Use of Intelligent Techniques for Analysis of Faults and Protective Relay Operations

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***Abstract*—Analysis of faults and protective relay operations is crucial for understanding the fault clearing sequences. Today, this analysis is performed off line and mostly through manual inspection of different data records captured by digital protective relays (DPRs), digital fault recorders (DFRs), Sequence of Events Recorders (SERs), and other substation IEDs. This paper introduces several tools developed for automated analysis of faults and protective relay operations. The tools are implemented using intelligent techniques based on synchronized sampling, expert systems, neural networks, and fuzzy logic.**

***Index Terms*— Faults, protective relaying, automation, intelligent systems, event analysis, synchronized sampling**

I. Introduction

The power system is getting more stressed under new market rules introduced by deregulation. The reliability of operation of power systems may be affected by relay operation in many different ways [1]. It appears that about 75% percent of the US major power system undesired disturbances are related to protection issues [2]. Better understanding of the interaction between the relay operation and reliability of the power system operation is needed. This may be achieved through better monitoring of the interaction between power system operation and relay operation.

Correct operation of protective relays is critical to assuring a secure and reliable operation of power systems. There is a need to develop analysis tools that will allow for automated monitoring of protective relay operations to determine whether the relay operation criteria during normal conditions and faults are met. The problem of the analysis reduces down to two steps: analysis of the faults and analysis of relay operations. Why the two steps seem to be quite straight forward, it is not as simple to develop tools for the automated analysis. The complexity of implementation and deployment is associated with the type of data made available for the analysis, as well as the objective of the analysis.

This paper explores the means for automated analysis of protective relay operations. Three issues related to correctness of relay operations are the focus of this paper: a) evaluation of relay "near operations", b) verification of dependability and security of relay operation, and c) performance assessment of the entire fault clearing sequence.

II. Overall Scheme

The approach for automated analysis of protective relay operation reported in this paper was developed at Texas A&M University during the last few years. It first uses a steady state approach utilizing the topology processing method and power flow method to identify vulnerable lines due to stressed operation conditions [3]. Power flow method is used in static contingency analysis to identify overload and low voltage problems due to transmission line outage. To verify a possible relay operation, dynamic analysis of relay behavior is needed. Dynamic bus voltage phasors are calculated from the time-domain transient stability analysis. They are used to calculate the apparent impedance seen by distance relay and obtain the dynamic impedance trajectory [4]. If the apparent impedance falls into the relay protection zone longer than the setting time, the relay will operate based on its design character. This dynamic approach can identify vulnerable relay locations (lines) and vulnerable fault conditions. Once such a condition is identified, the system vulnerability tool invokes monitoring tools located at the substations. The local tools are capable of analyzing performance of local relay operation and informing the centralized tool about the outcomes. This interactive scheme is show in Fig. 1.

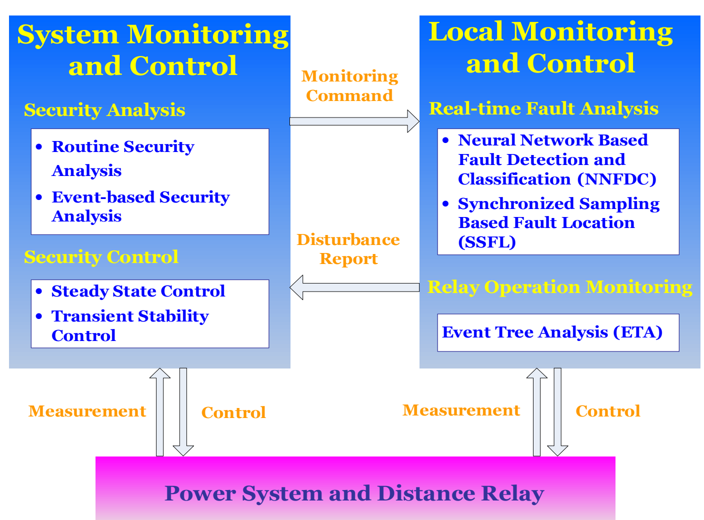

Fig 1. Interactive scheme for system-wide and local evaluation of impacts of relay operation

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III. Local monitoring

The local analysis tool is intended for installation at selected substations. As shown in Fig. 2, it consists of real time fault analysis tool using neural network (NN) and synchronized sampling (SS). Being more accurate than the traditional relays, this tool is used as a reference for fault analysis of relay operation. It is supplemented with a relay operation monitoring tool that uses event tree analysis to assess the correctness of fault clearing sequence.

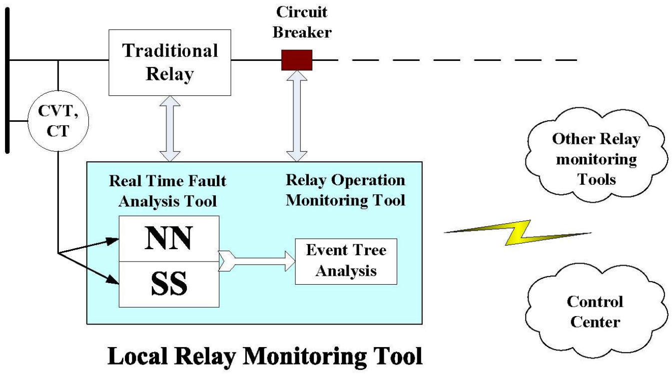

Fig. 2. Real time relay monitoring tool

The real time fault analysis tool takes voltages and currents from the secondary of instrument transformers, relay trip signals from the digital outputs of a relay, and the contact status from the circuit breaker control circuit. This tool works in parallel with traditional relays to detect whether the relay operation is correct. Once the fault is detected by the relay itself or the real time fault analysis tool, the event tree analysis will be triggered and the monitored information will be shared with the monitoring tools installed at neighboring relays, as well as with the system operator located in the control center. Next, a brief introduction to each individual technique used in the proposed tool for automated relay monitoring is outlined.

