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Fault location in series-compensated transmission lines based on heuristic method

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ABSTRACT

This paper presents an algorithm for fault-location for series-compensated transmission lines based on phase components and on an heuristic method. The proposed algorithm uses voltages and currents measurements provided by intelligent electronic devices installed at both line ends to calculate the voltages at the fault point and to determine the exact fault location. The paper also presents a detailed mathematical model of the series compensation, which is capable of representing its behavior accurately, improving the algorithm's response. The authors implemented a series-compensated double-circuit transmission line using the Alternative Transients Program, in order to evaluate the performance of the proposed algorithm. The results indicate that it presents a high level of accuracy.

1. Introduction

Nowadays, electricity is present in several human activities and consequently the demand for a high quality electric energy has increased. Therefore, in order to comply with this demand, electric utilities are concerned with the transmission system reliability and fast restoration in case of faults occurrences.

In that way, advances in digital technology have enable creating tools to protect and speed up the restoration of the electrical system. Algorithms of fault-location are one of these tools. In the literature, it is possible to find several fault location algorithms, which evidences the concern on this issue, and these algorithms may be classified into two categories, with respect to the currents and voltages measurements. The first category uses one-end currents and voltages measurements. Under these circumstances, fault-location may become more imprecise, since measurements from the other end are not available (as in [1], where the maximum error for a line-to-ground fault in a single transmission line is 2.6%). The second category, currents and voltages measurements are available at both ends (as in [2], where the maximum error for a line-to-ground fault in a single transmission line is 0.6%). In this category, it may be required to perform time synchronization among the two ends.

Despite of where the measurements are taken, locating faults in transmission lines with series compensation is a very difficult task, since the components employed to protect the series capacitors have highly nonlinear characteristics, leading to nonlinear changes in the voltage profile across the series compensation during faults.

The main component that introduces the nonlinearity to the circuit is the metal oxide varistor (MOV), which is connected in parallel to the series capacitor, protecting it from overvoltage in case of overcurrent events. Nevertheless, in the presence of high magnitude currents, the MOV tends to heat up considerately and it is common to insert a thermal protection element.

However, series compensation, which consists in inserting reactive power elements into the transmission lines, brings benefits to the electrical system, once its employment reduces the transference reactance of the transmission line at the frequency of the network.

In electrical power systems, it is common the presence of long transmission lines, which may carry a great amount of electrical power from the generation sites to the consumption ones. In that way, it is common the employment of capacitors in series with the transmission line, which enhance its transmission capability and transient stability margin [3] as well as, in case of more than one circuit, the load balancing among circuits. These features avoid construction of new transmission lines being an economical approach very used by the utilities [4–6].

Although the benefits brought by the series compensation to the electrical system, the algorithms employed to protect and to locate faults must be capable of dealing with the presence of nonlinear

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components, such as MOVs. Recently, some study efforts have been focusing in fault-location with series-compensated power lines. The methods that locate faults on single-circuit transmission lines with series-compensation are [7–11] and those for double circuit are [12,13,5].

The method proposed in [12] applies to double-circuit transmission lines and is based on two-terminal unsynchronized voltages and currents measurements. The authors use the symmetrical components to estimate the fault point and resistance. The method applies to transmission lines with the series capacitor in the middle of its length and, despite the fact that the maximum error presented in the paper under ideal conditions is approximately 0.38%, the method is not suitable for transmission lines with series capacitors at both ends. Besides, it is not clear whether the MOV operated or not in the presented simulations.

At the same way as in [12], the method proposed in [13] applies to double-circuit transmission lines and is based on two-terminal unsynchronized voltages and currents measurements. Reference [13] locates the fault by modeling the transmission line in symmetrical components, as in [12], where the authors estimate the fault location through an iterative process that minimizes the angle between the voltage at the fault point and the fault current, under the assumption that the fault impedance is purely resistive. The method is dependent of the fault type and resistance, and is focused on locating faults in transmission lines with the series capacitor in the middle of its length. The maximum error presented in the paper, when considering ideal conditions and untransposed lines, is 1.00%. However, the method is not suitable for transmission lines with series capacitors at both ends, and it is not clear whether the MOV operated or not in the presented simulations.

