Electrical Power and Energy Systems 89 (2017) 136–145

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

An spatiotemporal information system based wide-area protection fault identification scheme

Rahul Dubey [a,*], Subhransu Ranjan Samantaray [b], Bijay Ketan Panigrahi [c]

[a] Department of Power Grid/Grid Automation, ABB R & D Center, Bengaluru, India
[b] School of Electrical Sciences, Indian Institute of Technology, Bhubaneswar, India
[c] Department of Electrical Engineering, Indian Institute of Technology, Delhi, India

ARTICLE INFO

Article history:
Received 7 April 2016
Received in revised form 2 January 2017
Accepted 1 February 2017

Keywords:
Wide area back-up protections (WABP)
Koopman mode analysis (KMA)
Phasor measurement units (PMUS)
Power swing

ABSTRACT

The paper presents a synchronized phasor measurement based fast and accurate comprehensive wide area back-up protection scheme for transmission lines. The proposed scheme uses Koopman Mode Analysis (KMA) technique on fault current data obtained from Phasor Measurement Units (PMUs) for fault identification in back-up protection. The principal advantage of Koopman operator is that it is based on spatiotemporal information system (STIS). In real world applications, often time and space exists together and hence, dealing with spatial aspect without considering temporal aspect is of limited use. The wide area back-up protection scheme is developed using STIS for fault identification and classification including wide variations in operating conditions of the power network. The New England 39 bus system is used as the test system which is developed on Dig-Silent power factory commercial software (PF4C) platform for evaluating the performance of proposed technique. Further, the efficacy of the proposed scheme is also tested for stressed conditions such as symmetrical fault during power swing and load encroachment and found to work effectively.

1. Introduction

Wide-area measurement and protection is a novel technique presented in recent years, which uses multisource information to make fault identification decision which prevents catastrophic blackouts. Since long communication delay often occurs during the information transmission process, which does not match with the speed of the traditional primary protection scheme and thus, researchers are inclined to use wide-area information to improve the reliability of back-up protection [1–3]. Conventional back-up protection schemes for the electric power network rely on local measurements. These schemes face difficulty in distinguishing the fault from heavy loading conditions [4]. Back-up protection malfunctions during stressed conditions results in propagation of cascaded tripping. Coordination among several back-up protection zones in a complex power system is another challenging issue and may be the cause of hidden failures in a power system [2–5]. Protection schemes based on intelligent technologies [6–8], including genetic evolution, tabu searches, and fuzzy control principle, are proposed to realize the fault-tolerance function of the WAP system. However, the computational burden delays the response time and lowers down the speed of the relay.

Faults identification during power swing by monitoring the voltage phase angle at the relay location [9–10], has been found suitable. However, only the single-phase faults have been considered and the method has not been applied to symmetrical and other unsymmetrical faults. Research on building intelligent schemes for blocking power swings using adaptive, neuro-fuzzy inference systems (ANFIS) [11] has been reported. However, neuro-fuzzy systems require huge numbers of training patterns in achieving a reliable relay function. Moreover, it might need retraining for use in different power systems. Recently, a new technique based on wavelet singular entropy (WSE) has been proposed for distinguishing stable power swing from unstable one [12,13]. However, all of the aforementioned protection schemes for the electric power network rely on local measurements and find difficulty in distinguishing the fault from other stressed conditions such as heavy loading conditions. Even though WABP schemes [14–18] for uncompensated and compensated line [19] are existing, however the reliability in case of power swing and load encroachment needs further improvement. Thus, there is strong motivation in developing a wide-area measurement based fast relaying decision making scheme such as WABP.

* Corresponding author.
E-mail address: rahul.dubey2011@gmail.com (R. Dubey).

http://dx.doi.org/10.1016/j.ijepes.2017.02.001

The method proposed in this paper is an alternative technique for Wide Area Protection (WAP) by analyzing the current magnitude and angle data obtained from Phasor Measurement Units (PMUs). Koopman proposed the technique for analyzing non-linear systems by using Koopman operator and studying its spectrum [20] detailed in [21,22]. This operator itself is in infinite dimensional and is defined for any finite dimensional non-linear system. The KMA is based on an expansion of vector-valued observable (function) using Eigen-functions of the Koopman operator. The principal advantage of KMA is that the spatiotemporal databases can be defined as a database that embodies spatial, temporal and spatiotemporal database concepts, and captures both spatial and temporal aspects of data. But, there are many other methods to handle such spatiotemporal data such as Proper Ortho-normal Decomposition (POD), Empirical Mode Decomposition (EMD), Principal Component Analysis (PCA), and so on. But EMD is used for separating out the individual modal components from a multi-modal complicated signal. EMD signal will require considerable amount of data points with multiple maxima and minima occurring in the signal to identify the individual constituent. In order to satisfy the constraints of expedited identification that is required for fault identification techniques, EMD method is clearly not a viable alternative as it won't be able to separate out the components from the same time window over which the proposed technique operates. Again, PCA is used for transforming a spatiotemporal set of data into basis functions that are orthogonal or completely uncorrelated from each other. The basis functions would be arranged in decreasing order of variance i.e. the first basis function would incorporate the maximum variability in the data. Depending on field of application PCA is also known as POD. If POD is used in our current application (time series data from PMU after occurrence of fault on one of the lines) then it would provide a minimal set of basis function that would represent the data set. Depending upon the nature and type of fault the POD technique would produce different basis functions and thus an identification parameter cannot be assigned to determine whether a fault has occurred or not from the basis function. Furthermore the faulted line identification (line number on which fault occurs) cannot be ascertained from the basic functions as the coefficients relating the basis functions to the corresponding line current shows abrupt variation and does not necessarily indicate the line on which fault has occurred.

