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A new algorithm for fault location in series compensated transmission lines with TCSC

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ABSTRACT

In this paper a new algorithm for accurate fault location in advanced series compensated transmission lines with Thyristor Controlled Series Capacitor (TCSC) is presented. Time domain modeling of a transmission line and the TCSC system are used in the proposed algorithm. This algorithm consists of two subroutines considering faults in the line sections i.e. in front of TCSC and behind it. Subroutines selection in the algorithm is performed by using a parameter known as the Fault Section Indicator (FSI). FSI is, in fact, the virtual resistance of the TCSC measured during the first cycle of fault inception. The one-cycle FSI trend indicates the faulty section, and an accurate method is adopted for fault location estimation. Extensive simulations were carried out using ATP-EMTP software on a 400 kV, 300 km transmission system with the TCSC installed in the middle of the line. The results confirm the capability of the FSI parameter for correct identification of faulty section and the accuracy of the proposed fault location algorithm.

1. Introduction

Different types of fault in power systems are always threatening the continuous supply of the electric energy for consumers. This subject is very important for companies responsible for supplying electrical energy. Therefore, correct determination of the fault point is very vital for these companies to find and repair the problem in minimum maintenance time.

A fault locator is used for identifying fault location in a power transmission line. Operative algorithms in fault locators can be classified in two categories: first, algorithms based on the fundamental frequency component [1–4], and second, algorithms utilizing the higher frequency components of the fault signals such as methods developed based on traveling waves on the transmission lines [5–10].

Furthermore, the fault location algorithms can be categorized based on the required data from the line terminals. There are two main categories; in the first category required data are provided only from one line end [1,6,7,11]. In these schemes, delivered fault location is not accurate or the determination of precise fault location is difficult, hence line repair time may be long. In the second category, synchronized or non-synchronized measured voltages and currents samples at the both line terminals are used [2,3,5,12,13]. The methods related to this category are generally more precise; however, they need a communication channel placed between the local and remote line terminals.

In some algorithms the lumped model is used for the transmission line and shunt capacitance of the line is ignored which results significant error in fault location estimation, some others use π model of the line [14]. These models introduce small errors in results in short transmission lines but these errors are not negligible in long transmission lines. More accurate results can be achieved by using the distributed line model [15]. Table 1 summarizes the different categories of the mentioned methods and relevant references. It should be mentioned that the fault location algorithms are rarely applied in transmission lines compensated by TCSC, and a few algorithms applied in the lines with TCSC are often time consuming or need several cycles data of post fault [16,17].

The TCSC is an important member of Flexible AC Transmission System (FACTS) family; it is capable of changing the transmission line impedance and load current continuously [18]. A typical TCSC module consists of a series capacitor and a parallel path with a thyristor valve in series with an inductor known as the Thyristor Controlled Reactor (TCR). To protect these elements during the fault, a Metal Oxide Varistor (MOV), an air gap and a breaker are installed in parallel with the capacitor and TCR. A practical TCSC module is shown in Fig. 1 [19].

However, the employment of the series compensation creates certain new problems for conventional fault locators and protective relays in a transmission line compensated by TCSC and also for adjacent transmission lines. TCSCs have a complex transient behavior during the fault [20–22].

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Table 1
Categorization of fault location methods.

No.	Algorithm base	Required data	Data synchronization	Accuracy	Difficulty	Transmission line compensation	References
1	Fundamental power frequency	Single terminal data	Not applicable			No/TCSC	[1], [28]
2		Double terminal data	Yes			TCSC	[2], [16]
3			No			Fix capacitor	[3], [4]
4	High frequency components	Single terminal data	Not applicable			No	[6], [7]
5		Double terminal data	Yes			TCSC/fix capacitor	[5], [9], [17]
6			No			No	[8]

