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Fuzzy Control the Thyristor Controlled Series Capacitor to the Fault Current Limiting in Transmission Lines

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Abstract: As the fault current increases the installed power switches in the system are not able to cut such high current passing through them. On the other hand replacing the power switches with higher current cutting capable switches requires more money payment. In addition, the FACTS devices can control the lines power and buses voltages because of their fast controlling characteristics and continuous compensation capability. In this paper, the functionality of thyristor controlled series capacitor is investigated and it is tried to improve its abilities by changing the conventional applied controlling approaches and utilize it as a fault current limiter. Here, the fuzzy control method is applied. The simulation results well show that the mentioned control strategy can effectively limit the fault current.

Key word: Fault current limiting, Thyristor controlled series capacitor, Fuzzy control.

INTRODUCTION

One of the disadvantageous of power systems is fault level increase in the buses and in result high currents passing through the system during the fault occurrence. Therefore, the ability of power cutting of the switches in the system is not constant and it increases day by day. This imposes high expenses on the system exploiters. A solution is applying devices decrease fault current level to make the switches with the lower power cutting ability be able to separate the short-circuited part from the rest of the network. If it were possible to make changes in devices usually applied in systems and utilize them for fault current reduction, the new structure would be economically justified. This is the aim of this paper (Chang, P.C. Loh, 2001; Rubenbauer, G. Herold, 2006; Nagata *et al.,* 2001). In follows, the impacts of fault current increase are briefly mentioned (Chang, P.C. Loh, 2001; Rubenbauer, G. Herold, 2006; Nagata *et al.,* 2001; Meyer, R. W. De Doncker, 2006; Calixte *et al.,* 2002; Schmitt *et al.,* 2006; Calixte, *et al.,* 2004):

- The fault current increase causes an increase in the power wasted as heat in network devices especially the transformers and the generators.
- The recycled voltages increase and the transient state caused due to fault current increase damage the system insulation devices.The mechanical power increase caused by fault current increase suppresses the system devices such as transformers, generators, and power switches.
- Depend on the magnitude and the duration of the fault current, it tends the system to the unstable border and rises sever problems for system stability.
- Paralleling transformers is avoided to limit the fault current increase and in consequence, the bus reliability is decreased.
- As fault current increases, the installed power switches are not able to cut this current off due to their low ratings. A solution is to replace low power switches with high power ones which imposes high costs to the power system.
- As the fault current increases, the current transformers ratio error increases. This phenomenon occurs due to their core saturation.
- The fault current increase finally causes power interruption and leads to reliability decrease and economical losses.

Here, two solutions are proposed:

a).Applying techniques aim avoiding any fault occurrence in power system designing stage.

b).Applying techniques decrease the losses during fault occurrence as much as possible.It is impossible to eliminate the probability of fault occurrence and this is not economically justified. The system should be designed in a way that the losses are minimized during fault occurrence as much as possible.

Some parameters considered to prevent and restrict the electrical defects in power system designing and

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utilizing process are:

Applying correct maintenance and utilization techniques, using proper electrical insulator, applying protection wire, minimizing the ground connector resistance in power transmission towers, and designing transmission network mechanical devices in a way that the defect occurrence contingency is decreased as much as possible (Calixte *et al.,* 2002; Schmitt *et al.,* 2006; Calixte, *et al.,* 2004).

Some of the traits traced in system designing and utilizing process targeting reduction of fault consequences are fault current limitation, fast defected section separation, system stabilizing during the fault occurrence interval until fault elimination, investigating the system from reliability and proper performance point of view, appropriate response of protection system to the existing fault, and considering the network expansion plan. In this investigation, as it is obvious, one of the designing techniques applied to minimize the damages imposed to devices and electrical systems and power interruption prevention during the fault contingency is fault current limiter installation on the power system (Calixte *et al.,* 2002; Schmitt *et al.,* 2006; Calixte, *et al.,* 2004). If no limiter is used, high power switches should be installed to make it possible to cut high fault currents as soon as possible. This is rather hard and requires higher costs. The fault current can not be completely eliminated at the first few cycles even if high power rated switches are installed and usually it takes 8, 5, 3, and may be 2 cycles to completely turn off the arc in the switches as fault occurs.

