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An Adaptive Protection Methodology for Power System Reliability Enhancement

By

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Abstract

The power system conditions always keep on changing because of the continuous variation nature of the system loads over time and also because of being subjected to several disturbances. According to the size of these disturbances, the power system maintains its stability. As a result of this disturbances, the power system may operate on the verge of stability. The protective relays within the power system should offer the required flexibility and adapt its setting to help maintain the system stability. Many adaptive techniques have been introduced so that the power system protective schemes always offer the required protection for the system elements thus increasing its reliability.

It is highly important to use a dependable algorithm that can evaluate the system conditions, and define the current status of the power system. The data mining-based techniques are distinctive as they are highly dependable and accurate. The most frequently used data mining algorithm for the system evaluation process is the decision trees (DT).

This thesis is interested in the data mining techniques that is used in evaluating the status of the power system. It presents a data mining model depending on support vector machines (SVM) that is built for classifying the system condition after analyzing the data coming from the system. This model is responsible for triggering on and off a protective methodology according to the system status whether it is normally stable; referred to as safe, or on the verge of stability; referred to as stressed.

The thesis offers two comparisons between two different data mining models; one of the models depends on DT which is the most widely data mining technique in power system, and the other model uses SVM technique presented in this thesis. The two comparisons depend on training and testing the two models using two different databases; data base-1 and data base-2. Data base-1 was used in a previous study, while data base-2 was generated from IEEE 30-bus test system. It was built by solving load flow analysis problem for IEEE-30 bus test system several times at different loading conditions. For each individual case a load flow analysis is performed, the system parameters at each bus of the IEEE-30 bus test system such as voltage magnitude, current, active and reactive powers are recorded in the database. The result of the two comparisons shows that the SVM model proves to have higher correct rate in evaluating and predicting the system conditions than the decision trees model. Using a higher correct rate model in determining the system conditions helps enhancing the power system reliability.

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List of Abbreviations

Artificial neural network	ANN
Classification and regression trees	CART
Data base	DB
Decision trees	DT
Flexible ac transmission system	FACT
Iterative Dichotomiser 3	ID3
Multi-criteria decision making	MCDM
Phasor measurement unit	PMU
Support vector machines	SVM
Unified power flow controller	UPFC
Vapnik-Chervonenkis dimension	VC dimension
Wide area measurement	WAM
Western Systems Coordinating Council	WSCC

Chapter 1 Introduction

1.1 Adaptive Protection in Power Systems

The conditions of any power system always keep on changing over time, due to the continuous load variation nature. The traditional conventional relays that had always been used for power system protection have fixed settings parameters that show difficulties to comply and offer the required protection for all variable operating conditions **[1]**. The thinking of adaptive protection schemes had started to solve this problem, where the setting parameters or the operation characteristics can vary according to the prevailing system conditions in order to increase the power system reliability.

Adaptive protection was defined by Horowitz, Phadke and Thorp as "a protection philosophy which permits and seeks to make adjustments to various protection functions in order to make them more attuned to prevailing power system conditions" **[2]**. Many adaptive techniques had been used in order to enhance power system reliability for various circuit elements **[3], [4]**, and their concept of operation depends on real time analysis **[5]- [9]**.

This thesis discusses an adaptive protection scheme so that when the power system is in normal conditions, where there is a sufficient generated power for all the system loads, and also the transmission facilities can easily withstand the power transmission operation for all connected loads, the relay settings during such conditions are set to provide high level of dependability for the system. The power system during this conditions will be referred to as "Safe" **[1]**. The most feared scenario that may happen is the appearance of a faulted system element which the protection relays fails to clear quickly thus causes instability for the system. So by default all the protective relay settings are designed to have high bias towards dependability. But unfortunately that is accompanied by loss in the security, which may lead to an unnecessary operation of the protection system that causes the removal of an un-faulted circuit element (false trip). Such accident may be not harmful during safe system condition, but it can be extremely harmful during stressed system conditions **[1]**. During stressed conditions the power generated within the power system is barely sufficient for the system loads and some overloaded transmission lines may present, so the removal of a wrong circuit element may lead to an unnecessary power interruption or even causing potential cascading events leading to a partial or total black out. As a result, adaptive relaying is needed, where the settings of the relays that are used for the system protection depends on the varying system conditions. It can offer the essential protection during all possible scenarios that the power system may face, be safe or stressed conditions.

1.2 Wide Area Measurement

As shown earlier in section 1.1, the power system has a dynamic nature, so it is highly important to always keep an eye on the power system prevailing conditions. This can be achieved by performing wide area measurements for the system parameters, through the spreading of several phasor measurement units (PMU) all over the power system. The PMU is a device that has the ability to measure current, voltage, and the phase angle between them. The PMU's are also synchronized with each other via GPS to the same time reference, thus they can provide the measurements at the exact same time. They give an accurate snap-shot for the system at any time which happens to be very useful in analyzing the measurements and knowing the system current condition. PMU's are widely used for different application within the power system **[10]- [15]**.

