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Fault localization in electrical power systems: A pattern recognition approach

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ABSTRACT

Electrical power system is one of the most complex artificial systems in this world, which safe, steady, economical and reliable operation plays a very important part in social economic development, even in social stability. The fault in power system cannot be completely avoided. In this paper, we developed a method to resolve fault localization problems in power system. In our researches, based on real-time measurement of phasor measurement units, we used mainly pattern classification technology and linear discrimination principle of pattern recognition theory to search for laws of electrical quantity marked changes. The simulation results indicate that respectively study on the phase voltage, positive sequence voltage, negative sequence voltage, phase current, positive sequence current, negative sequence current of single-phase grounding faults and the positive sequence voltage, positive sequence current of three-phase short circuit faults, the pattern classification technology and linear discrimination principle are able to quickly and accurately identify the fault components and fault sections, and eventually accomplish fault isolation. In the study of electrical power systems, pattern recognition theory must have a good prospect of application.

1. Introduction

A fault is defined as a departure from an acceptable range of an observed variable or calculated parameter associated with systems. It may arise in the basic technological components or in its measurement and control instruments, and may represent performance deterioration, partial malfunctions or total breakdowns. Fault analysis implies the capability of determining, either actively or passively, whether a system is functioning as intended or as modeled. The goal of fault analysis is to ensure the success of the planned operations by recognizing anomalies of system behavior. A system with faults does not necessarily imply that the system is not functioning. Detecting a fault involves identifying a characteristic of the system, which when a fault occurs, can be distinguished from other characteristics of the system [1–4].

It is relay protection that plays the role to isolate the various random faults, which is also the first guarantee line for security operation of power system. Inevitably, if the primary protection fails to operate or to be in service temporarily, the backup protections should have the task to operate and clear the fault. However, many power system cascading events in recent years have underlined the limitation of traditional backup protections, which only utilize the local data without considering the impact on the whole system. The installation of the wide area measurement system (WAMS) [5–8] has opened a new route for the design of relay protection, especially for the backup protections. Accordingly, a novel wide area backup protection, which is based on identification of fault component, has become one of focuses in relaying field with the application of wide area information. The traditional fault diagnosis methods are usually based on the data provided by the Supervisory Control and Data Acquisition/Energy Management System (SCADA/EMS), which mainly contains the operation information of Circuit Breakers (CB) and protection devices and the recorded sampling data in fault recorder during the process of fault clearance [9–12]. Then, the fault section will be estimated by the playback of the development and clearance of fault. On the contrary, the fault component identification used in novel backup protection principle needs to be carried in an on-line way before the expire of time delay setting. During this time range, the data source utilized in the new fault location algorithm is the nodal voltage and branch current synchro-phasors from WAMS. In addition, enough time should be saved for the adaptive adjusting of the corresponding backup protections. In this way, the corresponding Circuit Breakers will be inspired to isolate the fault, so that the security and stability of the rest of power system will be guaranteed. In a summary, the novel fault location algorithm needed in wide area backup protection is different from the traditional fault diagnosis method in main target and data source.

Pattern recognition (PR) is one of the most vigorous science and engineering research areas nowadays. It is concerned with the finding and identifying structures which may be hidden amid a great deal of confusing and irrelevant data [13–16]. The process of PR consists of extracting information from an object and

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subsequently making decisions on a course of action which will be taken. PR is performed mainly in the following three stages:

(1) Data measurement and enhancement (information vector);
(2) Feature vector generation (the acquired information is reduced to a feature vector of lesser and more manageable dimensions, but containing all the necessary information);
(3) The classification stage.

In the classification stage, the goal of PR is to classify the objects into a number of categories or classes. A typical PR system has three major components:

(1) Input module that acquires the observations;
(2) Feature extraction module that transforms the observations into a vector in some domains;
(3) Classification module that classifies the observations based on the extracted features.

The classification based on the priori knowledge about observations is known as supervised PR, or is called unsupervised PR or clustering when this information is not available. In both type of problems, the algorithms are based on the notion of similarities between observations. And similarity measures are placed on the heart of any PR system. PR techniques are not only "theoretic", but also practical in our daily life. It has already been applied to a wide range of areas including image analysis and retrieval, computer vision, automatic target detection, face recognition, handwriting and character identification, speech and voice understanding, remote sensing, computer-aided diagnosis and others. As a result, PR means the study of analyzing, detecting, recognizing, and describing patterns in structural or statistical data. In fact, it has grown into an interdisciplinary field that includes engineering, computer science, biology and medicine, and so forth.

