



Protection system analysis using fault signatures in Malaysia

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ABSTRACT

Electrical power outages are major concerns to power utilities throughout the world. Unfortunately, power outages will continue to happen and they cannot be totally prevented. Outages could be due to lightning strikes, tree encroachments or equipment failures. However, the impact can be reduced if power system operators are equipped with appropriate tools to analyze the root causes of the outages. To ensure system operators have the system fault conditions immediately after a tripping has occurred, this paper discusses practical solutions to be applied in the control center. This paper presents a tool for analyzing protection system performance with special emphasis on the fault signatures using Digital Fault Recorders (DFRs).

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1. Introduction

Nowadays, consumers throughout the world place greater demand on power utilities to provide higher quality and reliability of power supply. Electricity is no longer a luxury item. It is now an essential commodity which has great economic and security implications. Power outages and blackouts have become unacceptable disruptions to our daily lives and routine activities in this challenging 21st century.

In the year 2003, the world experienced at least five major electrical power supply disturbances affecting a few countries resulting either partial or total national blackouts. The famous wide-scale power outages are as follows:

- (i) 14th August 2003 at 1610 h, north-eastern United States of America (USA) and central Canada [18,46,13].
- (ii) 28th August 2003 at 1826 h, central United Kingdom [18,46,13].
- (iii) 1st September 2003 at 0958 h, northern Malaysia [34].
- (iv) 23rd September 2003 at 1235 h, eastern Denmark and southern Sweden [18,46,13].
- (v) 28th September 2003 at 0328 h, whole of Italy and southern Switzerland [31].

All those blackouts have caused great financial losses that were estimated to be more than a billion US Dollars [18]. Blackouts can be initiated by many causes, such as severe demand and generation imbalance, protection system failures, incorrect or slow actions of system operator. Generally, blackouts are due to a

combination of circumstances which stresses the network beyond its limits. The difficulty is in seeking solutions that would prevent cascaded tripping that eventually lead to partial or even total blackouts.

An important fact is that, electrical power outages will continue to happen and they cannot be completely prevented. Outages could be due to lightning strikes, storms, broken conductors, random equipment damages, fire, tree encroachments or human errors. Unfortunately, system operators are not equipped with sufficient tools to identify the nature of the faults and the accuracy of the protection system operations before any decision can be made to restore the supply. This is one of the factors that often delay the restoration process.

In actual fact, system operators have to depend mainly on information from relay indications, flags, facias and Supervisory Control and Data Acquisition (SCADA) system. The information provided may sometimes leads to inaccuracies in fault analysis due to uncertainty of correct relay operations and unsynchronized information. Unfortunately, with complex disturbance events in a power system, system operators have to make critical decision in order to minimize the duration of outages and economic impact although the exact nature of the faults are not known.

2. Review on existing methodologies

2.1. Protection system

As the power system grows, the protection system's reliability, selectivity and speed have become a very critical issue compared to the last century. Therefore, a Digital Fault Recorder (DFR) is a very important tool for protection system analysis [23,30]. One

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advantage is to confirm the correctness of protection operation compared to the normal utilities practice, and any special rectification that needs to be done.

Rodriguez et al. [10] presented a paper on modular approach for fault diagnosis. They described the application of neural networks in order to detect the faulty elements in a power system taken from alarm messages. They used these alarm messages to formulate a model classification representing the behavior of the protection system. On the other hand [25] proposed a fault diagnosis using protection relays and circuit breakers (CBs). The purpose was to overcome confusion due to incomplete and corrupted alarm messages. That approach managed to identify the faulty feeder and phase affected by the system fault.

There are some literatures which discussed the protection system performance information to identify the faulty section and confirmation of protection operations. Mc Arthur et al. [32] discussed the combination of an expert system and model-based system to identify the accuracy of the protection schemes. The principles were based on correct protection operation schemes and modeled for any given disturbances. The model needs to be updated to the latest power system status in order to perform the correct diagnosis. The findings were extended by [19]; which they used DFR to identify the faulty section. They utilized power system modeling to analyze the protection system reactions corresponding to a tripping.

Dongyuan et al. [33] introduced an integrated power system protective relaying fault information system. With that approach, the relay and fault recorder information were captured and stored in the local management computer located at the substation. All those information were transmitted to the control center for the operator to make a decision. That approach requires all the protective relays to be upgraded to digital relays.

