Research of the Effect for Relay Protection Based on STATCOM

YANG Xiao-ping，GAO Li-gang，LIANG Zhen-feng，ZHONG Yan-ru

***Abstract*-- This paper deals with the influence of the STATCOM to the relay protection. The fundamental compensation principle, the main circuit and control strategies of STATCOM are all proposed. Then the mathematical model of the distribution system with STATCOM is established, the three-phase short-circuit fault is analyzed. The EMTDC/PSCAD is used for analyzing the dynamic characteristics and protection of distributed power system during balanced fault. And then the instantaneous over-current protection, the time delay instantaneous over-current protection and definite time over-current protection are installed. The operation logic of the relay protective in distribution system with STATCOM is analyzed. Simulation results show that a STATCOM voltage controller can improve the stability performance of voltage and reduce the reactive and fault current, but the selectivity of the relay protection is impacted. To ensure the protective selectivity, a new five-step protection scheme is presented. The results of the dynamic simulation verify the validity of the presented scheme.**

***Index Terms*--Distribution system; EMTDC/PSCAD; Five-step protection scheme; Flexible AC Transmission Systems (FACTS); Power system; Relay protection; Selectivity; Static Synchronous Compensator (STATCOM); Sensitivity; SPWM**

I. INTRODUCTION

The static synchronous compensator (STATCOM) is reactive power compensation with the best performance in the power system, which is a critical technique in the flexible alternative current transmission system (FACTS). The STATCOM technology is gradually employed to increase power transfer capability and provide voltage support. Compared with the traditional Static VAR Compensation (SVC) device, it has faster dynamic response, better reproducibility and reversibility, wider measurement range, lower harmonic output, smaller wastage and more credible capability.

Many research in the voltage regular and provides efficient damping of oscillations by STATCOM have been studied [2~3]. They focused on the theory and application of controller. The new research in the field of the influence to system faults and the relay protection by the STATCOM is still at starting stage. The influence of STATCOM on the distance protection of high-voltage transmission line is analyzed based on the characteristics of harmonics as in [4]. It concluded that the effect related to the installed position of STATCOM. The shorter the distance is; the greater influence will be impacted by the harmonics. In [5], a dynamic study about the influences of ac generator and DSTATCOM on the dynamic behavior of distribution network is presented, the performance of a DSTATCOM as a voltage controller or a power factor controller is analyzed. The impact of this controller on the stability and protection system of distribution with distributed generators is determined. It shows that a DSTATCOM voltage controller can improve the stability performance of induction generators significantly. In [6], a control of unbalanced voltage based on STATCOM is introduced, the single-phase-to-ground fault and unbalanced load is analyzed. In [7], a synchronous frame voltage regulator is presented when three phase symmetry is lost. This regulator employed separate regulation loops for the positive and negative sequence components to control unbalanced voltage. The proposed regulator allows the STATCOM to ride through severe transient unbalanced without disconnecting from the power system.

In summary, all these concerned is the influence to the system or the faults, the research of the impact to relay protection is limited.

The contents of this paper are as follows. First, the SPWM control strategy of STATCOM is used [8]. Mathematical model of the distribution system with STATCOM is established. Then the EMTDC/PSCAD package and defined modules are used for analyzing the dynamic characteristics and protection of distributed power system during system faults. Finally, a new protection scheme for transmission line of five-step protection scheme is presented to ensure the protective selectivity of distributing line. Theoretical analysis shows that STATCOM can improve the stability performance of voltage and compensate unbalanced reactive current in the distribution system. By the new scheme of the five-step protection, the protection sensitivity is improved and the selectivity is ensured in the distribution system.

