Computers and Electrical Engineering 000 (2018) 1–16

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

Fault localization for transmission lines with optimal Phasor Measurement Units☆

M. Meenakshi Devi*, M. Geethanjali, A. Rama Devi

Department of EEE, Thiagarajar College of Engineering, Tamilnadu, India

A R T I C L E I N F O

Article history:
Received 1 April 2017
Revised 31 January 2018
Accepted 31 January 2018
Available online xxx

Keywords:
Smart grid
Wide area monitoring, protection and control
Phasor Measurement Units
Fault location
Genetic algorithm
Transmission lines

A B S T R A C T

This paper discusses a novel fault localization algorithm for multi-terminal transmission lines. The technique is tested for different fault types and fault locations. The exact fault location is determined along with the latitude and longitude by involving geo-referenced data of the power system. In addition, Phasor Measurement Units (PMUs) are effectively used for complete system observability. The number of PMUs is optimised using Genetic Algorithm. Thus, the objective is to find the distance of the fault occurrence and to locate the fault point along with the latitude and longitude, using optimal PMUs. For evaluation purpose, Indian Utility (TamilNadu Electricity Board) 49 bus system is used and validated, using software such as MATLAB, Power World Simulator and Google Earth View. The results show the effectiveness of the proposed technique to spot the exact fault point in the transmission lines with a minimum number of PMUs, to make the concept economical.

1. Introduction

Developing a model, maintenance, control aspects of electric power systems and communication networks are becoming a challenging aspect. It is still more complicated for power engineers, to maintain the system reliability and to increase the effectiveness in power system protection [1]. This is due to the increase in demand of power, diffusion of renewable energy sources, enlarging interconnections and deregulated energy markets. This has raised the need for synchrophasor measurement technology in the field of Wide Area Monitoring, Protection and Control (WAMPAC). Synchrophasor is said to be a phasor value measured at an instant and therefore it consists of time-tagged data [2].

The time-tagged data are to be measured simultaneously and synchronised, to enhance the Phasor Measurements recorded at a particular instant, across a huge geographical area. The time intervals are the multiples of a period of the nominal power system frequency. This synchronisation is provided by Global Positioning System (GPS) receiver. In this measurement technology, basic parameters such as voltage, current, phase angles, and frequency can be measured by using Phasor Measurement Units (PMU). Also, the data provided by the PMUs are accurate and useful in the determination of the exact sequence of events, which improves the monitoring. Likewise, it increases precision and speed of state estimation [2]. Due to these distinguishing features, PMUs are adopted for huge power system applications [3]. In the proposed algorithm, the PMUs are used in fault localization for multi-terminal transmission lines.

The concept of fault location has attracted many researches to work on it to avoid the consequences due to the fault occurrence. Numerous works are carried out on fault location in one-terminal and two-terminal transmission lines [4–6].

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. J. Yogapriya.

* Corresponding author.
E-mail addresses: mdeee@tce.edu (M.M. Devi), mgeee@tce.edu (M. Geethanjali).

https://doi.org/10.1016/j.compeleceng.2018.01.043

Though the fault location algorithms using single and two terminals are uncomplicated and economical, it has some flaws regarding accuracy and selection of the faulted section. In addition, real-time power system has numerous nodes making the system complex [4]. To face this complexity and improvise the demerits of the older techniques multi-terminal fault location algorithms are used. Here fault location for multi-terminal transmission lines is chosen because it does not completely rely on the values of un-transposed lines and line-loading, and so it improves the accuracy too. Hence, instead of modifying the lower level algorithms, multi-terminal fault location is taken into account. From the literature review, it is understood that Smart Grids employing distributed and renewable energy resources are made secured by utilising the PMUs effectively. There are several methods such as decision tree method [5], and least square estimation technique [6,7] which elaborate the phasor estimation and classification of fault types. The methods based on synchronized sampling do not require line parameters and settings free. The basic concepts could be understood using three-terminal transmission line [8,9]. A circuit approach for three-terminal transmission lines is examined and learnt that it uses voltage and current phasor values [8]. In this reference paper fault location for three-terminal transmission lines is done with time-time transformation to report the arrival time of fault generated travelling waves in [9]. The paper [10] comes up with a novel method of fault location using binary differential evolution optimization algorithm with ‘weight factor' and ‘reduction factor' that improves convergence speed. Also, references [11,12] explain the fault location technique with optimal placement of PMUs. This reduces the cost of installation and maintenance of PMUs. A thorough work on the fault detection and localization of smart power grids using synchronous phasor angle measurements is achieved from the literatures [13,14]. References [15,16] are the inspirational papers that deliver a clear derivation for fault location for multi-terminal transmission lines.

