An enhanced fault detection and location estimation method for TCSC compensated line connecting wind farm

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ABSTRACT

The paper presents a new approach to enhance the fault detection, and location determination based on travelling waves using Fast Discrete S-transform (FDST) for TCSC compensated lines connecting to wind farm. The FDST is applied to the modal components of measured currents at each terminal to detect the arrival time of the first travelling wave (transient) produced by the fault. The proposed method includes detecting the terminal with fastest arrival time of wave to identify the faulted section and estimate the fault location by using proper distance index. The simulation results have demonstrated good performance of the proposed scheme under different fault locations, fault resistances, fault inception angles, fault types, faulted sections, variations in TCSC parameters and changing wind speeds. The performance validation on the real-time digital simulator (RTDS) platform enhances the applicability of the proposed protection scheme for the TCSC based compensated line integrated with wind farm. The performance comparison with the conventional travelling wave fault location algorithms using Continuous Wavelet Transform (CWT) shows potential ability of the proposed method.

1. Introduction

In modern era, the development of electric power transmission facilities has been confined, because of energy, environmental, and regulatory issues [1]. Among the FACTS devices, Thyristor Controlled Series Capacitors (TCSC) is one of the most effective tools to provide compensation to transmission systems that enhance system stability, raise power transfer capability, reduce power system oscillations and transmission losses [2]. However, the introduction of series compensation raises several concerns for the protection relays using traditional methods because of the sudden changes initiated by the corresponding TCSC control mechanisms in system parameters such as load currents and line impedances. There are several operating modes of TCSC in normal and faulted conditions namely bypass mode, blocked mode, capacitive boost mode and inductive boost mode. During system disturbances, basically when TCSC operation switches between different modes, TCSC dynamics have a notable effect on the power system protection causing problems like overreaching, loss of security and hence mal-operation of relay [3].

In recent times, wind-farms are also growingly unified to the grids at different levels of voltage. Integration of such wind-farms has a significant advantage as it enhances the reliability of the system. The trouble that appears in unifying wind farms is basically because of uncontrollable wind speed which continually changes throughout a day leading to fluctuation in wind-farm output power which has a nonlinear relationship with the wind speed. When such a farm is connected to the grid through a transmission line, the transmitted power and the relay end voltage fluctuates continually. Furthermore, wind-farm generation capacity also significantly influences the tripping boundary of the distance relay. So the protection task becomes more complex and challenging [4]. Thus, when both TCSC and wind-farms are integrated together in the transmission line the system becomes more complicated and the conventional relaying scheme is greatly affected.

Various fault location algorithms have been devised in past decades such as extracting fundamental frequency current and voltage phasors [5], using differential equations of transmission line for calculation of line parameters [6] or artificial intelligence techniques like neural network [7]. Among these, impedance-based schemes are the most used by researchers and utilities because of their simplicity and low computational complexities [8]. However, these fault-location methods are normally sensitive to power system load flow, high fault resistance, and series compensation [9]. To mitigate this issue, the travelling-wave-based fault locators (FLs) have been growingly used as an substitute, as their precision depends primarily on time synchronization and the data-acquisition system sampling rates [10].

Apart from the conventional ones, a differential relaying scheme based on the transient energy extracted using the discrete wavelet transform (DWT) in the current signals is proposed for transmission line
connected to wind-farm in presence of FACTS device [11]. However, this technique finds limitations as the WT is highly prone to noise and sometimes provides erroneous results. Data-mining (DT)-based intelligent differential relaying scheme for transmission lines, including FACTS and wind farms are proposed in [12,13] which uses extended Kalman filter PMUs for phasor estimation and computation of several potential features, but it requires good amount of dataset for training. So, travelling wave based methods can be implemented, especially in TCSC and wind farm environments considering its major advantage that the presence of FACTS or DFIG does not affect the time of arrival of transient waves, hence can provide a robust solution for fault detection and location estimation issues.

Over the years, various single and two terminal travelling wave-based algorithms are developed. The transient based fault location algorithms for two-terminal line using data from both line ends are reported with optimum cost advantage, as they are simpler than multi-terminal fault-location techniques that need monitoring devices at more than two terminals and are less prone to errors compared to single-terminal techniques [14–16]. In [17], the authors have proposed a travelling wave-based fault location algorithm for hybrid multi-terminal transmission systems that uses DWT of synchronized transient voltage measurements at all terminal endings. These traditional two-terminal methods need synchronized data from both line ends, which can be considered as a disadvantage as it can reduce the accuracy of two- and multi-terminal travelling wave-based FLs [18]. However, this problem can be eliminated substantially by using low sampling frequency and still maintaining high accuracy level [19].

In this paper, enhanced fault detection and location estimation method for TCSC-compensated two terminal line connecting windfarm, without and with infeed is proposed using measured transient waves produced by faults. The key technique in the proposed method is Fast Discrete S-transform (FDST) which is applied over the appropriate modes of the currents in three phases, for detection of fault by collecting the time of arrival of the transient waves at the terminals of the

![Flow Chart of our proposed method for fault detection and location estimation.](image-url)
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