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Improved fault analysis technique for protection of Thyristor controlled series compensated transmission line

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ABSTRACT

Transmission lines are major component of a power system. Any fault on them results in outage of power not only in the area fed by them but also in the neighboring area as well. Therefore, protection of them is very important. Nowadays, in order to allow maximum power transfer series compensation both uncontrolled and controlled are used. Due to the introduction of compensating devices the protection methodology of transmission lines requires changes. A new transmission line fault analysis method based on half cycle post fault three-phase current data has been presented in this paper for series compensated transmission line equipped with Thyristor Controlled Series Compensator (TCSC). The proposed two-step methodology has been developed with the help of Discrete Wavelet Transform (DWT) and implementation of Chebyshev Neural Network (ChNN). ChNN is derived from regular neural network, but is functionally superior. The performance of the developed algorithm has been tested over a vast fault pattern data set dynamically generated with EMTDC/PSCAD. The results with extensive testing indicate effectiveness of the developed scheme with higher level of accuracy and speed. The algorithm is capable of doing classification with minimal training.

1. Introduction

The continuously increasing power market demands increase in power transmission capacity. This force the power engineers to transmit maximum possible power through transmission lines (up to thermal limits). To this end the power sector is required to install series compensation in transmission lines. The main two variants of series compensators are, fixed series compensator and controllable series compensator [1], each with its own advantages and limitations. The selection is made based on the application requirements. The controllable compensator (Advanced Series Compensation (ASC)) utilizes power electronics control to regulate power flow by changing the conduction of the power electronic devices. Thyristor Controlled Series Compensation (TCSC) is one of the main controllable compensation techniques.

The protection requirements of ASC transmission line differs from uncompensated or fixed series compensated transmission lines due to non-linear changes introduced in system due to the implementation of ASC. The TCSC injects additional harmonics in the system. It introduces rapid changes due to TCSC control actions in primary system parameters such as line impedances and load currents. In the event of fault, quick changes would be registered in TCSC's control system for protective measures. To reduce the fault current, it varies the firing angle to take TCSC in to inductive mode. As shown in Fig. 1, an over-voltage protection with the help of Metal Oxide Varistor (MOV) is provided to the capacitor of the TCSC module as a normal practice. This leads towards different impedance conditions during fault; according to severity of the fault current. For a more severe and long duration fault, the TCSC module will be bypassed through the circuit breaker provided for this purpose.

The conventionally used series compensated transmission line protective algorithm uses impedance measurement approach. This is used for identification of the phases involved in the fault and position of fault with respect to the compensator. This paper describes a newly designed fault type and zone identification system for TCSC compensated transmission line.

Digital signal processing has emerged as a potential tool for protection requirements. Application of adaptive Kalman filter for fault analysis has been demonstrated in [2]. However, the presented algorithm in this article proved slow as it involves a number of Kalman filters implementation, and this method lacks in authentication for various fault resistances. Wavelet Transform (WT) techniques, an extension of Fourier Transform, have been extensively used for power system protection and has emerged as one of the potential tools for protection analysis [3]. The WT implementation for fault analysis has been presented in [4].

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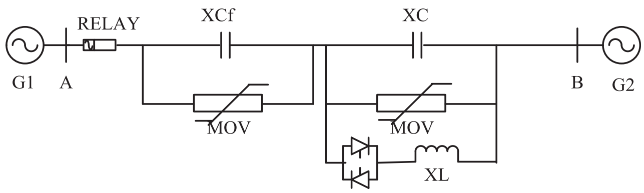

Fig. 1. Studied system.

However, authors fail to prove efficacy of the method in the absence of sufficient testing for varying system conditions. Applications of Discrete Wavelet Transform [5,6] and s-transform (extension of Gabor and Wavelet Transform) [7] can be observed in the literature for fault analysis of ASC transmission line. A s-transform energy based relaying are presented in [8]. A WT based fault zone identification scheme for series compensated line has been proposed in [9]. The sampling rate of 240 kHz proved to be high for implementation from the computational aspect. This makes the algorithm sluggish.