II. DSTATCOM CONTROL ALGORITHM

STATCOM is used to regulate the voltage by absorbing or generating reactive power in the network, like a thyristor static compensator. Two-level converter of three phase bridges voltage source converter (VSC) is built with IGBT in main circuit. The reactive power control strategy with SPWM of

YANG Xiao-ping is with the department of the Power System, xi'an university of technology. (E-mail: yangxiaoping@xaut.edu.cn)
GAO Li-gang is with the department of the Power System, xi'an university of technology. (E-mail: gaolg0612@163.com)
LIANG Zhen-feng is with the department of the Power System, xi'an university of technology(E-mail: Lzf@xaut.edu.cn)
ZHONG Yan-ru is with the department of the Power System, xi'an university of technology(E-mail: Zhongyr@xaut.edu.cn)

STATCOM is used .The conventional *PI-dq* current control method is selected to design the controller. The strategy is shown in the Fig.1.The ac line current value was measured by investigated *PI-dq* current controller, and then was transformed into dq-axis quantity. I_{pref} is the active current reference, I_{qref} is the reactive current reference, and U_{dcref} is the reference voltage of capacitance. By calculating the errors of i_d, I_{pref} and i_q, I_{qref}, they compensated by two PI controllers and then transform them back to three phase signal e_v. Reactive current injection is controlled by e_v and the triangle waveform. The three-phase reference signals are then transformed to d-q axes modulation signals using the inverse transformations of (1) and (2). *sin(ωt)* and *cos(ωt)* is calculated by phase-locked loop(PLL).Theoretically, ω should strictly match the line frequency, thus implying online measurement of system frequency. However, for a power system, the frequency variation is restricted to a small range. Therefore, a constant ω corresponding to the most probable frequency can be used without significant deterioration of transient performance.

$$\begin{bmatrix} i_a \\ i_\beta \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & 0 & 0 \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) \\ \sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (2)$$

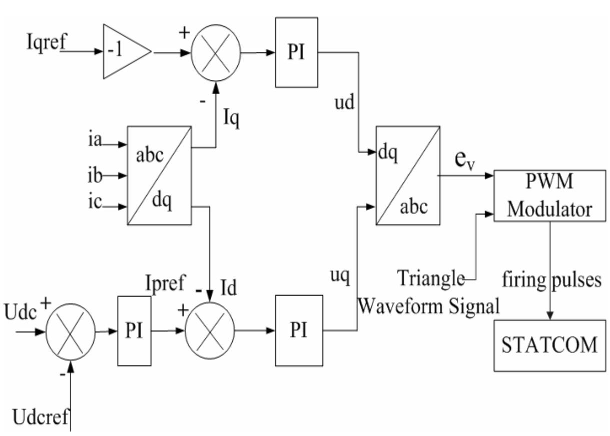


Fig. 1. Block diagram of the control implemented in the STATCOM

III. ANAYSISTHEIMPACTOF STATCOM ON PROTECTION SYSTEM

The system network with STATCOM is analyzed during three-phase short-circuit fault. Under balanced three-phase fault conditions, it is convenient to use the per-phase equivalent circuit to represent the three-phase fault system. The STATCOM is controlled as a voltage source; a single fault system is shown in Fig. 2.

U_s is the voltage of distribution system , U_{I1} is the output voltage of STATCOM, Z_{s1} is the impedance of power source system to the installation position of STATCOM, Z_{I1} is the connected impedance of STATCOM to the system,Z_{s1I} is the impedance of node A to the fault point. We assumed the $Z_{I1} >> Z_{s1}$ for convenience, and then the voltage of U_A is according to (3).

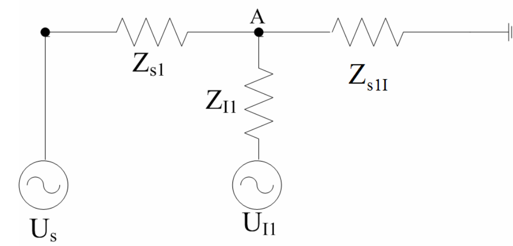


Fig. 2. Simple system network including DSTATCOM when the three phase fault

$$U_A = \frac{U_s}{\frac{Z_{s1}}{Z_{s11}}+1} + \frac{U_{11}}{Z_{11}} \times \frac{Z_{s1}}{\frac{Z_{s1}}{Z_{s11}}+1} \qquad (3)$$

Where, U_A is maintained by the voltage of U_{I1} and U_S.U_{I1} is restricted by dc voltage and the output current of STATCOM.

