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# A performance oriented impedance based fault location algorithm for series compensated transmission lines

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A R T I C L E I N F O

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A B S T R A C T

This paper proposes a performance oriented fault location algorithm for series compensated transmission lines. The algorithm estimates the fault location based on the calculated fault voltage and current using two end measurements and line parameters. Fault location computations are carried out considering faults existed before or after the compensator location on the line. The calculated MOV impedance is the key factor in determining whether or not the fault is located in front of the compensator. A 380 kV transmission line with a series capacitor and an MOV has been tested for various fault types, fault locations and fault resistances. The results show that the algorithm accurately estimates the fault location for all cases.

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## Introduction

An accurate fault location in transmission lines is a crucial task for reliable and sustainable power system operation. Many algorithms have been developed and applied to pinpoint the line faults. These algorithms are based on travelling wave phenomena [1–3] and voltage and current data provided by one end or two ends [4–6]. The accuracy of these algorithms may vary depending on the some parameters such as source impedances, fault types and fault resistance. The existence of series capacitors in transmission lines is another factor where the conventional fault location algorithms may not be adequate.

Series compensated lines can provide improved power transfer capability, increased transient stability limit and reduced line losses [7]. Series compensation can be accomplished by the use of a series capacitor and a metal oxide varistor (MOV) for overvoltage protection during any fault. In spite of the benefits of series compensation, nonlinear behavior of the series capacitor and MOV may result in improper distance protection and inaccurate fault location with the conventional approaches [8].

Researchers tried numerous methods to overcome the influence of the series capacitor and MOV in fault location algorithms. Fault location algorithms have been developed by using pre-fault variables [9], pre-computed and stored current dependent impedance matrix [10], negative sequence current and voltage, zero sequence voltage [11]. Some algorithms may also include equations derived for each fault type [9,12]. But, conventional fault location algorithms usually use measured voltage and current from buses, calculated zero sequence current and line parameters to locate the fault location [13,14]. These additional requirements to common fault location algorithms are causing complex calculations.

This paper presents an efficient fault location algorithm for series compensated lines. The proposed algorithm requires only basic parameters to avoid complexity, based on the data taken from the both terminals of the line. Lumped model of the transmission line is considered without giving up accuracy. The paper is organized as follows: Section 2 summarizes the fault location techniques for series compensated lines. Section 3 introduces the proposed algorithm while Section 4 presents an application of the proposed algorithm on a test system and discusses the results. The algorithm has been tested for a variety of fault types, fault resistances and fault distances. Additionally, Section 5 compares the presented algorithm with two selected algorithms developed for series compensated transmission lines for various cases.

## Fault location issues in series compensated transmission lines

Many algorithms have been developed to estimate the fault distance for power systems with series capacitors. Generally, the algorithms can be grouped into three categories; travelling waves based algorithms, distributed time domain line model based algorithms and phasor measurement unit (PMU) based algorithms. Artificial intelligence methods can also be included in this generalization, but their complex structure and learning abilities differ these methods from other algorithms.

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Fault location methods based on travelling waves are independent of network configurations. Therefore, they have been suitable for series compensated lines [12,15,16]. Further improvements have taken place to make these algorithms to be independent of a fault type, a fault impedance and a fault inception angle. Measurements taken from one terminal instead of two are used in most of this kind of algorithms to avoid synchronization problem. On the other hand, the need for a high sampling rate and the difficulty of distinguishing travelling waves received from the remote terminal and the fault point are the drawbacks of these methods, which limits the methods' application.

Transmission lines are modeled with a distributed time domain line model in some fault location algorithms [17–20]. Some developed algorithms are insensitive to fault resistance and fault inception angle. However, the algorithms require synchronous current and voltage samples taken from both end of the line.

PMU based algorithms have been preferred for series compensated transmission lines since they are less complex and easier to improve [9–12,21–24]. They can use either one-end or two-end measurements. The performance of these algorithms can be improved with additional information such as pre-fault measurements, source impedance and current dependent impedance matrix.

Artificial intelligence (AI) is a subfield of computer science that mimics human abilities by machines; like learning, decision making and comparing. Precision, adaptation and improving itself can be considered as important parts of these algorithms [25–33]. However, the algorithms are very complex and usually require some considerable learning time and knowledge base. Measurements taken from one or two terminals of the line are inputs for these techniques. Hybrid techniques are utilized to locate the fault. AI methods such as support vector regression, extreme learning machine, adaptive neuro-fuzzy inference system and particle swarm optimization can be used with wavelet transforms for hybrid algorithms.