The short circuit or fault current limiter is a device stands in series with transmission line and limits the fault current before it reaches to its maximum value to make it possible to cut the current by the existing power switches (Chang, P.C. Loh, 2001; Rubenbauer, G. Herold, 2006; Nagata *et al.,* 2001). In addition, the fault current limiter has the following advantageous, which economize the power network expenses:

The voltage drop or voltage attenuation prevention in intact or faultless lines as fault occurs in the system. Voltage stabilization during fault occurrence on the bus the limiter is installed on, increasing the lifetime of network devices such as transformers, generators, power switches etc by decreasing the passing through fault current magnitude, increasing the capacity of buses due to the possibility of paralleling power transformers and the capability of fast system reconnection after fault clearance (Chang, P.C. Loh, 2001; Rubenbauer, G. Herold, 2006; Nagata *et al.,* 2001; Meyer, R. W. De Doncker, 2006; Calixte *et al.,* 2002; Schmitt *et al.,* 2006; Calixte, *et al.,* 2004).

The most common ways to decrease the fault level are the existing bus discretion, adding series reactor in transmission line, applying high impedance transformer and replacing devices with the ones able to bear new fault level. These ways do not enable system to transmit more power or control the power flow direction (Karady, 1992; Smith et al., 1993; Steurer *et al.,* 2003; Kondoh and I. Ishii, 2004; Power, 1995).

The fault current limitation techniques can be classified in the following categories:

- Fault current reduction through fuses (Power, 1995)
- Impedance limiters using mechanical switches (Power, 1995)
- Thyristor switches equipped limiters (Power, 1995; Zou *et al.,* 2002) Super conductive limiters (Kang *et al.,* 2003; Ahn *et al.,* 2004; Cheol Ahn *et al.,* 2005; Grornoll *et al.,* 1997; Ye *et al.,* 2002; Waynert *et al.,* 2003; Yazawa *et al.,* 2004; Ye, A. Campbell, 2006; Sokolovsky *et al.,* 2004)
- Voltage source converters based limiters (Vilathgamuwa *et al.,* 2006; Nielsen *et al.,* 2004; Sugimoto *et al.,* 1996; Choi *et al.,* 2005; Baghaee *et al.,* 2008)
- Interline power control limitation (Farmad *et al.,* 2006)

There exist several shapes of super conductive limiters such as inductive, resistive, and saturated core fault current limiters (Kang *et al.,* 2003; Ahn *et al.,* 2004; Cheol Ahn *et al.,* 2005; Grornoll *et al.,* 1997; Ye *et al.,* 2002; Waynert *et al.,* 2003; Yazawa *et al.,* 2004). Applying superconductive limiters in 120 kV and higher voltage levels are economically justified [21]. In general, all limiters mentioned above have the following advantageous or disadvantageous (Ye, A. Campbell, 2006; Sokolovsky *et al.,* 2004):

- Their impedance magnitude equals to zero in super conductive condition and the conduction is accomplished under zero losses state.
- The super conductivity state transmission to the normal state (high resistance) is executed very fast and generally, the supper conductive limiters are fast operating limiters.
- The low recovery speed of super conductivity after the fault tackle makes reconnection a major problem.
- These limiters require special fault recognizer relays.
- They are expensive.

Applying the power electronic devices based limiters is another way of fault current limitation. The voltage source converters, consist of a dc voltage source provide ac voltage by proper switching pattern. The converters intend to operate as voltage source, should apply switches with switching off capability (like IGBT). Applying such elements in the system structure raises the following advantageous:

- According to very applicable control of such devices, the transmission system operation under different operational conditions can be flexibly controlled.
- These devices respond to the created variations very fast.
- Their multiple capabilities under different operational conditions economically justify their utilization.