2.2. Fault signature

Fault signature can be defined as a defect in any electrical power system which produces the same characteristic. Therefore, a failure in the electrical power system can be identified by looking at the fault signature produced by the failure agent. Since the benefit of fault signature analysis is so useful to power utilities, a large number of researches were conducted by Intelligent Electronic Devices (IEDs) manufacturers, Universities and individual persons who were interested in understanding the nature of the problem.

The signature approach was successfully implemented in medical industries such as an electrocardiogram (ECG) which measures the electrical activity of the heart [9,26]. This includes the irregularity of beats as well as the damage to the heart. Other industries such as security used this approach to identify the thumbprint, retina characteristics, voice pattern and object recognition [11,24,41]. In the electrical field, this approach was adopted in electronic system, cable television network, and computer processes [39,42,1,8,12,2]. On the power plant there were literatures [14,16,3] and the US patents [20,22] which tried to identify the problem such as pump failure, internal tank leakage and other localized component failure. However, in the electrical power transmission overhead line, it is still new and not many researches were conducted on the fault signature application and is still an open question.

Keerthipala et al. [44] proposed the implementation of neural network to identify the faulted phase by using a simulation from Electromagnetic Transients Program (EMTP) result. Since there is a great demand to identify the fault characteristic in the electrical power sector, Abdul Karim et al. [29]; did his research and attempted to categorize the fault signature by analyzing data from the protection relays and CB operations using a knowledge-based expert system. In his findings, Szali utilized the hypothesis approach which consisted of different combinations of pre-prepared

simulated events. This approach is relatively similar to the model-based approach that had been discussed by Mc Arthur et al. [32]. However, the disadvantage of this approach is that the system requires an ideal protection system without any relay mal-operations.

In the year 2002, Xu and Kezunovic [45] utilized a wavelet transform to identify a transient fault, capacitor switching, motor starting, line switching and transformer energizing. In the same year, Jeffery and Demetrios [7] patented their idea to identify the faulty phase for the relay's application. They successfully identified the faulty phase using the above technique but not the fault signature as what power utilities aspire to have.

Lim and Shoureshi [28] presented an approach to detect a broken conductor's strands by analyzing the reflected displacement waves using Electromagnetic Acoustic Transducer (EMAT) in the year 2006. EMAT measured the waves generated by a conductor's vibration which required an additional monitoring device to be installed on each towers and conductors. However, that approach could not identify the fault signature caused by a flashover and moreover it was not practical to retrieve the information from each EMAT during the tripping of an overhead line.

El-Zonkoly and Desouki [6] conducted a research to identify the fault type. However, they only focused on distance protection for transmission lines.

Uppendar et al. [15] conducted a research on fault type identification for protection relay which is used by the relay's manufacturer. They used Classification and Regression Tree (CART) method to analyze the current signals captured by a recorder.

Ajami and Daneshvar [5] presented a statistical signal processing using Independent Component Analysis (ICA) to detect and diagnose thermal power plant turbine system. This approach can be used to avoid false alarms due to changes in operation conditions. However, ICA is not able to identify the root cause of the failure.

Another research by Abdelsalam et al. [4] discussed on power quality identification and classification using linear Kalman filter with discrete wavelet transform (DWT) which could not identify the fault signature.

A paper presented by Hamzah et al. [21]; highlighted their experience in utilizing the recorders information. They observed that a few signatures could be extracted from the recorder traces such as tree encroachment, contamination and lightning. In their paper, they did not highlight any scientific technique to be used to justify the relevant fault signatures.

To continue with their findings from Hamzah et al. [21]; this research will develop an integration for a systematic approach for fault signatures via mathematical equation and protection system operation analysis to solve one of the problems highlighted by the Working Group D10 [43].

3. Protection system analysis

Protection system analysis is a systematic approach to identify the operational behavior of the protection system components. It incorporates protection basic rules namely; reliability, selectivity and speed. This research utilizes the recorders' information where all the power system data during flashovers are captured.

The protection system analysis (PSA) module will analyze the protection system response using the data that have been sampled by the selected DFR at a substation level. The data sampling rate being used by the selected DFR for this research is 5 kHz. This approach will produce 100 arrays of data for every 1 cycle (20 ms for a 50 Hz system) of information. As a result, the PSA module will analyze the data for every 0.2 ms in a matrix form as shown in the analog and digital matrices.

The analog inputs array is tabulated in a matrix of $(N \times 7)$ with " N " rows and 7 columns. The maximum number of rows (N) being

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