In [5], the authors proposed a fault location method that uses voltage and current measurements from one end of the transmission line, whose is composed of two circuits. The authors consider series capacitors installed at the two circuits and at both ends of the transmission line. In order to determine the fault location and resistance, the authors solve two quadratic equations that involve real and imaginary parts of the transmission line impedance, voltage, and current. Such equations hold as variables the fault distance and resistance and the maximum error presented in the paper, when considering ideal conditions, is 1.00%. However, the method is strongly dependant of the short-circuit capacity of the equivalent sources at both line ends and does not consider the effect of the shunt capacitances of the transmission line. Besides, it is not clear whether the MOV operated or not in the presented simulations. These characteristics indicate that it is not suitable for long and untransposed transmission lines.

The method proposed in [8] applies to single-circuit series-compensated transmission lines, where the series capacitors are located at the middle of their length. In order to locate the fault, the authors use unsynchronized voltages and currents measurements from both ends of the transmission lines. The proposed method uses the transmission line components, as well as the voltages and currents phasor quantities, in symmetrical components. With this data, the authors have obtained a set of equations that involve the synchronization of measurements, and the fault distance. Ref. [8] considers that the MOV element does not conduct above a certain threshold, once the authors are dealing with high-impedance faults they disregard the MOV operation.

The fault location algorithm proposed in this paper applies both to single- and double-circuit transmission lines with series compensation installed either at both ends of the transmission line or at the middle of the line. The authors consider that voltages and currents measurements are available at the both ends of the transmission line and use its distributed parameters, in order to minimize modeling deviations. Furthermore, series-compensation impedance, composed of series capacitors and MOV, is modeled as in [4]. The fault location is performed by taking the differences among the voltages at the fault point, calculated from both ends of the transmission line, making the method independent of the fault impedance. The authors implemented the fault location method in Matlab program and evaluated it by using test data produced by Alternative Transients Program (ATP) simulations.

2. Series-compensated transmission lines

This section presents details about the typical topologies of series-compensated transmission lines, as well as constructive and behavior details of the series compensation units based on MOV protection. Besides, it presents some aspects of fault location in such transmission lines.

2.1. Typical topologies of series-compensated transmission lines

Series-compensated transmission networks may use single- or double-circuit transmission lines. Double-circuit transmission lines may have both circuits at the same towers, circuits at different towers and at the same corridor, or circuits at different towers and at different corridors. In most cases, series capacitors are installed in the middle of the line in order to avoid misoperation of conventional impedance relays, which are affected by faults occurring near the line end where they are connected. However, digital protection systems employed nowadays are capable of addressing this issue and the capacitors installations can be near the line ends, in order to provide a better maintenance solution.

It is important to point out that the proposed algorithm, which is presented in Section 4, is capable of accurately locating faults in any transmission system, as detailed in Sections 4.1–4.3.

2.2. Series compensation units

Fixed-series-capacitor compensation and thyristor-controlled-series-capacitor compensation have been successfully employed for many years to enhance the stability of power systems and the load capability of transmission lines. The first one is capable of providing fixed reactive compensation and the afore mentioned benefits, and the second one is capable of providing the same benefits, while reducing the impacts of such compensation in the transmission systems [14] (e.g. subsynchronous resonance and transient problems).

Both series compensation technologies employ overvoltage protection of the capacitors during power system faults. The first series compensation units used spark gaps as overvoltage protection, and nowadays the overvoltage protection is performed by MOVs, as depicted in Fig. 1. The MOV protection provides benefits such as [4]: instantaneous reinsertion; lower capacitor protective levels; greater reliability and lower maintenance.

Typically, MOV protection is connected in parallel with the capacitor and it is capable of holding the voltage across it within its protective level voltage, while conducting part of the system

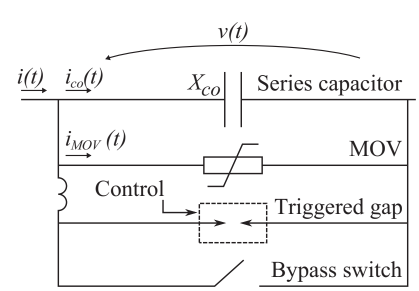

Fig. 1. Series-compensation details.