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A noncommunication adaptive single phase auto-reclosure of transmission lines using phase space based criteria

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ABSTRACT

This paper presents two phase space (PS) based criteria, and then on the basis of which it illustrates the preparation of a new non-intelligent and noncommunication adaptive single phase auto-reclosure (ASPAR) scheme to detect the secondary arc extinction for reclosure of transmission lines after self-clearing of transient faults. This scheme, which is fed by local voltage signal, can accurately distinguish between transient and permanent faults in transmission lines. Moreover, in the case of transient faults, the secondary arc extinction can be detected by the proposed algorithm within 8 ms and under effective operational and structural conditions, including different fault locations, load amounts, number of circuits, ideally transposed, partially transposed and un-transposed circuits, existence of shunt reactors and measurement noise. Besides, the presented PS based algorithm can be implemented sample by sample and does not need complicated integral computation, which connotes that it can be embedded in reclosing relays in transmission systems.

1. Introduction

Overhead transmission line faults can be classified into three classes including (1) transient (or temporary) faults, (2) semi-permanent faults and (3) permanent faults. Statistics confirm that a large number of line faults are transient and most of which are single phase to ground (SPG) faults caused by lightning and temporary contacts of lines with branches of trees [1]. A popularly accepted practice to deal with such faults has been the employment of the single phase auto-reclosure scheme, which is based on turning out and re-energizing the faulted phase after occurrence of a transient SPG fault. This reduces the outage times compared with the systems where the faulted phase is tripped and manually re-energized. Moreover, the single phase auto-reclosing increases the transient stability level [1].

Regardless of whether a fault is transient or permanent, the conventional single auto-reclosure schemes turn out and re-energize the faulted phase after the fault [1]. Therefore, the auto-reclosing operation may be performed for a permanent fault, as result of which is to jeopardize the transient stability. Moreover, the conventional schemes employ a reclosing circuit breaker (CB) fixed dead time. However, in cases of transient faults that the secondary arc has not been cleared during the prescribed dead time, the reclosing operation will be unsuccessful. Therefore, performing the single phase auto-reclosing operation for only transient faults and with adaptive dead time is important. This can be obtained using the adaptive single phase auto-reclosing (ASPAR) schemes which have been found interesting by power system protection engineers.

There are a large number of proposed ASPAR schemes [2–17], in each of which one and/or both of voltage and current signals are analyzed to distinguish between transient and permanent faults and detect the secondary arc extinction. These schemes can be divided into two categories including communication and non-communication based algorithms.

The communication-based methods includes the proposed algorithms in [2–5]. Elkalashy et al. introduced an algorithm which monitors the fundamental component of the instantaneous differential zero sequence power to detect the secondary arc extinction [2]. Khorashadi-Zadeh et al. presented a scheme based on synchronized phasor measurement Units (PMUs) for transmission lines with and without shunt reactors. Employing PMUs, the proposed algorithm was designed based on voltage and current phasors at the two ends of a transmission line [3]. Also, Zahlay et al. proposed a new neural network based autoreclosure method to distinguish between transient and permanent faults, and to accurately detect secondary arc extinction, in transmission lines without shunt reac-

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tors [4]. The authors employed the Prony analysis method for extraction of features of the voltage signal. Dadash Zadeh et al. proposed a communication based algorithm to discriminate transient faults from permanent faults, and to determine the secondary arc extinction time, in transmission lines with and without shunt reactors [5]. They used the magnitude and angle of faulted phase voltage phasor. However, for installation of communication based methods, the telecommunication infrastructure should be provided which needs too much investment. Besides, the performance of such methods highly depends on the reliability of the communication systems. Therefore, for design of an ASPAR scheme in a reliable way, the communication based methods are replaced by noncommunication-based methods and/or combined with them.