When electric power system operates from normal state to failure or abnormal operation, its electric quantities (current, voltage and their phase angles, etc.) may change significantly. In our researches, after some accidents, based on pattern recognition theory, we utilized real-time measurements of phasor measurement unit (PMU) [17–19] and used mainly pattern classification technology and linear discriminant principle [20–22] to search for laws of electrical quantities marked changes. We developed these methods to quickly and accurately identify fault components and fault sections, and eventually accomplish fault isolation.

2. Wide area measurement system

Currently, PMUs are widely used in modern power system. In the substations that PMU has been installed, the main function of PMU is to measure the state variables as phasor representation from the nodes and branches [5]. Due to the time service in the global position system (GPS), the phasor data could be stamped with the unified time mark [23,24]. A typical block diagram for the synchronized phasor measurement equipment is shown in Fig. 1.

Owing to the cost of phasor measurement device, the installation of the PMU in power system is implemented step by step and classified into different construction stages. The main prior placements for PMU are constituted of large generating sites, major transmission paths and significant control points. Wide area measurement system has been put into operation for some regional electric power transmission network. This advanced measure system provides central synchro-phasor data acquisition in substation level, and the data transmission to the phasor data concentrator (PDC) is executed by a special communication system. After some treatments in data concentrator, a more accurate picture of power

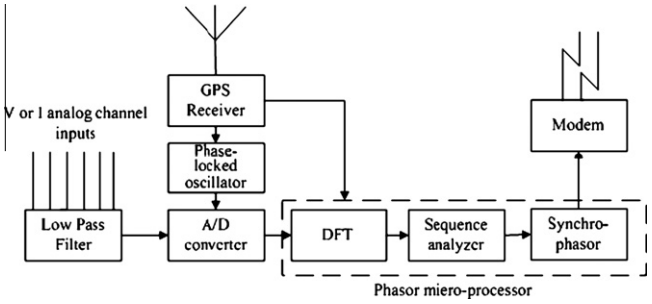

Fig. 1. A typical block diagram of PMU device.

system in real-time will be described from WAMS. The hierarchy of the WAMS could be illustrated in Fig. 2.

Based on the advantages of wide area time synchronization capability and fast transmission speed, WAMS has become one of the most important data source for the current power system analysis and calculation. It also provides a global view for the operation of electric network. Hence, the new challenges and opportunities have been introduced into the power system research fields, such as dynamic monitoring, state estimation, feedback control, wide area backup protection, and so on.

Comparing to the conventional measurement system SCADA/RTU, the advantages of the new WAMS/PMU measure system are listed as following:

(1) Except for the switch status information, the PMU also provides the analog phasor data including nodal voltage, branch current and the power-angle information;
(2) The data refreshment rate is quicker in WAMS/PMU, such as 25 frames/s, 50 frames/s or 100 frames/s in China. Obviously, the refresh period is much shorter than in SCADA/RTU about 4 s;
(3) All the measurement value will be stamped with the same time mark, so nodal voltage phasors from difference nodes could be put into the same time coordinate, and the angle difference between two phasors can obtained in order to monitoring the power system stability;
(4) The high precision synchro-phasor of nodal voltage and current could be introduced into the traditional state estimation method, which will lead to the condition change in the algorithm.

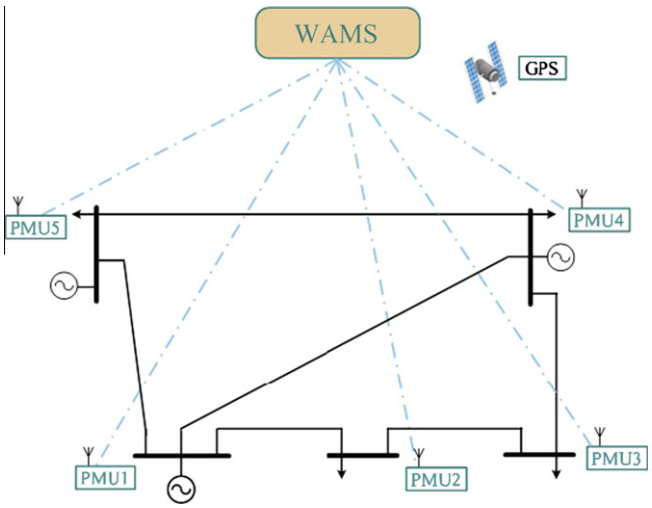

Fig. 2. The hierarchy for the wide area measurement system.