Applying power electronics devices for fault current reduction is an idea, which is under, consider due to the following reasons:

First is that adding limitation capability to these devices does not weaken their main operation. In other words, FACTS devices can operate as fault current limiter during fault contingency in addition to operations such as transient stability improve, dynamic stability improve, network safety increase, and power flow control.

The second issue is the fact that there is no further demand to the existing hard wares and fault current limitation capability is just achieved by changing the switching control strategy.

In applying voltage sources for fault current limitation, these sources stand in series with lines change their own injecting voltage angle and amplitude in a way that the fault current is limited (Vilathgamuwa *et al.,* 2006; Nielsen *et al.,* 2004). The general principles of series compensation for fault limitation are previously investigated in details (Nielsen *et al.,* 2004; Sugimoto *et al.,* 1996; Choi *et al.,* 2005; Baghaee *et al.,* 2008). In (Nielsen *et al.,* 2004), a dynamic voltage restorer is used to decrease the voltage sag (drop) magnitude in the distribution system. It is also investigated there that the injected voltage proper control can result in proper voltage restoring and fault current limiting in the distribution system. In (Sugimoto *et al.,* 1996), a fault current limiter with series compensation capability is presented. The hybrid control schemes are also investigated for series compensation and for fault current limitation in low voltage and medium voltage networks.

In this paper, the performance of thyristor controlled series capacitor (TCSC) is investigated and it is tried to apply it as a fault current limiter in addition to the expected compensation capability by changing the applied conventional controlling techniques. It is targeted here to make TCSC to track different aims for upstream and downstream faults. The fuzzy control technique is applied to achieve this. The simulation results well show that the mentioned control scheme is effectively able to limit the fault current.

1. System Modelling:

1.1. The Synchronous Generator Modeling:

The generator is modeled in rotating reference frame based on the following equations considering the existence of damping winding:

$$\frac{d\delta}{dt} = \omega_B (S_m - S_{m0}) \tag{1}$$

$$\frac{d\delta_m}{dt} = \frac{1}{2H}[-D(S_m - S_{m0}) + T_m - T_e] \tag{2}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{do}^{'}}[-E_q^{'} + (x_d - x_d^{'})i_d + E_{fd}] \tag{3}$$

$$\frac{dE_d^{'}}{dt} = \frac{1}{T_{qo}^{'}}[-E_d^{'} + (x_q - x_q^{'})i_q] \tag{4}$$

The electrical torque relation is as follows:

$$T_e = E_d^{'} i_d + E_q^{'} i_q + (x_d^{'} - x_q^{'}) i_d i_q \tag{5}$$

For a system with no losses, the stator equations are considered as follows [29, 30]:

$$E_q^{'} + x_d^{'} i_d = v_q \tag{6}$$

$$E_q^{'} + x_d^{'} i_d = v_q \tag{7}$$

$$v_q = -x_e i_d + E_b \cos\delta \tag{8}$$

$$v_d = x_e i_q - E_b \sin\delta \qquad (9)$$

$$i_d = \frac{E_b \cos\delta - E_q}{x_e + x_d^{'}} \qquad (10)$$

$$i_q = \frac{E_b \sin\delta - E_q}{x_e + x_q^{'}} \qquad (11)$$

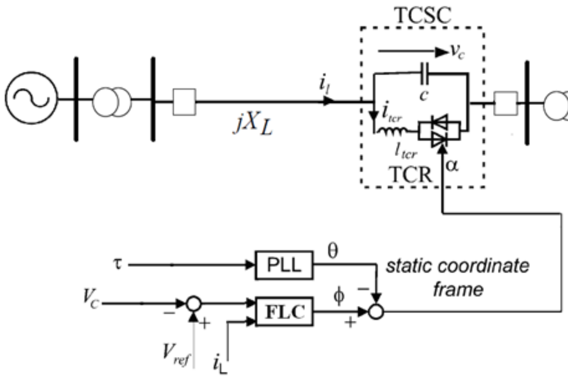

Fig. 1: the investigated system

TCSC Modeling:

TCSC is one of the best and the most important devices among the FACTS devices. It has been used for many years to control power flow and to improve power system stability. TCSC consists of three main parts: thyristor bank, bypass inductors, and bidirectional thyristors. The trigger angle control of the thyristors leads to line reactance change.

