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Digital distance protection of transmission lines in the presence of SSSC

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ABSTRACT

In this paper the impact of Static Synchronous Series Compensator (SSSC) on the impedance calculated by distance relay is investigated. Analytical results are presented and verified by detailed simulations. Six different phase to phase and phase to ground measuring units of the distance relay are simulated to resemble the behavior of the relay. It is shown in this paper that zero sequence of the injected voltage by 48 pulse SSSC converter has the most impact on the apparent impedance seen by the phase to ground fault measuring unit and cause under reaching of distance relay. It can be concluded from the results that SSSC located in the middle of the transmission line cause to divide trip characteristics of distance relay into two separate parts. It is also shown that the over-reaching operation of distance relay might happen in some cases in the presence of SSSC. All the detailed simulations are carried out in MATLAB/Simulink environment.

1. Introduction

The voltage source inverter based series VAr compensator, called Static Synchronous Series Compensator (SSSC), was first introduced by Gyugyi in 1989 [1]. Using the power electronic based technologies, a uniform and versatile shunt and series reactive power control throughout the system as well as bus voltage angle control become possible. SSSC principally can play the role of a pure series capacitive or inductive compensation in a transmission line if the output voltage of its series element lags or leads the transmission line current by 90°. Alternatively, in voltage compensation mode, by adjusting the injected series voltage independent of the current, both active and reactive power of the transmission line can be controlled simultaneously [1].

Taking advantages of the power electronic switches, the SSSC can fast modify system parameters like current and impedance of transmission line. Since distance relay calculates the fault location by measuring current and voltage in transmission line, SSSC can disturb the normal operation of a distance relay. Literature in this field can be divided up into three distinct categories concerning the installation method of the compensators in the network; series compensation impact [2–5], shunt compensation impact [6–9] and series/shunt compensation impact [10–13] on transmission line distance protection. In these work, it is shown that the presence of FACTS compensators in a fault loop affects the apparent impedance seen by the distance relay.

In [3,5] the impact of SSSC has been investigated for phase to ground faults. The study first deals with the impact of SSSC on the calculated impedance by a distance relay. In the next stage, SSSC is simulated in detail based on 48-pulsed voltage source converters. Analytical results are validated using the simulations. In [7,8], the performance of distance relays in the presence of shunt FACTS compensation devices, i.e., SVC and STATCOM. The work in [10] presents the impacts of VSC-based FACTS controllers on distance relays while controlling the power flow of compensated lines are evaluated analytically and by detailed simulations for different fault types and locations. In [11], an apparent impedance calculation procedure for a transmission line with UPFC based on the power frequency sequence component is investigated.

In this work, it is shown that despite of the single phase to ground faults, the presence of SSSC in a fault loop cause to over-reaching operation of the relay when two-phase to ground faults occur in the system. In other words, whereas the fault is not in the relay zone, relay operates wrongly which this important issue should be considered in relay setting. It is also shown that SSSC located in the middle of the transmission line cause to divide trip characteristics of distance relay into two separate parts. Simulation results include different power system operating conditions, SSSC control system settings and fault scenarios. Finally, a solution is provided to eliminate the impact of SSSC on low resistive phase to ground faults (which is the most probable fault).

2. Sample system modeling

The configuration of the under study power system equipped with a SSSC device implemented in MATLAB/Simulink environment is shown in Fig. 1. It contains two series 200 km, 400 kV transmission lines having the following data:

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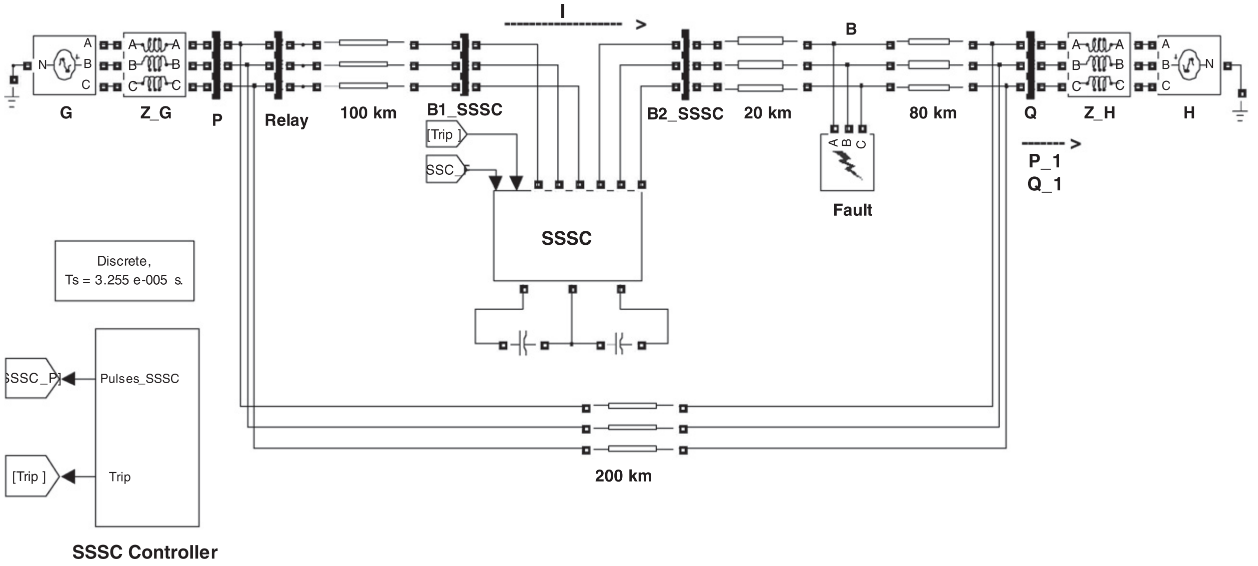

Fig. 1. SSSC setup in MATLAB/Simulink environment using the SimPowerSystems toolbox and the Simulink library.