1.3 Hidden Failures

Relay hidden failure is one of the most common reasons that causes a protection relay to trip falsely. It is defined as a dormant permanent defect inside the protective relay. It may cause the relay to miss-operate and to unnecessarily removes a circuit element **[16]**. The critical property of hidden failures is that they stay dormant inside the protective devise. As a result, the protective devise or the relay keeps working normally, until a certain event takes place and triggers that hidden failure causing the relay to give a false tripping signal that results in a removal a certain circuit element, and an unnecessarily power interruption. Such action could be extremely harmful to the power system, especially if the system is in a stressed condition. It may lead to cascading events resulting in partial or total black out **[17]**.

A region of vulnerability is defined to be a region in the network where if a fault takes place there, it will activate a hidden failure **[18]**. An example of hidden failure is shown in **Fig 1.1,** suppose there is a defect in the zone 2 timer inside an impedance relay located at bus A. This will cause a lack of coordination between the relay located at bus A and the impedance relay located at bus B. As a result, if a fault F_1 occurred within zone 2 of the impedance relay A, the relay may give a tripping signal before the relay at bus B takes an action. Resulting in the removal of the transmission line between the buses A and B causing unnecessarily power interruption at bus B. The dotted area shown in **Fig 1.1** represents the vulnerability region in this case. If a fault takes place within this region, it may result in the manifestation of a hidden failure. While if another fault F_2 takes place outside the vulnerability region, it will not activate the hidden failure in the impedance relay at bus A as it is outside the relay protection range. The impedance relay at bus B will normally be able to clear the fault **[1]**.

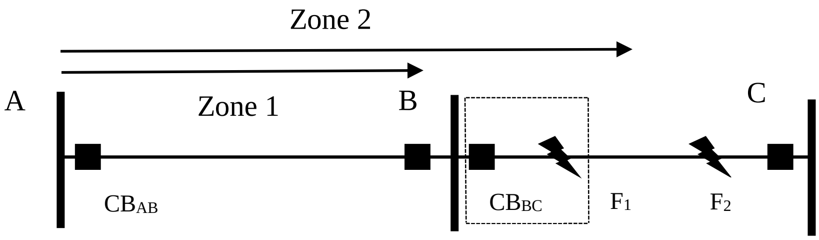

Figure 1.1- Example for hidden failure

1.3.1 Hidden Failures Main Characteristics

Hidden failures can hit any element that takes part in the protection systems such as current transformers (C.T), potential transformers (P.T), cables, connectors, and all types of relays. The main characteristic of a hidden failure is that the defected element in the protective system will not lead to any immediate action on the power system, but it will remain dormant. It may only be triggered as shown in the example in section 1.3, if an external event takes place such as a fault or any sudden change in the power system condition. The most dangerous characteristic of hidden failures is that it often appears under stressed system conditions such as during faults, under voltages, and overloads **[19]- [21]**.

1.4 Security and dependability

Reliability in general is a measure of the certainty degree that a power system element will operate and perform as intended. Relays for example are very essential for power systems because they represent the core of the protective system. They should reach high levels of reliability, and should neither fail to operate when needed in case of a fault nor operates unnecessarily during normal conditions. As in both cases, it will cause a removal of a wrong circuit element that may lead to a power interruption, thus reducing the overall reliability degree of the power system. This leads us to define two terms that affect the reliability of the power system:

1. Dependability
2. Security

Dependability is a measure of the certainty that the protective system will operate correctly on a given fault. While security is the measure of certainty that the protective relay will not miss-operate and falsely triggers a tripping unit, and causes an unnecessary removal of a circuit element **[22]**. Most of the protective systems are designed with high level of dependability, so that when a fault occurs it will be always cleared by some relay. But when the system has a high level of dependability it happens to have less degree of security and vice versa so protection engineers try to compromise between those two terms to enhance the overall power system reliability.

1.4.1 Effect of Redundancy

Here comes the effect of redundancy, as for example the presence of adequate transmission lines redundancy provides several paths for the power delivery process all over the system. The system in that case can withstand losing of a transmission line due to lack of security, because of the presence of a suitable alternative. However, of course there is a cost limit for redundancy of the system elements, which make the system designers always search for the perfect dependability/security balance to enhance the reliability of the Power system.

1.5 Voting System

An adaptive methodology was suggested by Emanuel E. Bernabeu **[1]**, aims to reduce possibility of manifestation of hidden failures thus reducing the likelihood that potential cascading occurrence. This methodology depends on adjusting the balance of the protective system in between dependability and security. The adaptive methodology depends on a voting system that is controlled and can be set to activation or deactivation according to the power