As the trigger angle, α, or the conduction angle, σ, vary, the transmission line inductance varies. If the current passing through TCSC is assumed sinusoidal, there exist a relation between α and X_{TCSC} in the steady state of the system as follows:

$$X_{TCSC} = X_C - \frac{X_C{}^2(\sigma + \sin\sigma)}{(X_C - X_P)} + \frac{4X_C{}^2}{(X_C - X_P)} \times \frac{\cos^2(\sigma/2)}{(k^2-1)} \times \frac{[k\tan(k\sigma/2) - \tan(\sigma/2)]}{\pi} \qquad (12)$$

Due to the above relation, TCSC operates in the operational region depicted as follows:

$$X_{TCSC,\min} < X_{TCSC} < X_{TCSC,\max} \qquad (13)$$

$$X_{TCSC,\min} = X_{TCSC}(\alpha_{\min}) \qquad (14)$$

$$X_{TCSC,\max} = X_{TCSC}(180^o) \qquad (15)$$

It is assumed here that the controller operates in its capacitance compensation region ($\alpha_r < \alpha_{min}$) and α_r is the trigger angle in proportion with the resonance.

2. The Proposed Control Scheme:

In the recent years, applying fuzzy controllers due to their simplicity and proper control capabilities is considerably increased. The fuzzy controllers also are more flexible if compared with the conventional PI controllers when an exact model of the system does not exist and the data are not completely exact.

The fuzzy theory is designed to process and analyze the non-exact data. This theory expresses the non-exact data in terms of the membership functions. The membership functions can easily be applied for logic conclusions.

In order to design a fuzzy controller, the inputs and outputs of fuzzy controller should be determined at the first step. In this paper, load current and the difference exist between upstream bus voltage and the load voltage magnitudes are considered as inputs. The controller output is the reference voltage injected by TCSC. The inputs are allocated to a linguistic variable through the fuzzy membership functions. The linguistic variables are big negative (BN), small negative (SN), zero (Z), small positive (SP), and big positive (BP). The input and output membership functions are illustrated in Fig. 2. After inputs changed to fuzzy variables, the linguistic variables should be combined through the fuzzy logics. The fuzzy logics are shown in Table 1.

Table 1: the fuzzy logics

V_C-V_{ref} I_L	Bn	SN	Z	SP	BP
BN	BN	BN	SN	SN	Z
SN	SN	SN	Z	Z	SP
Z	SN	SN	N	SP	SP
SP	SN	Z	SP	SP	BP
BP	Z	SP	SP	BP	BP

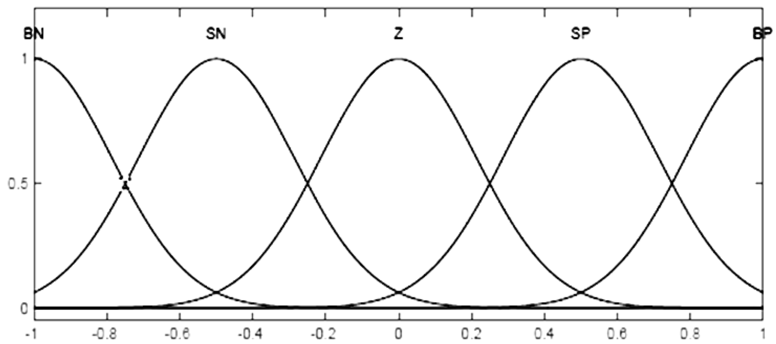

Fig. 2: the membership functions

3. Simulation Results:

The investigated network is simulated in Matlab/SIMULINK in two different conditions for a three-phase to ground fault: one with no fault limitation strategy and the other with fault limitation strategy. The three-phase fault current for both conditions is shown in Fig.3. The upstream bus voltage for both conditions is also shown in Fig.4. In addition, the TCSC conduction angle is illustrated in Fig.5. The simulation results well show that the proposed control scheme is effectively able to limit the fault current of the network.