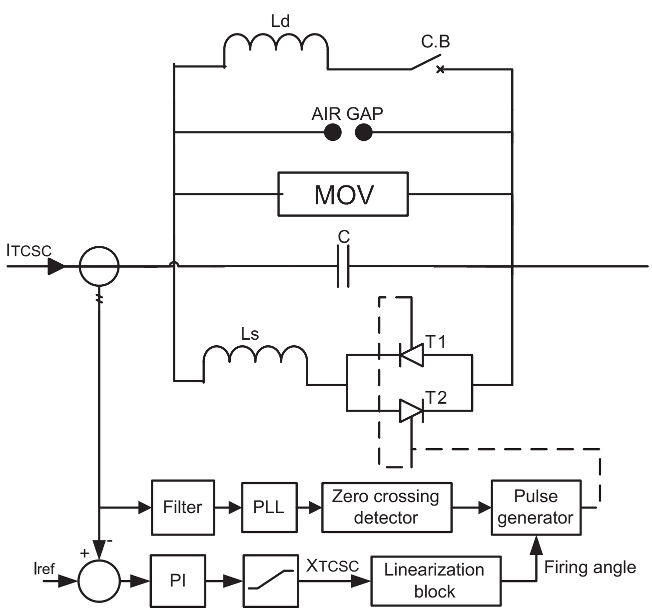

Fig. 1. Practical TCSC module.

The fault location problem in the series compensated transmission lines has been considered in some publications [23–25]. Yet in most of them, proposed methods for fixed capacitors and their problems have not been well defined in transmission lines with TCSC. In [14] two subroutines for computation of fault location in front and behind of these series capacitors and a method for selecting one of them were proposed, in which lumped model of transmission lines was used.

In [25] it has been suggested a fault location algorithm for series compensated lines with fixed capacitor and claimed it operates in a very small error for series compensated lines with TCSC (this means the TCR effect is negligible). This may be acceptable for a small compensation rate when the TCSC operates with a large firing angle (e.g. $170 < \alpha < 180$); but for a high compensation rate the error of fault location is not negligible. For instance in our case study, neglecting the TCR effect leads to the errors more than 3% and in certain locations the error reaches more than 10%.

In this paper, a new algorithm for fault section identification and fault location in series compensated transmission lines with TCSC is proposed. The algorithm uses the transmission line distributed model and a time domain model for the TCSC. The algorithm requires synchronized current and voltage samples from both ends of the transmission line. Two points for fault location can be obtained, one in front and the other behind the TCSC. A new approach to identify the correct fault point is proposed in the present paper applying a new parameter named Fault Section Indicator (FSI). FSI is the transient resistance of the TCSC which is seen as a black box from its two terminals. The proposed algorithm is evaluated by simulations on a 300 km, 400 kV transmission line equipped with TCSC in the middle. Many simulations carried out with ATP-EMTP software on the system confirm capability and accuracy of the proposed algorithm.

2. Modeling of TCSC

2.1. TCSC operating modes

In normal operating conditions, the TCSC has four modes of operation, blocking mode, bypass mode, capacitive boost mode and inductive boost mode [21]. In the blocking mode the thyristor valve is not triggered and the TCSC performs like a fixed capacitor but in the bypass mode the thyristor valve is conducting continuously. The capacitive boost mode inserts capacitors to the line, up to nearly three times the fixed capacitor. This is the normal operation mode of the TCSC. In the inductive boost mode, TCSC operates as an inductance. This mode is less attractive for steady state operation.

During a fault, different modes of operation occur that incorporate the TCSC protection equipment. The TCSC transits from one mode to another one based on the control strategy of thyristor firing pulse generation and severity of fault. Chronicle operation modes, with/without MOV are capacitive boost mode, blocking mode, TCSC bypass operation, inductive boost mode and circuit breaker bypass.

For a high speed protective relaying, the air gap sparking does not take place prior to detecting a fault position. Also it is assumed that in the first cycle of fault inception, thyristor firing angle remains unchanged because of the time constant and the delay of TCSC control loop.

2.2. Time domain modeling

In normal operation, TCSC operates in the capacitive boost mode. In this mode, the capacitor conducts current continuously and the inductor conducts in a part of each cycle dependant on the firing angles of thyristors. For identifying the inception instant of inductor conduction, the TCSC current is filtered using an analogue band pass filter with 50 Hz frequency characteristic, 5 Hz bandwidth.

With fault inception, the TCSC voltage exceeds its limit and MOV is inserted in order to reduce TCSC voltage. By trapezoid integrating and digitizing the relationship between capacitor voltage v_c and current i_c, the following result is obtained:

$$v_c(t) = \frac{T}{2C}(i_c(t) + i_c(t-T)) + v_c(t-T) \quad (1)$$