Electrical Power and Energy Systems 42 (2012) 702–709

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Impact of SVC on the protection of transmission lines

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ARTICLE INFO

Article history:
Received 17 March 2010
Received in revised form 21 April 2012
Accepted 23 April 2012
Available online 26 June 2012

Keywords:
Distance relay
Trip boundary
Static Var Compensator (SVC)
Thyristor Controlled Reactor (TCR)
Thyristor Switched Capacitor (TSC)

ABSTRACT

The impact of Static Var Compensator (SVC) on the apparent impedance seen by the transmission line distance relay is investigated in this paper. Analytical results are presented and verified by detailed simulations. It is shown that the connection type of the windings of the shunt coupling transformer of the SVC has a remarkable effect on the apparent impedance seen by the distance relay. Six different phase to phase and phase to ground measuring units of the distance relay are simulated to resemble the behavior of the relay. The impact of SVC is more pronounced on the apparent impedance seen by the phase to ground fault measuring units than the others as is shown by the results. Simulation results include different power system operating conditions, SVC control system settings and different fault-type scenarios. The impact of SVC on the relay tripping boundaries is also clearly demonstrated. Detailed and sophisticated models are used for simulating distance protective relay in a digital simulation environment.

1. Introduction

Static Var Compensator (SVC) is one of the earliest Flexible AC Transmission System (FACTS) devices. It generates or absorbs reactive power at its point of connection, usually in the middle of a high voltage transmission line. Before the evolution of SVC in the 1960s, synchronous compensators performed such compensation. Generally, SVC is used to maintain the voltage magnitude at the middle of a long transmission line, thereby to increase the power transfer capability in a given transmission line. Since SVC cannot generate or absorb real power (neglecting its relatively low internal losses), the power transmission of the system is affected indirectly by the voltage control. SVC regulates the voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When the system voltage is low, SVC generates reactive power (capacitive mode) and when the voltage is high, it absorb reactive power (inductive mode) [1].

However, the employment of a SVC in a transmission line creates certain problems for the protective relays and fault locators using conventional techniques because of the rapid changes introduced by the associated control actions. Apparent line impedances seen by conventional distance relays are affected due to the variation of the voltage at the point of SVC connection. It is worth noting that distance relays estimate the fault location by calculating the apparent impedance using the voltage and current values at the relaying point [2,3]. When a single a phase fault occurs on a transmission line compensated by SVC; the system voltage decreases, so the SVC takes remedial actions to recover the voltage to its reference value (V_{Ref}). In this sense, reactive capacitive current is needed to be injected by SVC; therefore, the impedance seen by the distance relay starts to change by the intervention of SVC.

Generally, the impact of compensators on the transmission line protection is categorized as series compensation, shunt compensation and series/shunt compensation. The impact of series compensation on the performance of conventional distance relay is presented in [4–7]. The impact of shunt compensation on conventional distance protection has already been studied in [8–10]; meanwhile the impact of series/shunt compensation devices are reported in [11–14]. In these works, it is shown that the presence of FACTS compensators in a fault loop affects the apparent impedance seen by the distance relay. In [8], the impact of STATCOM is investigated. In [9], the performance of distance relays in presence of shunt FACTS compensation devices, i.e., SVC and STATCOM is presented. The main focus of Sidhu et al. [9] is on the impact of STATCOM on the performance of distance relay.

In this paper, the impact of SVC on the apparent impedance seen by a conventional distance relay is evaluated both analytically and by detailed simulations. The merits of this study are summarized as follows:

(1) The impact of SVC is investigated analytically by applying accurate modeling concepts which is missing in most of the literature in this regard, then the analytical results are verified by detailed simulations.
(2) Sophisticated models are used for sources, transmission lines, protective relay and other devices in the sample network.

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0142-0615/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2012.04.029

(3) SVC control system is simulated by detailed transient models. Static models for SVC, as used in some published papers, does not accurately present the behavior of SVC during a fault; hence the performance of the distance relay is not clearly evaluated in this case.
(4) The impact of SVC on the trip boundaries of the distance relay is investigated and interesting results are provided.
(5) In this paper, it is shown that the connection type of the windings of the SVC's coupling transformer directly affects the behavior of the relay.

2. Sample system modeling

Fig. 1 shows the sample system used for the study. It contains two parallel 300 km, 230 kV transmission lines, with the SVC installed in the middle of Line 1. The positive sequence line impedances are the same and equals $Z_{1L1} = Z_{1L2} = 0.0255 + j0.3520\ \Omega$/km; the zero sequence line impedances are $Z_{0L1} = Z_{0L2} = 0.3864 + j1.5556\ \Omega$/km. Short Circuit Level (SCL) at G and H = 8500 MVA; system frequency = 60 Hz; load angle between sources = 30° and the ratio between the magnitudes of the source voltages at G and H = 1.07.

The SVC considered contains one 100 Mvar TCR bank and three 100 Mvar TSC banks which are connected to the middle of Line 1 using a 230 kV/16 kV (Yg/d), 340 MVA coupling transformer. Each three-phase bank is connected in delta so that, during normal balanced operation, the zero-sequence triplen harmonics (3rd, 9th, etc.) remain trapped inside the delta, thus reducing harmonic injection into the power system. Switching the TSCs in and out allows a discrete variation of the secondary reactive power from zero to 300 Mvar capacitive (at 16 kV) by steps of 100 Mvar, whereas phase control of the TCR allows a continuous variation from zero to 100 Mvar inductive.