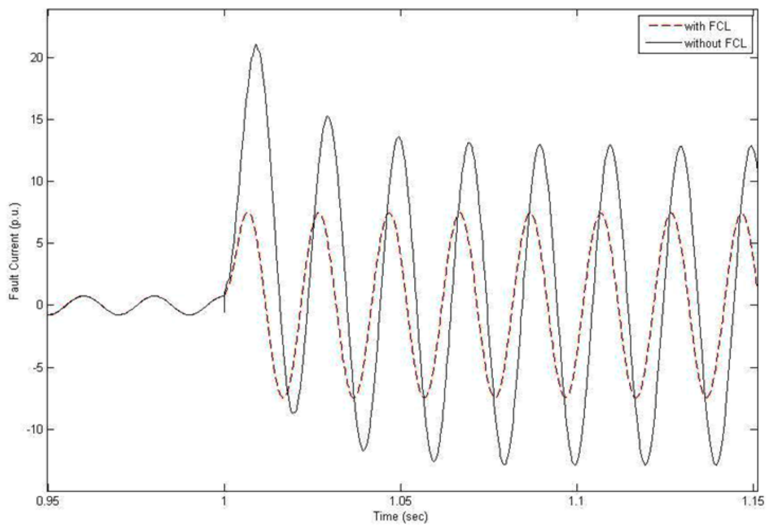

Fig. 3: the three-phase fault current with and without limitation strategy

Conclusion:

In this paper, a method is presented to control the thyristor controlled series capacitor. The proposed method is based on the fuzzy control. The simulation results depict that the fuzzy controller can limit the fault current under fault occurrence condition by injecting proper voltage in addition to power flow control in its normal operation mode, which is due to its flexibility and nonlinear systems control capability.

