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Review

# Protection of series compensated transmission line: Issues and state of art

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ABSTRACT

In the present-day scenario, per-capita power consumption symbolizes the development of any society. This has resulted in a multifold increase in power demand. This drives power engineers to generate and transfer maximum possible power through transmission line, i.e. up to thermal limits, which leads toward installation of compensating devices. However, this inclusion of compensation introduces changes in system parameters, i.e. in its impedance seen from relay point, voltage and current inversion, introduction of sub-harmonic frequency components, etc. This requires changes in existing protection concepts. Therefore, there is a need to track all experiences, developments and research in the field of protection of series compensated transmission line and look for the gaps in it. This paper gives bibliographical survey and general backgrounds of research and development in the field of series compensated lines (fixed capacitor and TCSC) since the application of series compensation. This article also compares and evaluates different techniques with their relative advantages and disadvantages to lead toward optimum technique for application. More emphasis is given to modern techniques. The literature is divided into parts to reduce the difficulty for new researchers to evaluate different techniques with a set of references of all concerned contributions.



**Contents**



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## 1. Introduction

To switch from protection of an uncompensated transmission line to a transmission line with series compensation is considered to be a difficult task for protection engineers, as it needs to be adapted to the changes introduced by compensation devices.

With sustainable growth in power demand, the size of the power system is continuously increasing; it has become the most complex system ever built. A large amount of money is spent for development of the power system right from generation of power to transmission and distribution; thus proper protection system is a must for every power apparatus [1,2].

Continuous increase in power demand leads fast development in transmission system, and requirement of power transfer up to the thermal limit of the transmission line. This will lead to installation of series compensation on long Extra-High Voltage (EHV) transmission lines. The series compensation not only increases power transferring capacity, but also improves system transient stability, voltage control, power flow control and will reduce losses. Two main types of series compensation used are fixed capacitor series compensation and controllable capacitor series compensation, each with their own advantages [3]. Two different line configurations are used in practice according to position of the compensating device on the circuit; end-line compensation and mid-line compensation.

To take full advantage of the series capacitor installation in a utility network, it is necessary to understand the impact of series compensation on protection to design appropriate schemes with necessary changes. As mentioned earlier compensation in a transmission system is normally introduced for high-power EHV transmission line, which usually employs distance relay for protection purpose. A distance relay works on real time impedance calculation of the line with real time measurements aided with fault type information. In case of series compensated transmission line, inclusion of compensating device affects the line impedance. Therefore, the position of fault with respect to the compensator (fault zone) is required for a distance relay to accomplish its overall decision. Faulted phase selection also increases system stability and availability by allowing single pole tripping. This will improve transient stability and reduces switching overvoltage in the system [4].

Therefore, the fault type classification and fault zone identification are very important aspects for protection of series compensated transmission line. Research efforts toward fault analysis have been evaluated in Section 3. With the help of this information, contributions toward fault location are analyzed in Section 4. Moreover, Section 2 investigates briefly, the effect of series compensation on transmission line protection.

## 2. Series compensation impact on transmission line protection

Integration of the series compensation in transmission line makes the protection complex due to the abrupt changes in line parameters at the point of series compensation. This will lead to change in apparent impedance measured by the relays. In this section, the impact of series compensation on the impedance based transmission line relay is briefly discussed.

### 2.1. Change in line impedance seen by relay

The distance relay resolves the impedance calculations from just finished measurements of voltages and currents. The impedance calculation gets effected due to inclusion of the series compensation, and leads the impedance relay for exaggerate conclusion. In ideal conditions, the apparent impedance seen by a distance relay for an uncompensated line at the relaying end can be seen by a dashed line in Fig. 1(a) and on R–X plane in Fig. 1(b). With inclusion of series compensation, the characteristic got modified at the point of compensation, as seen by solid lines in Fig. 1(a) and (b). It is clear from Fig. 1(b) that the distance relay overreaches if Series Capacitor (SC) is included in the fault circuit [4,5]. The directional integrity of the distance relay can be lost in the case of a fault just after compensator for end line compensation as seen in Fig. 2.

### 2.2. Over voltage protection of series capacitor

It is advisable to make a modification in the relay settings to accommodate the series compensation, only when it is established that the capacitor is invariably going to be part of the fault circuit for a fault after compensator [6]. However, over-voltage protection of the series capacitor could bypass the capacitor from the faulted circuit. As a normal practice, a Spark Gap (SG) or Metal Oxide Varistor (MOV) or both with a bypass circuit breaker protects the capacitor against over-voltage as shown in Fig. 3. This leads to two different impedance conditions during fault:

(i) In high-current fault condition, voltage across the capacitor increases to a truly high value, which triggers MOV conduction to bypass the capacitor. In this case, SC–MOV combination impedance will be reduced to the impedance of MOV only.
(ii) During low-current fault condition; the MOV remained in its high impedance state. The SC–MOV combination offers impedance equal to parallel combination of the pair.

Two impedance conditions increases difficulty in relay setting. A relay setting without consideration of MOV conduction could overreach and easily lost its directional integrity. If the settings are made