The value of U_{I1}

$$U_{11} = KU_{dc} \qquad (4)$$

Where K is the ratio of modulation, U_{dc} is the dc voltage.

The output current of STATCOM:

$$I_{kI} = \frac{U_{11} - U_A}{Z_{I1}} \qquad (5)$$

Then

$$KU_c = U_A + I_{K1} \left| Z_{I1} \right| \qquad (6)$$

The running condition of the STATCOM is

$$\begin{cases} U_{c\max} > U_c > U_{c\min} \\ I_{k\max} > I_{k1} \end{cases} \qquad (7)$$

Where U_{Cmax} and U_{Cmin} are upper and lower limits, I_{Kmax} is the safety limits of STATCOM. Then

$$U_A = \frac{U_s}{\frac{Z_{s1}}{Z_{s11}}+1} + K_I I_{K\max} (Z_{s1} // Z_{s11}) \qquad (8)$$

Without the STATCOM, the U_A is

$$U_A = \frac{U_s}{\frac{Z_{s1}}{Z_{s11}}+1} \qquad (9)$$

It is obvious from (8) and (9) that the voltage can be improved greatly by the synthetic compensation of reactive power.

IV. DYNAMIC SIMULATION MODEL

Typical distribution system is shown in Fig. 3. The voltage of main bus is 13.2kV, 15MVA. The different loads of P1-P5 are shown in the table. As the principle for power distribution network, the simulation model is built in the PSCAD/EMTDC program. The three-step current protection is installed in the system.

load	type	P and $\cos\theta$
P_1	RL	0.5MW，0.95
P_2	RL	0.5MW，0.85
P_3	RL	4MW，0.85
P_4	R	1.5MW，1.0
P_5	RL	1.5MW，0.85

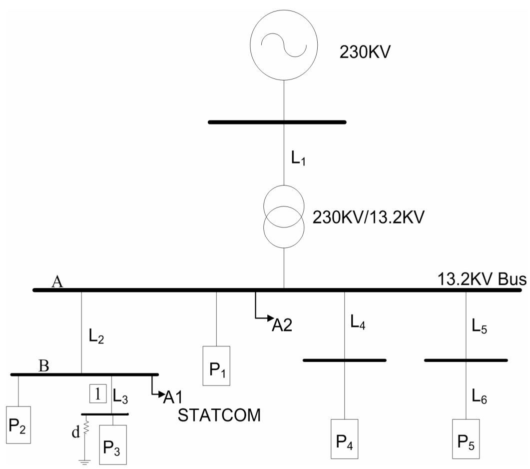


Fig. 3. The typical distribution system

The instantaneous over-current and the definite time over-current protection are installed in L_3, the relay setting are 0.6872kA and 0.2413kA respectively, the time delay of zone I, zone III is 0.1s and 1.2s.Set three-phase short-circuit fault in *d* at 0.3s. Without STATCOM, the operating time of instantaneous over-current protection of zone I is 0.42s. The main bus voltage of pre-and post-fault is 10.2kV, 7.94kV, there is an impulse voltage when the relay is operating, as shown in the Fig.4. The pre- and post-fault current of the L_3 is 0.22kA, 1.25kA, as shown in the Fig. 5. The RMS of the fault current is 0.721kA during the fault and decreased to 0 when the circuit breaker tripped at 0.42s, as shown in the Fig. 8.

With the STATCOM in the A1 where is point of common coupling (PCC). The main bus voltage of pre-and post-fault is 10.2kV, 8.19kV, as shown in the Fig. 6. The fault current of the L_3 is 0.922kA as shown in the Fig. 7; Then RMS of the fault current is 0.5328kA as shown in the Fig.8, the instantaneous over-current protection of zone I fails to operate, definite time over-current protection of zone III is started at 1.53s.

