A New PMU-Based Fault Location Algorithm for Series Compensated Lines

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***Abstract*—This paper presents a new fault location algorithm based on phasor measurement units (PMUs) for series compensated lines. Traditionally, the voltage drop of series device is computed by the device model in the fault locator of series compensated lines, but using this approach errors are induced by the inaccuracy of the series device model or the uncertainty operation mode of the series device. The proposed algorithm does not utilize the series device model and knowledge of the operation mode of the series device to compute the voltage drop during the fault period. Instead, the proposed algorithm uses two-step algorithm, prelocation step and correction step, to calculate the voltage drop and fault location. The proposed technique can be easily applied to any series FACTS compensated line. EMTP generated data using a 30-km 34-kV transmission line has been used to test the accuracy of the proposed algorithm. The tested cases include various fault types, fault locations, fault resistances, fault inception angles, etc. The study also considers the effect of various operation modes of the compensated device during the fault period. Simulation results indicate that the proposed algorithm can achieve up to 99.95% accuracy for most tested cases.**

***Index Terms*—FACTS, series compensation, synchronized phasor measurement units.**

I. Introduction

IN THE last two decades, the power electronic applications to ac power systems have provided many benefits. Applying series compensation in power systems can increase power transfer capability, improve transient stability and damp power oscillations. However, since the variation of series compensation voltage remains uncertain during the fault period, the protection of power systems with series compensated lines is considered as one of the most difficult tasks and is an important subject of investigation for relay manufacturers and utility engineers.

Series compensated systems can be mainly catalogued into switched capacitors (SCs) systems and thyristor controlled switched capacitors (TCSCs) systems. Typically, the main problem in designing series capacitors protection systems is overvoltage protection of the capacitor itself. The new metal oxide varistor (MOV) has been widely used in recent years as an overvoltage protection device for the series capacitors. However, the nonlinear characteristic of MOV will affect the compensated voltage of SCs/MOV in fault period. Moreover, additional transients introduced by the MOV systems will also render the compensation voltage difficult to estimate. To resolve the problems mentioned above, [1] has proposed a piecewise approximation model of MOV for distance relay application. Although the equivalent impedance can be used to calculate compensation voltage, the piecewise approximation model of SCs/MOV is incorrect during the transient period after the fault inception or when the nonlinear resistor is in some conducting mode [5]. Additionally, the nonlinear thyristor controlled reactance (TCR) branch of the TCSCs [2], [3] systems will introduce some new difficulties in computing the compensation voltage. For example, when the fault current is large, the TCR branch will operate between the block mode and bypass mode [2]–[4] to protect the capacitor and MOV. On the other hand, when the fault current is small for the high impedance ground fault, the MOV does not conduct and the TCR branch will remain in the vernier mode operation. This will also introduce some oscillation into the compensation voltage. Such an oscillation of the series capacitor voltage will cause further oscillation in the fault current. For the above phenomena, an accurate simulation analysis for the fault location of series compensated lines is difficult to achieve. Implementing the fault location algorithm based on a model of series compensation devices thus becomes impractical.

Recently, some studies associated with the easy analysis of series device models have been proposed in [6]–[8] and all produce satisfactory results. However, these algorithms must still need to consider the model of series device to compute voltage drop, limiting the accuracy of fault location. For example, the protection functions of series devices are too simplified in [6], [7], while [8] ignores the switching among different operation modes that initiates from the protection function. Thus, those algorithms inevitably suffer errors due to inaccuracy of the adopted models. Since the algorithm proposed here need not utilize the series devices model, the uncertainties mentioned above can be resolved completely.

To overcome the above problems, various protective schemes utilizing information from traveling waves launched by disturbances have been suggested. The high frequency components in fault waveform present undesirable effects for most fault location algorithms and are essential for accurate fault detection and location [9], [10]. Meanwhile, a fault detection/location algorithm derived from traveling wave principles can cope with high frequency transients since these basically depend on the traveling wave phenomenon. Fault location methods based on traveling waves are independent of network configurations and installations. Thus, the method is suitable for the series compensated transmission line [11]. However, identifying the desired high frequency signal becomes problematic. Additionally,

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