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Sequence component based approach for fault discrimination and fault location estimation in UPFC compensated transmission line

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ABSTRACT

This study presents an integrated approach for discrimination of internal and external fault, and to obtain pin-point location of the fault in a transmission line connected to unified power flow controller (UPFC). To detect internal fault, this method uses positive sequence component of voltage and current at the local and remote end bus. Fault location estimation technique requires both positive and negative sequence voltage and current components measured from both ends of the line. The performance of the proposed technique has been evaluated by simulating a 400 kV double circuit UPFC compensated transmission line. This technique can detect internal fault under stressed conditions, viz. high impedance fault (HIF), change in source strength, change in load angle, and power swing. Precise fault location has been achieved under wide variation of system and fault parameters. The comparative assessment has been provided to prove the efficacy of the proposed approach.

1. Introduction

The ever increasing demand of power has drawn our attention to expand the existing power system networks by building new transmission networks. Nevertheless, this is not always feasible due to restrictions of right-of-way. Aiming to meet power demand, and to make steady expansion of the network, double circuit transmission lines with compensation have been utilized. The uninterrupted operation of power transmission lines is affected mostly by faults, which occur frequently. In the past few years, researches have been focussed to develop reliable algorithm for quick detection of faults, which helps to improve the system stability and economy.

Discrete wavelet transform (DWT) is an effective mathematical tool to analyze the faulty voltage/current signals, which are mainly transient in nature. DWT technique has been successfully implemented in conjunction with artificial intelligent based methods for detection, classification, and location of faults in transmission lines [1–6]. The protection scheme of single circuit transmission line has been presented in [1,2] using artificial neural network (ANN) with DWT. These techniques utilize two ANNs for fault location, which increases execution time and computational burden. In [3], directional protection scheme for double circuit transmission line has been proposed using ANN and DWT. However, the accuracy of the scheme under high impedance fault has not been addressed. Deep neural network (DNN) is a better alternative for complex non-linear optimization problem, and has recently been successfully applied for fault location in series compensated three-terminal transmission line [4]. The main disadvantage associated with DNN is that, it requires large number of hidden layers to attain reasonable accuracy. The supremacy of adaptive neuro fuzzy inference system (ANFIS) over ANN in fault location scheme has been established in [5]. Fault location scheme has been presented in [6] using extreme learning machine (ELM) and DWT, and its superiority over support vector regression and ANN has been established. Support vector machine (SVM) can be a lucrative classifier tool as compared with ANN, because SVM solves quadratic optimization problem, which does not have the problem of local minima. Isolation strategy of faulty branch, and pinpoint location of fault in an interconnected power system using SVM, has been described in [7]. Fast discrete orthogonal S-transform (FDOST) in conjunction with SVM has been successfully applied for the protection of compensated transmission line in [8]. The main concern with this scheme is that, it requires eleven SVM units, involving huge computer memory space. The protection scheme of a new hybrid model, consisting of a transmission line and an underground cable, has been described using FDOST and SVM in [9]. The main drawback of this scheme is the use of high sampling frequency. A scheme has been reported in [10], to differentiate between faulty condition and swing condition for a series compensated line using modified full cycle discrete Fourier transform and SVM. However, the variation of source

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Nomenclature

1, 2	Bus numbers connected to the relaying line
U_{p1}, U_{p2}	Positive sequence voltage at bus 1 and 2 respectively
U_{n1}, U_{n2}	Negative sequence voltage at bus 1 and 2 respectively
I_{p1}, I_{p2}	Positive sequence current at bus 1 and 2 respectively
I_{n1}, I_{n2}	Negative sequence current at bus 1 and 2 respectively
S_{p1}, S_{p2}	Complex power at bus 1 and 2 respectively
z	Impedance of transmission line
m	Distance in per unit at which fault occurred

strength remains unaddressed in this study. Faulty phase selection using Hilbert–Huang transform (HHT), for shunt compensated transmission line has been described in [11]. However, the classification accuracy under swing condition has remained untouched. Cross correlation based detection and classification of faults in transmission line have been described in [12], in which the performance of the proposed scheme under critical scenarios, viz. HIF, swing, and load fluctuation have not been discussed. The authors of [13] have presented fault classification scheme in a transmission line with a high penetration of distributed generation using cross correlation technique. Decision tree (DT) based fault classification scheme for transmission line, utilizing magnitude of differential power, has been presented in [14]. Fuzzy inference system (FIS) based protection schemes utilizing positive sequence component of voltage and current signals have been reported in [15,16]. The main disadvantage associated with these techniques, viz. ANN, SVM, ANFIS, DT is that, they require a huge training data. Moreover, time required for making any decision may not be suitable for real time applications, as a very prompt response is desirable for digital relays. Wavelet analysis and fuzzy systems are sensitive to frequency variation; and hence, multilevel digital filtering becomes ubiquitous.