Simulation results show that the voltage can be improved by the synthetic compensation of reactive power, to be near rated value of voltage on principle. Impulse of fault current is limited; the fault current is reduced by the compensated of reactive current and the selectivity of the current protection is impacted.

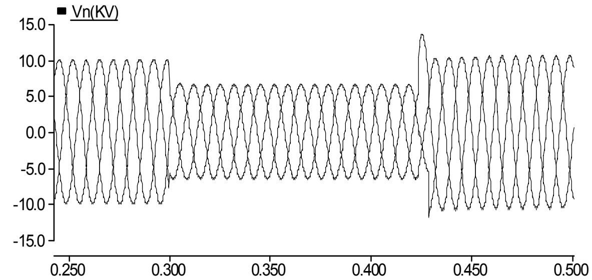


Fig. 4. Voltage of bus when three phase fault without the STATCOM

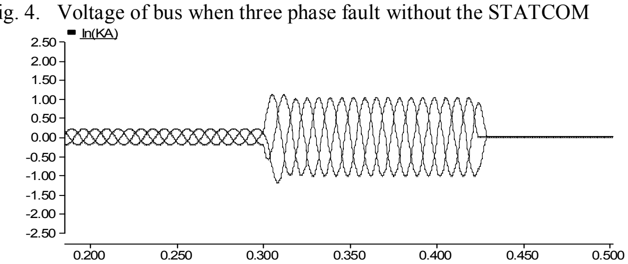


Fig. 5. Load currents of three phase fault without the STATCOM

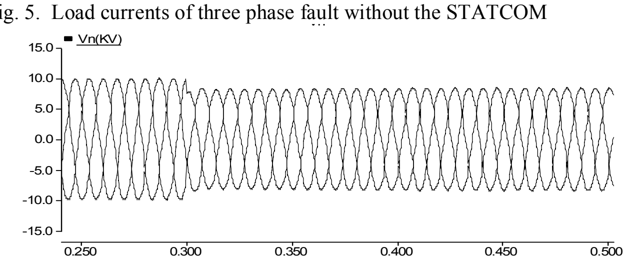


Fig. 6. Voltage of bus when three phase fault with the STATCOM

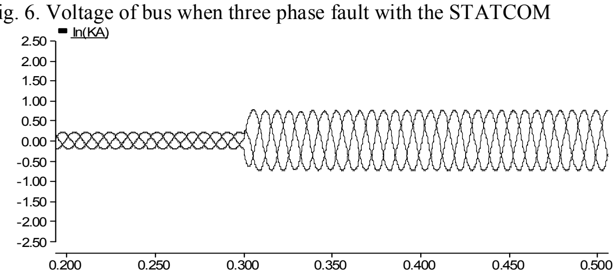


Fig. 7. Load currents of three phase fault with the STATCOM

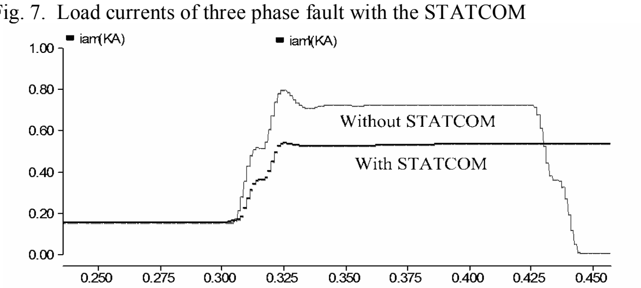


Fig. 8. Root-mean-square of A phase load current when three phase fault with or without the STATCOM

V. NEW SCHEME OF THE RELAY PROTECTION

In general, there is a selectivity problem in the current protection with the STATCOM as the typical model of the Fig.3. For the purpose of this discussion, the protection system is built as shown in the Fig.9. If a fault occurred on transmission line of d_1, the protection 1 is started. With the STATCOM, the fault current of line is influenced. Then it should result in maloperation and misoperation.