In real-time, the inspection of exact location of the fault is done manually and it is a tedious process which delays the further rescue actions. In some places, even helicopters are used in search of fault points without knowing them exactly [17]. This accomplishes an expensive service of restoration. Additionally, the real-time power system includes various electrical components and parameters within it and is located through a wide area in the landscape. In this aspect, with fault distance, it will be hard for the experts to locate the exact fault point, particularly for long lines in uneven terrains [17]. In practical, the assumption made is that the PMUs are placed at all the terminals [15,16]. But, in the economical point of view, the installation cost of a PMU depends on numerous factors, such as the number of measuring channels, current transformer connections, potential transformer connections, power connection, station ground connection and GPS antenna connection. Here, according to the number of channels, the cost of PMU differs from one another [18]. The remaining connections are similar to all the PMU installations. From the literature study [19], it is understood that the approximate cost of each PMU is 30,000–40,000 of US dollars. Thus, to make this an optimal technique, this paper proposes that the PMU counts optimised through Genetic algorithm. Further, the references [15,16] focus on identifying the fault distance and fault point from the sending end of the line. In order to deliver the fault point with latitude and longitude along with the fault type to the control system operator, the fault location identification algorithm is proposed in this paper. To experiment on this aspect, the goal of this paper is to capture the features of a real-time bus system in a simulation diagram, which could be used to run fault analysis and locate the fault point with latitude and longitude. Regarding the quantities of voltage and current phasors it is considered that they are completely observed and synchronously measured by the PMUs located at optimal terminals. The simulation is created and the fault analysis is carried out for the considered test system. The fault region is contoured and the exploration of the latitude and longitude of the fault point is done using real-time Indian utility - TamilNadu Electricity Board (TNEB) 49 bus system. Finding the fault point with geo-referenced data will definitely replace the operating time to restore the damaged section. To make this a winning concept, the proposed algorithm is developed in MATLAB for identifying the fault location and the spotting of latitude and longitude of the fault point is extended in Power World Simulator (PWS) along with Google Earth View. Geographic Information System (GIS) tools are the computer-based tools that deliver content with the geographic location and satellite imagery [20].

The paper is organized as follows. Section 2 depicts the concepts involved in optimal PMU placement technique. Section 3 describes the proposed algorithm for fault identification to establish the faulted section in the power system which is interpreted for both bus and line fault. Section 4 elaborates the results and discussion obtained from the optimal placement problem and the proposed method for the fault location. It is followed by the conclusion in Section 5.

2. Optimal PMU placement technique

In the field of Power system protection, the PMUs are known for their data acquisition technology for wide area monitoring and protection. This regulation of PMUs with the wide area monitoring systems is done by data synchronisation using Global Positioning Systems (GPS) receivers for 1 microsecond. In particular, the PMU is a device that is capable of measuring the entire parameters of a bus in which the PMU is placed and those of the adjacent buses connected to that bus [21]. Hence, the placement of PMUs at strategic buses makes the system completely observable. The target is to minimise the number of PMUs with complete observability to observe the fault locations. For this purpose, Genetic algorithm (GA) is considered for the optimal placement problem. GA is a popular one in meta-heuristic methods. In the field of Engineering and Technology, for a particular scenario, GA is used to explore a prominent result.

GA is an iterative process and at first, it starts with the randomly generated chromosomes. These chromosomes contain the information of the PMUs placed. This binary set has a length equal to the number of buses in the system. For example, if a bit denotes a value of ‘1′, the PMU is placed in that location or bus. A bit having a value of ‘0′ implies the absence of PMU at that particular bus. The chromosome information is encoded by GA, to solve the optimization problem and