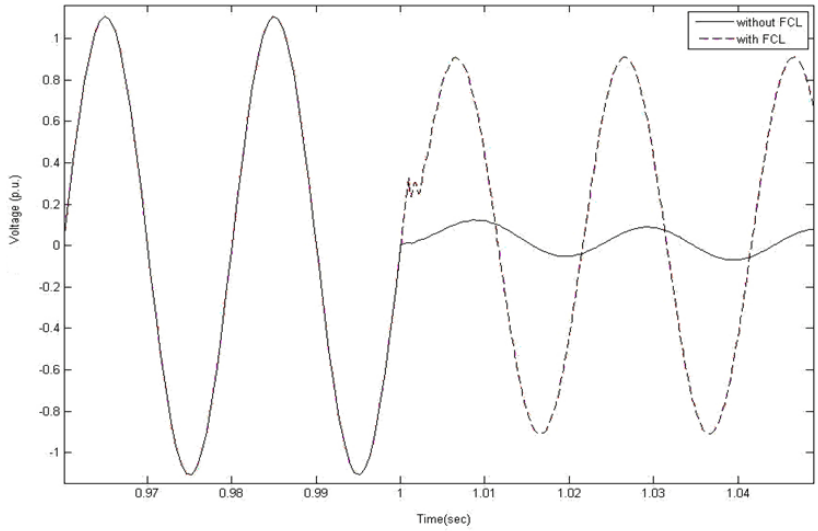

Fig. 4: the three-phase fault current with and without limitation strategy

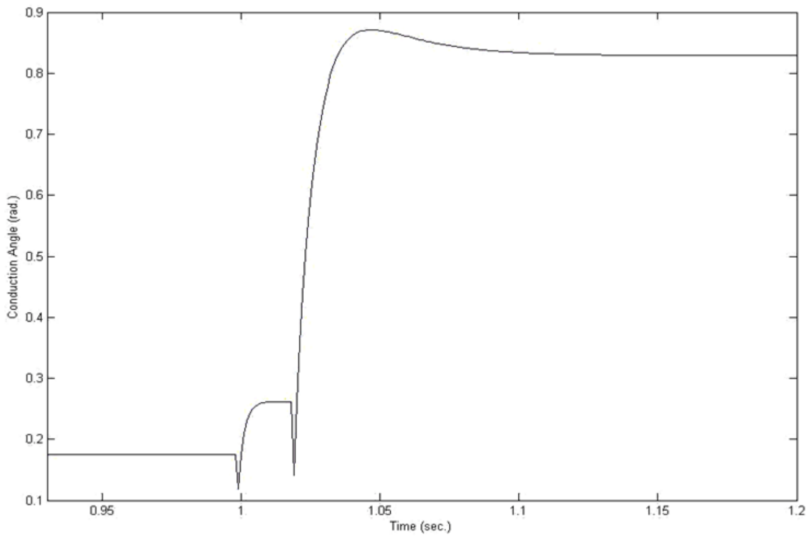

Fig. 5: the TCSC conduction angle

REFERENCES

Ahn, M.C., S. Lee, H. Kang, D.K. Bae, M. Joo, H.S. Kim and T.K. Ko, 2004. “Design, fabrication, and test of high-Tc superconducting DC reactor for inductive superconducting fault current limiter,” IEEE Trans. Appl. Supercond., 14(2): 827-830.

Baghaee, H.R., S.M. Mirsalim, M.J. Sanjari, G.B. Gharehpetian, 2008. “Fault Current Limiting in Distribution System with Penetration of DG Units using A New Dual Functional Series Compensator“,proceeding of 13th International Power Electronics and Motion Control Conference, EPE-PEMC 2008, Poznan-Poland, Sep.

Calixte, E., Y. Yokomizo, H. Shimizo, T. Matsumura, H. Fujita, 2002. "Reduction Effect of Semiconductor Type Fault Current Limiter on Interrupting Duty of a Circuit Breakers", IEEE.

Calixte, E., Y. Yokomizu, H. Shimizu, T. Matsumura, H. Fujita, 2004. "Reduction of Rating Required for Circuit Breakers by Employing Series-Connected Fault Current Limiters", IEE.

Choi, S.S., T.X. Wang and D.M. Vilathgamuwa, 2005. “A series compensator with fault current limiting function,” IEEE Trans. Power Delivery, 20(3): 2248-2256.

Chang, C.S., P.C. Loh, 2001. "Integration of Fault Current Limiters on Power Systems for Voltage Quality

Improvement", Elsevier.

Cheol Ahn, M., H. Kang, D. Kweon Bae, D. Keun Park, Y. Soo Yoon, S. Jin Lee and T. Kuk Ko, 2005. " The Short-Circuit Characteristics of a DC Reactor Type Superconducting Fault Current Limiter With Fault Detection and Signal Control of the Power Converter", IEEE Trans. on Applied Superconductivity, 15(2): 2102-2105.

Farmad, M., S. Farhangi, S. Afsharnia and G.B. Gharehpetian, 2006. ”An Efficient Algorithm for Determining the Values of Elements of Interphase Power Controller as a Fault Limiter”, accepted in 2006 Power Systems conference & Exposition.

Grornoll, B., G. Ries, W. Schmidt, H.P. Krarner, P. Kumrneth, H.-W. Neumuller and S. Fischer, 1997. “Resistive current limiters with YBCO films,” IEEE Trans. Appl. Supercond., 7(1): 828-831.

Karady, G.G., 1992. "Principle of fault current limitation by a resonant LC circuit", IEE Proc. C, 139(1):1.