The noncommunication-based methods include the proposed algorithms in [6–17]. Aggrawal et al. proposed an intelligent ASPAR scheme based on neural network fed by the discrete Fourier transform (DFT) based features of the faulted phase voltage signal [6]. However, its outcome was dependent on the capacitor voltage transformer (CVT) errors. Radojević et al. presented a voltage based index i.e. total harmonic distortion factor for design of a scheme [7]. Lin et al. proposed a dual-window transient energy ratio-based criterion for design of an ASPAR algorithm [8]. The algorithm is based on the current samples and employs the close–opening—open–closing morphological gradient (COOCG) tool. Jamali et al. used the fundamental and 3rd harmonic of the zero sequence voltage to distinguish between transient and permanent faults and detect the secondary arc extinction, respectively [9]. Jannati et al. introduced a voltage based index i.e. total harmonic inverse factor for providing their scheme [10]. In the presented scheme the ADALINE neural network architecture was employed to on-line harmonic estimation. However, the aforementioned proposed methods were not evaluated in the shunt compensated transmission line. Jamali et al. examined two indices based on wavelet packet transform (WPT) for designing an ASPAR scheme in existence of shunt reactors [11,12], where obviously employing WPT increases the computational burden. Khodadadi et al. employed one of the famous abrupt change detection methods named as cumulative sum (CUSUM) to identify the pattern of the magnitude local voltage for transient faults [13]. As reported in [13], the proposed algorithm is fast and accurate for a transmission with or without shunt compensation. However, all of abrupt change detection methods such as CUSUM suffer from the measurement noise which practically exists. Jazebi et al. proposed a classifier trained by Gaussian Mixture Models (GMM) to design a new ASPAR scheme [14]. Their algorithm could identify secondary arc quenching time in a short time. However, the intelligent methods suffer from this fact that applying them to another transmission line requires further investigations for becoming applicable under the new conditions [13]. Vogelsang et al. used the root mean square (RMS) of current measurement to provide a new method for a real time adaption of the dead time for auto-reclosing on transmission lines [15]. The proposed algorithm needs the output of the fault location module plus the load currents of the parallel non-faulty conductors. Zhalefar et al. designed a high speed algorithm based on local voltage phasor [16]. Their algorithm was tested for different topologies of a transmission line including ideally transposed, partially transposed and un-transposed. Moreover, the proposed algorithm was investigated for a transmission line with and without shunt reactors. More recently, Luo et al. proposed the index i.e. the ratio of even to odd harmonics calculated by DFT for designing a reclosure scheme in a transmission line with shunt reactors [17].

However, although the design of an ASPAR scheme based on time domain, frequency domain and time-frequency domain analysis of power system variables such as voltage and current was demonstrated over two past decades [2–17], little attention has been paid to solve the problem employing the phase space (PS) domain analysis. Transforming a power system signal to the PS based on the embedding theorem [18], the shape information of that signal can be obtained. In this work, the effort has been made to design a non-intelligent and noncommunication ASPAR scheme to detect to the secondary arc extinction for reclosure of transmission lines after self-clearing of transient faults. The first step is to distinguish transient faults from permanent faults in transmission lines. In the cases of transient faults, the time of the secondary arc extinction is determined rapidly, within 8 ms. If the secondary arc is extinguished, the de-energized transmission line is energized, again. In the proposed scheme, the PS information of the local voltage signal is provided by delay reconstruction method and used to distinguish between transient and permanent faults, at first. Then, this information is employed for the determination of the secondary arc extinction. This proposed algorithm can be implemented sample by sample and does not need complicated integral computation, which connotes that it can be embedded in reclosing relays in transmission systems. The main contributions of this work are as follows:

- This work is the first attempt to employ phase space (PS) tool for an ASPAR scheme. The present scheme manages to extract PS based information from the local voltage time series data for fault nature identification and secondary arc extinction, which is novel in transmission line adaptive reclosing methodologies.
- The sampling rate and the maximum arc extinction time of the present framework are lower than previous ASPAR schemes [5,10] and [16,17], resulting in reduced dead time for auto-reclosing of transmission lines.
- The proposed algorithm is assessed against effective operational and structural conditions including single/double circuit, partially transposed/transposed lines and shunt compensated lines. The simulation results demonstrate accurate assessment.
- The performance sensitivity analysis of the proposed scheme is evaluated under existence of measurement noise. The simulation results demonstrate accurate assessment.
- The presented algorithm does not need complicated integral computation, resulting in significantly easier to implement than previous integral based ASPAR methodologies [11,12] and [17].

This article was collected in eight parts as follows. Section 2 briefly describes the development of the basis for single phase auto-reclosing using PS. Section 3 presents the preparation of the proposed ASPAR scheme. Sections 4 and 5 present the system modeling and results, respectively. Section 6 gives a comparative assessment of the presented scheme. Section 7 illustrates the integration of the proposed algorithm with reclosing relay. Finally, conclusions are expressed in Section 8.

2. Developing the basis for ASPAR scheme using PS

Up to now, ASPAR scheme designing has been presented employing time domain, frequency domain and time-frequency domain analysis of power system variables over two past decades [2–17]. However, little attention has been paid to use the PS domain analysis for ASPAR scheme designing. The PS domain contents a valuable shape information of a power system signal for disturbance detection and fault detection in a transmission line. According to this information, some schemes were provided to the disturbance detection and transmission line protection [19–21]. In this paper, a set of PS based criteria was presented. On the basis of these criteria, the preparation of a new non-intelligent and noncommunication ASPAR scheme which is fed by local voltage signal was then described. Moreover, to compute