To ensure the protective selectivity and the sensitivity of distributing line, several solutions have been suggested. Adaptive instantaneous current protection scheme is presented in [10]; the protection relay setting can be adjusted when the STATCOM is connected. The method is influenced by the operating mode and the convenience is limited.

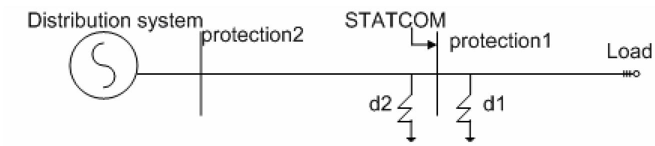


Fig. 9. Structure of the Distribution system

This paper presents a new protection scheme for transmission line that is five-step protection scheme [11]. The insensitive zone I is used to improve the operating speed of zone I of transmission line protection. The sensitive zone I is used to improve the sensitivity of zone I. The insensitive zone II is used to improve the operating speed of zone II, and it is also used to enhance property to detect arc-resistance fault. The sensitive zone II is used to improve the protection sensitivity of zone II and is used to improve the operating speed of backup protection of the next circuit. Zone III is used as the backup protection of the transmission line and also used as the backup protection of the next circuit.

The relay setting of sensitive zone I is according to the (10),

$$I_{op}^{1} = K_{rel}^{I} I_{k2\max}^{3} \tag{10}$$

Where $K_{rel}^{I} = 0.8 \sim 0.9$, K_{rel}^{I} is the reliable coefficient of current protection; $I_{k2\max}^{3}$ is three phase fault current of end transmission line under maximum operation condition of regulation. The relay setting of insensitive zone I is according to the (10), the reliable coefficient of current protection $K_{rel}^{I} = 1.3 \sim 1.4$.

The setting for zone II of current protection of transmission line with (11), (12)

$$I_{op1}^{2} = K_{rel}^{2} I_{op2}^{1} \tag{11}$$

$$I_{op1}^{2} = K_{rel}^{2} I_{op2}^{2} \tag{12}$$

Where I_{op1}^{2} is the relay setting of time delay instantaneous over-current protection, the reliable coefficient of $K_{rel}^{2} = 1.1 \sim 1.5$ when ignored periodic component in short circuit current. I_{op2}^{1} is the relay setting of instantaneous over-current protection 2. The insensitive zone II is according to (11) and the insensitive zone II is according to (12).

Zone III is used as the backup protection of the transmission line, which is the same as conventional protection in principle.

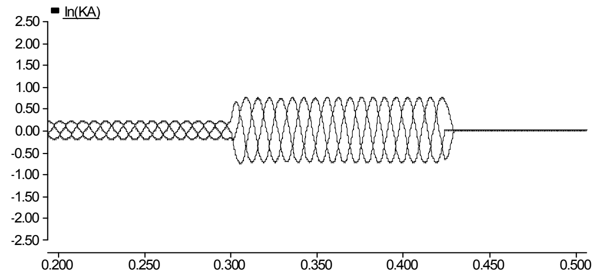


Fig. 10. Load currents of three phase fault with the STATCOM

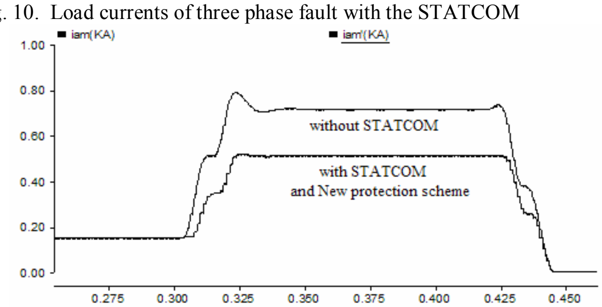


Fig. 11. Root-mean-square of the A phase load current when three phase fault with the STATCOM and the new protection scheme

According to five-step protection scheme, three steps are separately installed in location 1 as shown in Fig 3. The relay setting of sensitive and insensitive zone I are 0.4867kA and 0.7445kA respectively, the zone III is 0.2413kA. With the STATCOM, the instantaneous over-current protection is started at 0.42s, as shown in Fig.10 and Fig.11. The sensitivity is improved and the selectivity is ensured when the new protection scheme adopted in the distribution system.