On the other hand, algorithms, which are developed without using any transform based techniques, have drawn attention for their simplicity and low computational burden. Directional protection scheme for single and double circuit line, using positive sequence superimposed current signal, has been proposed in [17]. Back-up protection scheme for UPFC connected transmission line; utilizing magnitude of differential power has been discussed in [18]. Identification of fault zone and faulty line in wide area power system has been described in [19], using complex power. However, in [18,19], the performance under close-in and far-end faults have not been investigated. A new notion of integrated moving sum approach has been successfully applied in [20], for classification of faulty phase/s in transmission lines. A new algorithm of syntactic pattern recognition of power system signals has been introduced in [21,22], and has been successfully implemented in transmission line fault detection [23].Travelling wave based fault location schemes have been described in [24,25]. The primary concern of the travelling wave based schemes is that, it requires large sampling frequency for desired accuracy. The energies of the sequence components of voltage signals during fault have been utilized in [26], for locating fault in distribution systems.

Aforementioned schemes have contributed significantly to the various protection schemes of transmission/distribution lines; however, the dependency of line parameters on the accuracy of these schemes remains a genuine issue. Due to ageing, loading, and atmospheric conditions, line parameters change over the time, which may affect the accuracy of several relaying algorithms. The works reported in [27–30], propose a one step forward solution, making fault location scheme independent of line parameters. In [27], fault location scheme for single circuit transmission line has been proposed using positive and negative sequence voltage and current data. However, the effect of fault inception angle (FIA) on location accuracy has not been reported. The method presented in [28], describes impedance based fault location scheme for untransposed single circuit transmission line. The effect of variation of source strength has not been considered in this study. Fault location scheme for double circuit transmission line has been presented in [29], using the sequence components of voltage and current signals. The effect of mutual coupling between the parallel circuits, due to zero sequence networks, has not been considered. A novel method has been proposed in [30], where the fault location problem has been solved using an optimization technique. Faulty line identification and location scheme in multi-terminal transmission network using the voltage and current data has been proposed in [31]. However, the algorithm is vulnerable in a situation when, close-in fault is generated near a tapping node, or a far-end fault occurs at a point, where no phasor measurement unit (PMU) is present. Discrimination of faults and estimation of fault distance in a transmission line using the dynamic change in shunt admittance has been proposed in [32]. However, the effect of FIA on performance of this algorithm has not been reported. A new algorithm of fault location scheme in an untransposed, double-circuit transmission line having dissimilar voltage rating is presented in [33]. However, the effect of varying source strength is neglected. Impedance based fault location scheme for composite power system network using optimum number of PMU has been described in [34]. However, the response time for this algorithm is little bit on the higher side. Fault detection and localization scheme in double circuit three-terminal transmission network using sequence component of voltage and current has been proposed in [35]. However, the algorithm does not detect non-grounded faults.

From the above literatures, it is found that, protective relaying scheme for an overhead transmission line can be addressed in different ways. First, transform based techniques, viz. wavelet transform [1–6], S-transform [8], Fourier transform [10], Hilbert–Huang transform [11], etc. can be adopted for effective analysis of faulty signals. These methods have been successfully applied for detection, classification and location of faults. Further, machine learning tools, viz. ANN [1–3], ANFIS [5], DT [14], SVM [10], FIS [13,15,16] in conjunction with some transform based techniques can be another choice for detection, classification and location of faults. The time required for relays to respond remains a genuine issue, as these methods need proper training to attain the desired accuracy. In the recent past, few methods [18,33–35] have been developed without using any transform or artificial intelligent based methods. These methods are better in the sense that, they require less memory storage, as they need no expensive training or complex mathematical computation.

This paper proposes an integrated approach for detection and location of asymmetrical faults in a UPFC compensated transmission line. The proposed scheme utilizes time synchronized voltage and current signals from two ends of the line. It can successfully discriminate internal faults from external faults. Precise fault location scheme has also been presented. The performance of the proposed scheme has been evaluated under diversified simulation studies. The scheme is robust, as it correctly detects internal faults under challenging conditions, like power swing, HIF, pre-fault power angle variation, weak infeed, etc. The remaining part of this manuscript has been organized mainly in eight sections. Section 2 illustrates the proposed fault identification and location schemes. Section 3 presents the test power system. The results of detection and location scheme have been discussed in Sections 4 and 5 respectively. Discussion, comparative study and concluding remarks are presented in Sections 6, 7 and 8 respectively. The list of references has been given at the end of this paper.

2. Proposed scheme

Detection of various faults in a transmission line is essential for reliable operation of power system. However, a practical power system network consists of several interconnected lines. Proper detection of fault in an interconnected power system network is a challenging task. The proposed scheme has been addressed in two different stages. First,