening operation. We can imagine those two magnetic fields as two bar magnets, as we know a force, which tries to attract/repel those magnets, is maximal, when they are perpendicular to each other. It means that we want to control stator current in such a way that creates a stator vector perpendicular to rotor magnets. As the rotor spins we must update the stator currents to keep the stator flux vector at 90 degrees to rotor magnets at all times. The reactance torque of an interior PM type PMSM (IPMSM) is as follows, when stator and rotor magnetic fields are perpendicular. Torque=32*pp*lPM*I*qs *pp* – Number of pole pairs l PM – Magnetic flux of the permanent magnets *I* qs – Amplitude of the current in quadrature axis As shown in the previous equation, reactance torque is proportional to the amplitude of the q-axis current, when magnetic fields are perpendicular. MCUs must regulate the phase stator current magnitude and at the same time in phase/angle, which is not such an easy task as DC motor control.

How to Simplify Control of Phase Currents to Achieve Maximum Torque

DC motor control is simple because all controlled quantities are DC values in a steady state and current phase/ angle is controlled by a mechanical commentator. How can we achieve that in PMSM control? DC Values/Angle Control First, we need to know the rotor position. The position is typically related to phase A. We can use an absolute position sensor (e.g., resolver) or a relative position sensor (e.g., encoder) and process called alignment. During the alignment, the rotor is aligned with phase A and we know that phase A is aligned with the direct (flux producing) axis. In this state, the rotor position is set to zero (required voltage in d-axis and rotor position is set to zero, static voltage vector, which causes that rotor attracted by stator magnetic field and to align with them [with direct axis]).

1 Three-phase quantities can transform into equivalent two-phase quantities (stationary reference frame) by Clarke transformation.

2. Then, we transform two-phase quantities into DC quantities by rotor electrical position into DC values (rotating reference frame) by Park transformation. The electrical rotor position is a mechanical rotor position divided by numbers of magnetic pole pairs pp. After a control process we should generate three-phase AC voltages on motor terminals, so DC values of the required/generated voltage should be transformed by inverse Park/Clarke transformations.

IV MATLAB/SIMULATION RESULTS

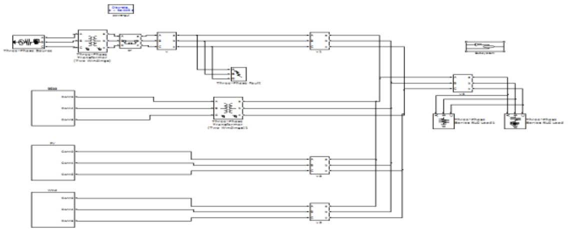


Fig 4 Matlab/simulation circuit of a typical microgrid integrated with the SFCL.