Positive sequence impedance of line I and II: $Z_{1L1} = Z_{1L2} = 0.0201 + j\ 0.2868\ \Omega/\text{km}$.
Zero sequence impedance of line I and II: $Z_{0L1} = Z_{0L2} = 0.1065 + j\ 0.8671\ \Omega/\text{km}$.
Positive sequence impedance of sources G and H: $Z_{1G} = 1.7431 + j\ 19.424\ \Omega$, $Z_{1H} = 0.8716 + j\ 9.7120\ \Omega$.
Zero sequence impedance of sources G and H: $Z_{0G} = 2.6147 + j\ 4.886\ \Omega$, $Z_{0H} = 1.3074 + j\ 2.4430\ \Omega$.
System frequency = 60 Hz.
Load angle between sources = 20°.
Amplitude ratio between the magnitudes of the source voltages at G and H = 1.0526.

3. SSSC specifications and control system

In this paper the model of SSSC has been put in based on a 48-pulse voltage source converter so as to improve power quality and reduce harmonic effects. A ± 100 Mvar SSSC device is connected in series with a 400-kV transmission line through four phase-shifting transformers [14].

Fig. 2 shows the control block diagram of the used SSSC. An instantaneous three phase set of line voltages, at B_{1_SSSC} bus is used for calculation of the reference angle $\theta = \omega t$ based on which the compensating voltage, *Vinj*, is decomposed into its real or direct component, *Vd* and reactive or quadrature component, *Vq*. The compensating voltage, *Vinj* is controlled by a simple closed loop controller. The absolute value of the reference voltage, V_{Ref} is compared to the measured magnitude of the injected voltage, V_{inj} and the amplified difference (error) is passed through a PI controller and then is added, as a correction angle $\Delta\alpha$, to the synchronizing signal $\theta = \omega t$. An instantaneous three phase set of measured line currents, I is decomposed into its real or direct component, I_d and reactive or quadrature component, I_q and then the relative angle, of the line current with respect to the Phase-Lock-Loop angle, are calculated. The phase shifter is operated from the output of polarity detector which determines whether reference, V_{Ref} is positive (capacitive compensation mode) or negative (inductive compensation mode). Depending on the polarity of $\Delta\alpha$, angle θ and consequently the converter gate drive signals will be advanced or retarded and, thereby the compensating voltage, V_{inj} will be shifted with respect to the prevailing line current from its original $+\pi/2$ or

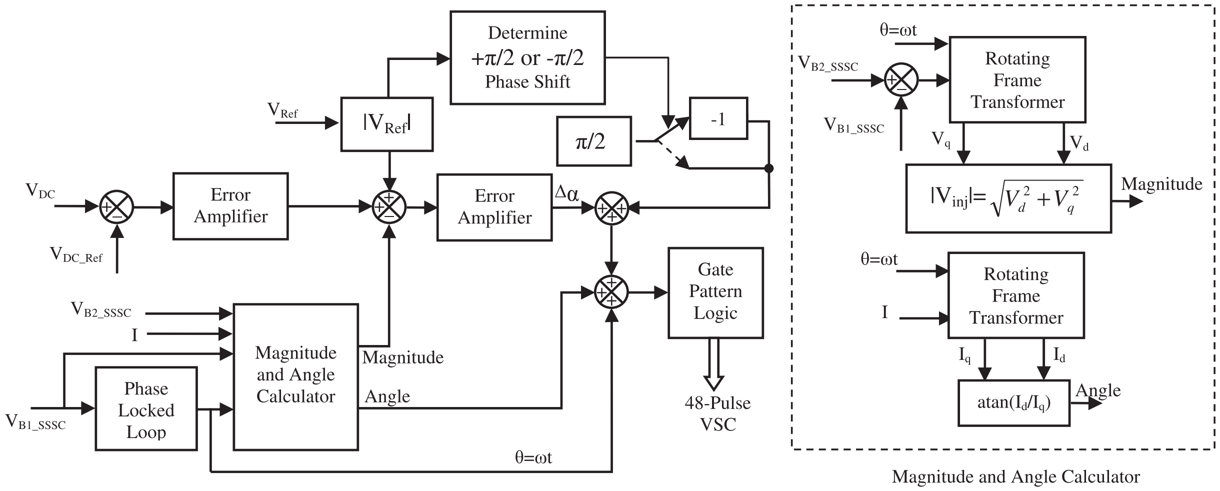

Fig. 2. Control block diagram of a SSSC.