VI. Conclusion

With the fundamental compensation principle, a mathematical model of the distribution system with STATCOM is established, the three-phase short-circuit fault is analyzed.

The main conclusions obtained from this work are the following: STATCOM voltage controller can improve the stability performance of voltage and compensate the balanced reactive current on the fault line, but the selectivity of the relay protection is impacted. By the new scheme of the five-step protection, the sensitivity is improved and the selectivity is ensured in the protection of the distribution system. Simulation results verify that the bus voltage is compensated and the load current is reduced, the new scheme is available to ensure the sensitivity and selectivity of protection.

VII. References

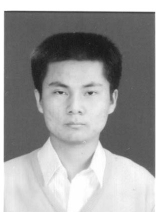
[1]YANG Xiao-ping; SUN Xiao-Juan, "control method of STATCOM," *Electric Machine & Electric Apparatus Technologies*, pp. 36-39, JAN.2004.

[2]Ji Sheng Lai,Fang Zheng Peng, "Multilevel converters-a new breed of power converters, " *IEEE Transactions on Industry Applications 32nd 1996*, pp. 509-517.

[3] YANG Xiaoping，ZHONG Yanru，WANG Yan. "A Novel Control Method for DSTATCOM using Artificial Neural Net," *IEEE 5th International Power Electronics and Motion Control Conf.* Aug.2006.
[4] WU zhengjie, "Research on Distance Relay in the Presence of STATCOM," *Master dissertation*, Dept.North China Electric Power University, 2003
[5] Walmir Freitas,Andre Morelato, "Impacts of AC Generators and STATCOM Devices on the Dynamic Performance of Distribution Systems," *IEEE Transactions on Power Electronics*, Vol:20, pp. 1493-1501 ,2005.
[6] TANG yafang ,SHI huaijin . "The Application of the Protective Control on the SATCOM," *Journal of Guizhou University of Technology* Vol.32, pp. 41-44, 2003.
[7] Clark Hochgra, Robert H. Lasseter. "STATCOM Controls for Operation with Unbalanced Voltages," *IEEE Transactions on Power Electronics*, Vol: 19, pp. 1242-1247, 2003.
[8] Jiang qi rong,Shen dong, Han ying duo etal. "Operation and control of ASVG under system asymmetric conditions," *Journal of Tsinghua University (Science and Technology)* Vol: 37, pp. 26-29, 1997.
[9] DONG yunlong, "Simulation of the STATCOM," Master dissertation, Dept. southeast University .Nanjing. 2005.
[10] OU yang-Bing, LV Yan-ping, LUO de-chang, "Research on network –based adaptive Current Protection principle for distribution network," *Power System Technology*, Vol: 27, pp. 52-55, 2003.
[11] Li xiaoming, Liu yaohui, Cao yan. "The Research on Five-step Protection Scheme for Transmission Line," *Automation of Electric Power Systems*, Vol: 31, pp. 74-78, 2005.

VIII. BIOGRAPHIES

YANG Xiao-ping was born in Shaan Xi, China, in 1964. As an associate professor of xi'an university of technology, her research interests include power electronics, power quality and Power System control.



GAO Li-gang was born in Shaan Xi, China, in 1981, as a master graduate student of xi'an university of technology, his research interests is power electronics, power quality and the control of microcomputer protection.

LIANG Zhen-feng was born in Shaan Xi,China ,in 1974,as a lecturer of the department of the Power System in xi'an university of technology, his research interests is the control of Microcomputer protection.

ZHONG Yan-ru was born in 1950, as a professor of department of the Power System, xi'an university of technology, his research interests include power electronics, power quality and Power System control.