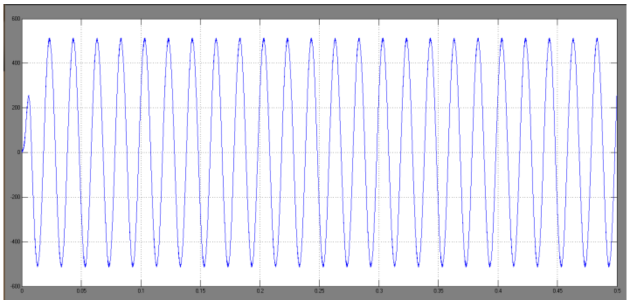


Fig 5 simulation wave form of fault current at the PCC

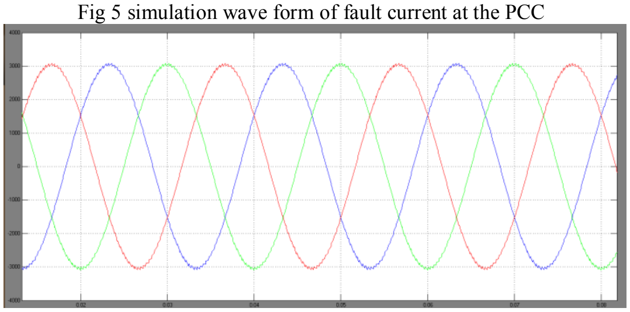


Fig 6 simulation wave form of fault voltage at the PCC

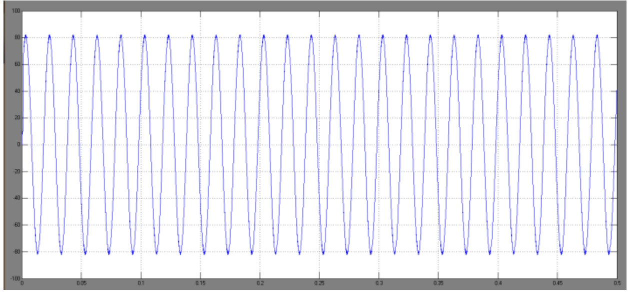


Fig 7 simulation wave form of wind current

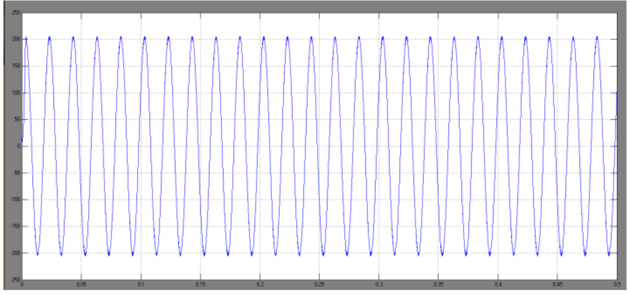


Fig 8 simulation wave form of PV current

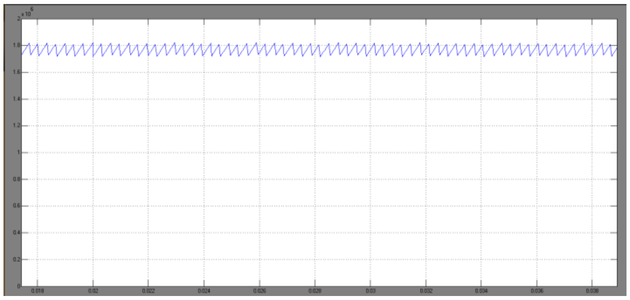


Fig 9 simulation wave form of active and reactive power

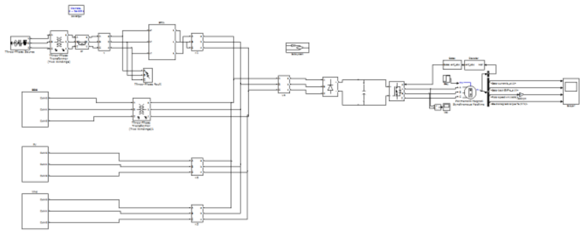


Fig 10 Matlab/simulation circuit of a typical microgrid integrated with the SFCL with PMSM motor drive

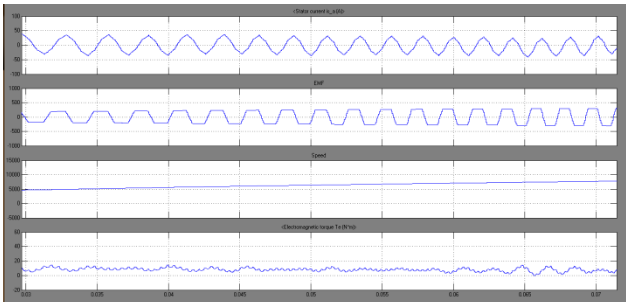


Fig 11 simulation wave form of microgrid integrated with the SFCL with PMSM motor drive current, EMF, speed and torque

IV CONCLUSION

The superconducting fault current limiter is a promising device to limit the escalating fault levels caused by the expansion of power grid and integration of renewable. Using SFCL module the transient rise in fault current are suppressed or limit to a desired value using SFCL. SFCL modules have ability to limit the sudden rise in fault current by providing the sufficient value of resistance. For the power frequency overvoltage caused by a single-phase grounded fault, the SFCL can help to reduce the overvoltage's amplitude and avoid damaging the relevant distribution equipment. But from the simulation analysis the FCL can as well suppress the short circuit current induced by a three-phase grounded fault effectively compared to the SFCL, and the power system's safety and reliability can be improved.In recently years, more and more dispersed energy sources, such as wind power and photovoltaic solar power, are installed into distribution systems. Therefore, the study of a coordinated control method for the renewable energy sources and the FCL becomes very meaningful, and it will be performed with PMSM motor drive to study the characteristics of stator current, EMF, Speed and electromagnetic torque.

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