Kang, H., M.C. Ahn, Y.K. Kim, D.K. Bae, Y.S. Yoon, T.K. Ko, J.H. Kim, and J. Joo, 2003. “Design, fabrication and testing of superconducting DC reactor for 1.2 kV/80 A inductive fault current limiter,” IEEE Trans. Appl. Supercond., 13(2): 2008-2011.

Kondoh, J. and I. Ishii, 2004. "Fault Current Limiting Transformer with Variable Reactance", IEEE Trans. on Applied Superconductivity, 14(2): 875-878.

Kundur, P., 1994. Power System Stability and Control. New York: McGraw-Hill.

Meyer, C., R.W. De Doncker, 2006. "LCC Analysis of Different Resonant Circuits and Solid-State Circuit Breakers for Medium-Voltage Grids", IEEE TRANSACTION, 21: 3.

Nagata, M., K. Tanaka, H. Taniguchi, 2001. "FCL Location Selection in Large Scale Power System", IEEE TRANSACTION, VOL. 11, NO. 1.

Nielsen, J.G., M. Newman, H. Nielsen and F. Blaabjerg, 2004. “Control and testing of a dynamic voltage restorer (DVR) at medium voltage level”, IEEE Trans. Power Electron., 19(3): 806-813.

Padiyar, K.R., 2002. Power System Dynamics Stability and Control, BS Publications, 2nd Edition, Hyderabad, India,

Power, A.J., 1995. "An overview of transmission fault current limiters",

Rubenbauer, H., G. Herold, 2006. "Simulation of a Power Electronic Based Fault Current Limiter (FCL) in Case of Different Faults" IEEE.

Schmitt, H., 2006."Fault Current Limiters Report on the Activities of CIGRE WG A3.16", IEEE.

Smith R.K. et al., 1993. "Solid-state Distribution Current Limiter and Circuit Breaker: Application requirements and control strategies", IEEE Trans. on Power Delivery, 8(3): 1155.

Sokolovsky, V., V. Meerovich, I. Vajda, V. Beilin, 2004. "Superconducting FCL: Design and Application", IEEE Trans. On Appl. Supercond, 14: 3.

Steurer, M., K. Fröhlich,W. Holaus and K. Kaltenegger, 2003. “A novel hybrid current-limiting circuit breaker for medium voltage: Principle and test results,” IEEE Trans. Power Del., 18(2): 460-467.

Sugimoto, S., J. Kida, H. Arita, C. Fukui and T. Yamagiwa, 1996. “Principle and characteristics of a fault current limiter with series compensation,” IEEE Trans. Power Del., 11(2): 842-847.

Vilathgamuwa, D.M., P.C. Loh, and Y. W. Li, 2006. “Protection of microgrids during utility voltage sags,” IEEE Trans. Ind. Electron, 53(5): 1427-1436.

Waynert, J.A., H.J. Boenig, C.H. Mielke, J.O. Willisand and B.L. Burley, 2003. “Restoration and testing of an HTS fault current controller,” IEEE Trans. Appl. Supercond., 13(2): 1984-1987.

Yazawa, T., Y. Ohtani, M. Sasaki, T. Kuriyama, S. Nomura, T. Ohkuma, N. Hobara, Y. Takahashi and K. Inoue, 2004. “Development of 66 kv/750 A high-Tc superconducting fault current limiter magnet,” IEEE Trans. Appl. Supercond., 14(2): 786-790.

Ye, L., L.Z. Lin and K. Juengst, 2002. “Application studies of superconducting fault current limiters in electric power system,” IEEE Trans. Appl. Supercond., 12(1): 900-904.

Ye, L., A. Campbell, 2006. "Behavior investigation of Superconducting Fault Current Limiters in Power Systems", IEEE Trans. On Appl. Supercond, 16(2).

Zou, J., J. Chaen, E. Dong, 2002. "study of fast closing switch based fault current limiter with series compensation", Electrical Power and Energy Systems, 24: 719-722.