SVC control system is presented in Fig. 2. Positive sequence fundamental-frequency primary voltage magnitude $V_{abc}(Prim)$, is measured by voltage measurement unit and then is compared with V_{Ref}. The obtained error passes through a PI regulator and presents the primary susceptance, B_{svc}. The associated Phase Locked Loop (PLL) is used to take into account the variations of the system frequency. Distribution unit in Fig. 2 uses B_{svc} to determine the TCR firing angle α and the status (on/off) of the three TSC branches. The firing angle α as a function of the TCR susceptance B_{TCR} is implemented by a look-up table extracted from:

$$B_{TCR} = \frac{2(\pi - \alpha) + \sin(2\alpha)}{\pi} \quad (1)$$

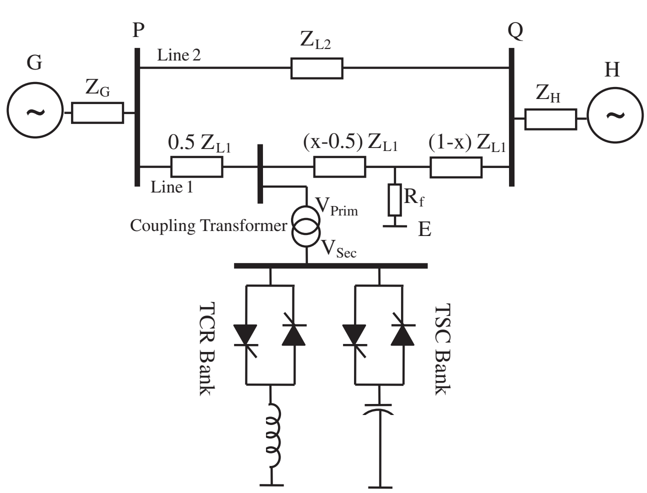

Fig. 1. Single line diagram of the sample system.

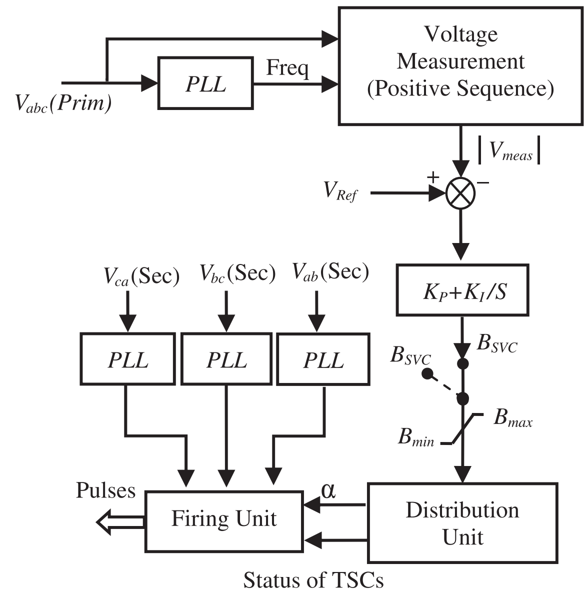

Fig. 2. SVC control system.

where B_{TCR} is the TCR susceptance in p.u. of rated TCR reactive power (100 Mvar). A synchronizing system using a three PLLs synchronized on line-to-line secondary voltages $V_{abc}(Sec)$, and a pulse generator that send appropriate pulses to the 24 thyristors (six thyristors per three-phase bank) are the main components of this SVC control system.

Generally, SVC has two different operational modes:

(1) Voltage regulation mode: In this case V_{Ref} value is specified by external controller. SVC holds output voltage in V_{Ref} by absorbing or generating reactive power and it is performed by a PI regulator.
(2) Var regulation mode: SVC reactive power is fixed in this case and the SVC susceptance is kept constant. The presence of voltage regulator is not necessary in the control system in this mode, so B_{SVC} is applied directly by external controller to the SVC.

3. SVC impact on the apparent impedance measured by the distance relay

Fig. 3 shows the positive, negative and zero-sequence networks of the sample system of Fig. 1 with the SVC in the middle of Line 1. Distance relay is installed at Bus P to protect the associated transmission line. Following parameters are used for the analysis:

V_{0p}, V_{1p}, V_{2p}	are sequence phase voltages at relay location at Bus P;
I_{0p1}, I_{1p1}, I_{2p1}	are sequence phase currents through Line 1 at relay location at Bus P;
I_{0p2}, I_{1p2}, I_{2p2}	are sequence phase currents through Line 2 at relay location at Bus P;
I_{0q1}, I_{1q1}, I_{2q1}	are sequence phase currents through Line 1 at Bus Q;
V_{0E}, V_{1E}, V_{2E}	are sequence phase voltages at fault location E;
Z_{0s1}, Z_{1s1}, Z_{2s1}	are sequence impedances of the Line 1;
Z_{0s2}, Z_{1s2}, Z_{2s2}	are sequence impedances of the Line 2;
R_f	is fault resistance;
x	is fault per-unit distance from the relay location.