Therefore, KMA having advantage over EMD, PCA and POD etc. in relay application. In real world applications, more often, time and space exists together and hence, dealing with spatial aspect without considering temporal aspect is of limited use. Spatiotemporal semantics is obtained by combining the two fields and defining the data types, types of change with respect to time and space, space-time topology, object identities and dimensionality. The technique of determining single frequency modes called Koopman Modes by spectral analysis of spatiotemporal data has been established in [21–24]. Koopman Mode has been extensively used for studying the dynamics of Power Systems e.g. determining coherency [22], identifying precursor to swing instability [25] and stability determination from Power Flow data [26].

In this paper, KMA is applied to magnitude and angle of the current signal obtained from the PMUs to detect the fault in the transmission network. Once the fault event is detected, the method identifies the faulted line so that required actions can be initiated by the system operator. New England 39 bus system is used as the test system for evaluating the performance of the proposed technique. The paper is organized as follows: Section 2 outlines the protection challenges during power swing, Section 3 describes the proposed method, Section 4 includes the system studied, and highlights the performance under fault during power swing, simultaneous fault identification and classification, Section 5 includes the backup protection scheme and, Section 6 concludes followed by references.

2. Protection challenges during power swing

Power swing is a phenomenon that creates large fluctuations of active and reactive powers between two areas of an electrical system following severe disturbances such as line faults, loss of generating units, and switching heavy loads. It could affect the distance relay's behavior which may result in relay malfunction. Mal-operation of Zone-3 of distance relay is likely to occur during system stressed conditions such as power swings [1–5], which is undesired. Conventional fault identification techniques may fail to detect fault during the power swing because of large variations in powers even before the fault. Further, due to the symmetric nature of phase voltages and currents during the swing, symmetrical faults are difficult to be detected.

The impedance trajectory during power swing enters zone-1 of the relay, as shown in Fig. 1.This corresponds to an stable/unstable power swing as the impedance trajectories enter zone-1 in case of unstable power swing. It gives an indication of the existence of the electrical center in the studied line. However, for stable or unstable swings, relays should not operate, as they derives a KMA analysis based fault detector based on which trip/block command can be given to the distance relay. Fig. 2 shows the respective voltage, current and apparent impedance for a 3-phase symmetrical fault during power swing.

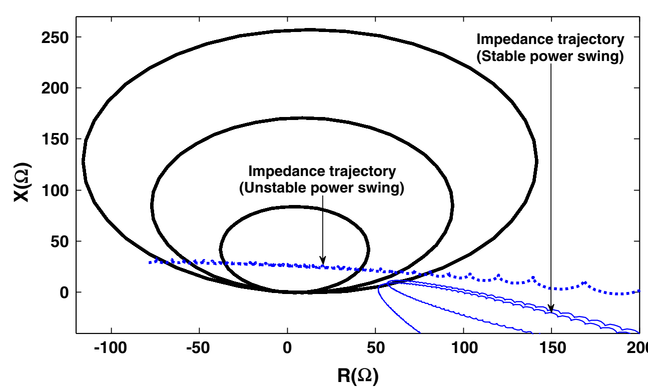

Fig. 1. Impedance trajectory during stable/unstable power swing.

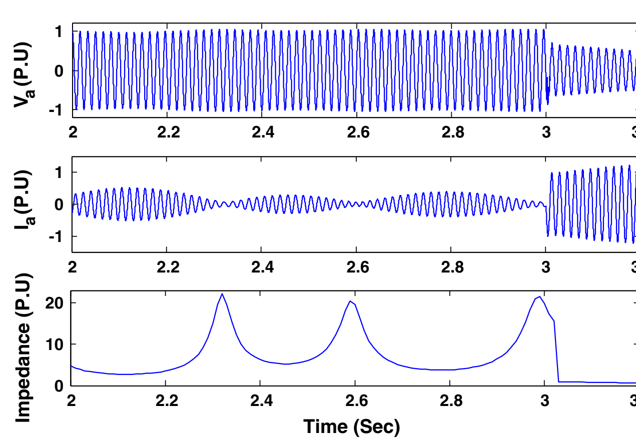

Fig. 2. Phase-a voltage, current and apparent impedance for a 3-phase symmetrical fault during power swing.