Another study on fault location estimation has been based on instantaneous values in time domain [34]. The algorithm has a good accuracy when compared to ANN technique, however it requires pre and post fault data [35].

The algorithms and models mentioned above mostly cause complexity and dependency to excessive computations on a large set of information. The more simple algorithms has limited accuracy or in need of additional variables about the power system. This paper presents a simple but performance oriented, impedance based algorithm without giving up accuracy.

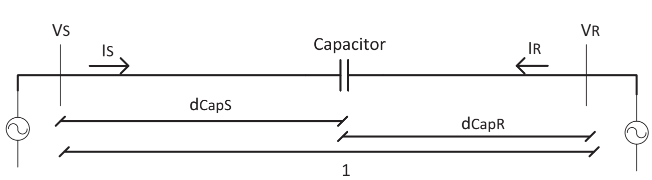


**Fig. 1.** Transmission line with a series capacitor.

## Proposed fault location algorithm for series compensated transmission lines

The proposed algorithm uses voltage and current variables measured from buses, line parameters and zero sequence current to locate the fault distance. A transmission line with the lumped impedance model is used for calculations.

A schematic of a transmission line with a series capacitor has been shown in Fig. 1.

Followings are assumed to be known parameters for the proposed algorithm.

- $V_S$, $I_S$ (bus voltage ($V$) and current ($A$) measured from terminal $S$).
- $V_R$, $I_R$ (bus voltage ($V$) and current ($A$) measured from terminal $R$).
- $Z$ (line impedance ($\Omega$)), $Y$ (line admittance, ($S$)).
- $d_{CapS}$ (distance between the sending end bus and capacitor (%)).
- $d_{CapR}$ (distance between the receiving end bus and capacitor (%)).

Two scenarios can be considered for the location of a fault in a series compensated line. The fault can occur either before or after the series capacitor. Each scenario should be taken into account separately.

In the case of a fault existed before the capacitor (as shown in Fig. 2), the voltage and current calculations are carried out based on the fault distance in percent from the sending end ($d_s$). This distance is varied until the fault location criterion is met.

The fault voltage and current need to be calculated for determining the fault distance. The fault current has two components one coming from the sending bus and the other from the receiving bus. The voltage at the fault location and the sending end component of the fault current can be computed using the sending-end voltage and current as given in Eq. (1).

$$\begin{bmatrix} V_F \\ -I_{FS} \end{bmatrix} = \begin{bmatrix} \left(1+\frac{(Zd_s)(Yd_s)}{2}\right) & (Zd_s) \\ \left((Yd_s)+\frac{(Zd_s)(Yd_s)(Yd_s)}{4}\right) & \left(\left(1+\frac{(Zd_s)(Yd_s)}{2}\right)\right) \end{bmatrix} \begin{bmatrix} V_S \\ -I_S \end{bmatrix} \tag{1}$$

The receiving end component of the fault current is dependent of the series capacitor's voltage and current. The voltage and current of the capacitor can be formulated as follows;

$$\begin{bmatrix} V_{Cap} \\ -I_{Cap} \end{bmatrix} = \begin{bmatrix} \left(1+\frac{(Zd_{CapR})(Yd_{CapR})}{2}\right) & (Zd_{CapR}) \\ \left((Yd_{CapR})+\frac{(Zd_{CapR})(Yd_{CapR})(Yd_{CapR})}{4}\right) & \left(\left(1+\frac{(Zd_{CapR})(Yd_{CapR})}{2}\right)\right) \end{bmatrix} \begin{bmatrix} V_R \\ -I_R \end{bmatrix} \tag{2}$$

The impedance between the capacitor and the fault point can then be given below;

$$Z_{Cap-F} = \frac{V_F - V_{Cap}}{\left[\frac{Y\left(1-d_S-d_{CapR}\right)^2}{2} V_{Cap}\right] - \left[(1-d_S-d_{CapR})I_{Cap}\right]} \tag{3}$$

The fault current can be obtained as follows;

$$I_F = I_{FR} + I_{FS} \tag{4}$$

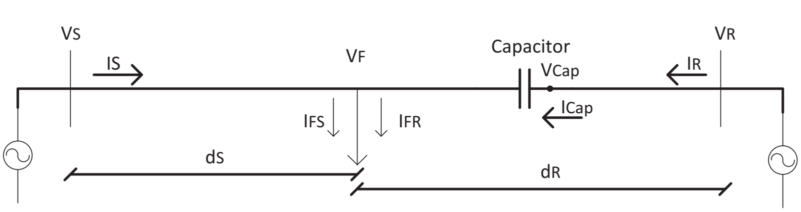


**Fig. 2.** Fault existence behind the capacitor.

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