An addition of Artificial Intelligence (AI) techniques to signal processing, improves classification requirements of power system [10]. The application of Wavelet Transform with Extreme Learning Machine has been shown in [11] and with Neuro-Fuzzy system in [12]. The Artificial Neural Network (ANN) is considered as one of the better AI methods for electrical signal analysis and finds many applications in protection. The application of ANN for ASC transmission line protection has been demonstrated in [13]. Again in this case, the requirement of one full cycle or more data makes the system sluggish. Applications of SVM for fault classification and zone identification have been presented in [14,15]. However, the method of [14] requires TCSC firing angle as an additional input data that necessitates a dedicated communication channel in case of mid-line compensation. Moreover, the SVMs are sensitive to its classification parameters and necessitate tuning different parameter with proper selection of kernel function that satisfies 'Mercer' condition. Radial Basis Function based Neural Network (RBFNN) has been demonstrated for fault analysis of ASC transmission line with Fourier analysis in [16]. The computation burden of the activation function of the RBFNN makes its slow. In the absence of design governing mechanism for higher performance, the ANN involves higher designing efforts and heavier network size. This leads towards higher computational burden. In this backdrop, the Chebyshev Neural Network (ChNN) emerged as an accurate, easy to design and faster classifier for protection requirements. Being a single layer NN, it gains advantage over MLP in design and training stage. Independence from system parameters for classification makes it better than other AI classifiers. A structural details and application of ChNN have been provided in one of the following sections for ready reference.

The algorithms developed for protection need not only accurate but fast as well. With this constraint, the developed two-stage algorithm in this paper uses only half-cycle post fault three-phase current data as compare to higher amount of data required by many cited article (one cycle or more). This not only reduces total operational time but, processing memory requirement as well. Moreover, reduces computation burden of the algorithm also as number of samples available are lesser for half cycle duration.

Most of protection algorithm applies voltage and current measurements for power system condition estimation. The developed algorithm in this article uses current measurement only for fault classification and fault zone identification applications. This eliminates voltage associated processing and computation. The algorithm presents ChNN as a capable AI technique with WT as signal processing tool both for fault type and fault zone classification. The authentication of this algorithm has been presented for a large size fault data set with all possible fault and system parameter variations. The data set has been generated dynamically with real time power system simulator PSCAD/EMTDC with system and fault parameter variations like fault resistance, fault inception time (angle), fault distances from relaying end, along with transmission line loading angles for all possible ten fault types.

2. Digital simulation studies

Fig. 1 shows a two area system considered for study in this investigation. The relaying algorithm has been developed with measurements at the substation A. The system consists of a 300 km, 50 Hz, 3-phase, 400 kV EHV transmission line connected with two generators on either ends. The generators (G1 and G2) represent two areas of a power system simulated with variation in generator impedance. The transmission line is equipped with an advanced series compensator TCSC at the middle of the line. The TCSC is aided with a fixed series compensator (SCf_1). The TCSC and the fixed series compensator are protected against over voltage by Metal Oxide Varistor (MOV) as shown in Fig. 1. All components and systems are simulated using dynamic power system simulation using PSCAD/EMTDC [17]. The transmission line is modeled using Bergeron line model with the following parameters:

Positive sequence resistance: 8.25 Ω
Positive sequence reactance: j94.5 Ω
Length: 300 km.
Voltage: 400 kV.
Frequency: 50 Hz.

The fixed series compensator is equipped with a capacitor (XCf_1) providing 30% compensation to the total line length. The TCSC carries capacitor sufficient to provide a variable compensation of 0–10% with variation of the firing angle (α) form 180° to 153°. The MOV used with TCSC and fixed compensator is set such that sufficient voltage is available across it at 2.5 times the normal operating current for its conduction. The generators are simulated with the following operating impedance values (ZG1 and ZG2):

Positive sequence resistance: 1.31 Ω
Zero sequence resistance: 2.33 Ω
Positive sequence reactance: 15.0 Ω
Zero sequence reactance: 26.6 Ω

These values are considered as the unit values ZG1 and ZG2. To evaluate the accuracy of the proposed algorithm, it has been tested with a large fault data set with a wide variation of system and fault parameters. To generate data in bulk, all system components are simulated using PSCAD/EMTDC, an established simulator for power system dynamic studies. These variations in system conditions are created by varying system parameters like source impedances (ZG1 and ZG2), TCSC firing angle (α) and generator loading angle (δ) as given in Table 1.

As mentioned in Table 1 combination of these variations creates 45-various system conditions. With variation in different fault parameters, faults are created under each of these system conditions, these parameters are:

- Fault inception angle (FIA): 0°, 45°, 115°.
- Fault resistance (R_f): 0 Ω, 5 Ω, 25 Ω, 50 Ω.
- Fault length: 60 km, 120 km, 138 km, 162 km, 180 km, 240 km.
- Type of faults: L–g, L–L–g, L–L, L–L–L. (All ten types of faults).