A. Neural Network Based Fault Diagnosis

A fuzzy ART neural network based fault classification algorithm was originally developed as an improvement to the traditional phasor based relay [5]. As shown in Fig.3, the voltage and current measurements are arranged as a pattern instead of calculating the phasor. The aim of the neural network training is to allocate the raw training patterns into different clusters using self-organized clustering technique. Then the clusters are assigned to the classes, which are associated with different fault types, such as "phase A to phase B fault in Zone I", etc. The size and position of each obtained cluster are stored and used for recognizing and classifying unknown patterns. When used online in detecting the fault, a fuzzy nearest neighbor algorithm is used for assigning the unknown pattern to a fault type based on the information delivered by the neighboring clusters. A great effort has been made for improving the ART neural network to be used as stand-alone fault diagnosis tool as the traditional relay [6,7]. The time-domain based method and extensive training and testing mechanism make this neural network based approach more accurate than the traditional relay when it comes to detecting and classifying faults.

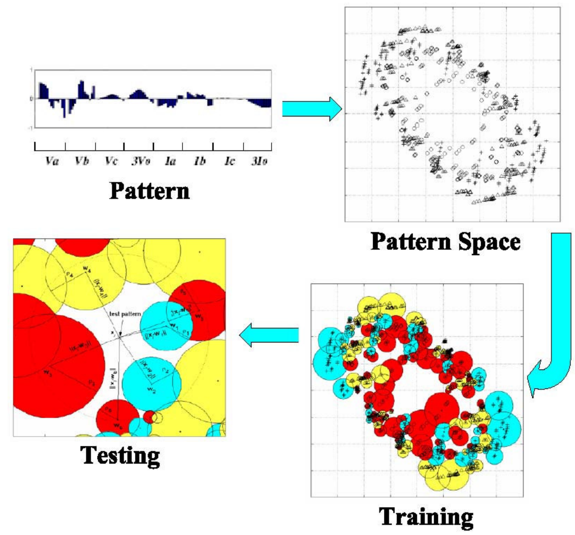

Fig. 3. A demonstration of neural network based fault diagnosis technique

B. Synchronized Sampling Based Fault Diagnosis

Synchronized sampling based fault location algorithm was developed in [8,9] to implement the precise fault location. As shown in Fig. 3, this algorithm requires raw samples of voltage and current data synchronously taken from both ends of a transmission line. The approach is more attractive now because the use of GPS time-synchronized data acquisition units is an emerging trend in the utility industry.

The principle of this algorithm relies on the fact that the voltage and current at the faulted point can be represented by both sending data and receiving data using certain linear relationship. If there is no fault within the primary line, such a faulted point can not be found. The fault location algorithm is derived for both short transmission line model using lumped parameters and long transmission line model using distributed parameters. The original fault location algorithm is further improved in term of functionality and speed as a complete fault detection, classification and location tool for online use [7,10].

The main advantage of synchronized sampling based fault location algorithm is that it precisely confirms whether a fault has indeed occurred on the transmission line of interest. The algorithm does not depend on any assumptions about system operating conditions, fault resistance, fault waveforms, etc. Using this approach, the protection system operation can be checked to avoid tripping on overload, power swing and other no-fault abnormal situations, which may otherwise initialize or facilitate cascading outage.

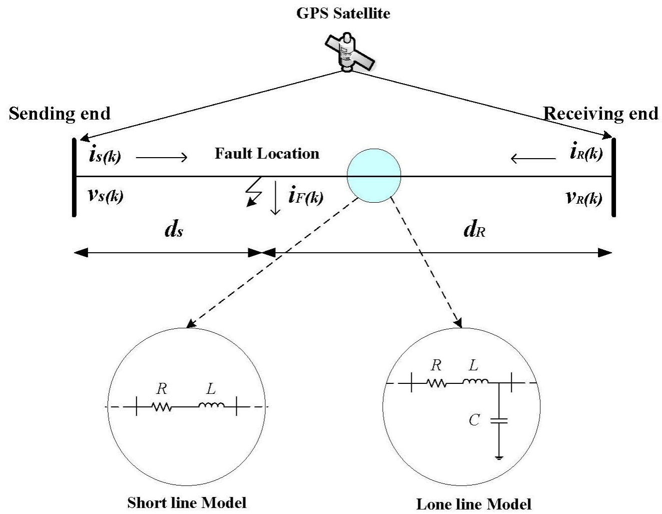

Fig. 4. An example of fault location calculated by SSFL

C. Event Tree Analysis

. Event tree analysis (ETA) is a commonly used event/response technique in industry for identifying the consequences following an occurrence of the initial event. We can use it for the relay monitoring purpose.

In the example shown in Fig.4, ETA takes the structure of a forward (bottom-up) symbolic logic modeling technique. This technique links system responses to an initial "challenge" and enables assessment of the probability of an unfavorable or favorable outcome. In an event tree, the nodes stand for the events or actions, where the white ones represent correct actions and the red ones represent incorrect actions. Following a set of events or actions from the root node (initial event), the protection system reaches an outcome that indicates if the entire actions are appropriate for a corresponding disturbance. If the event sequence is heading to or already reached a "red" node, a corrective action will be taken either at local level or at system level, according to the explanation and guidance behind the nodes.

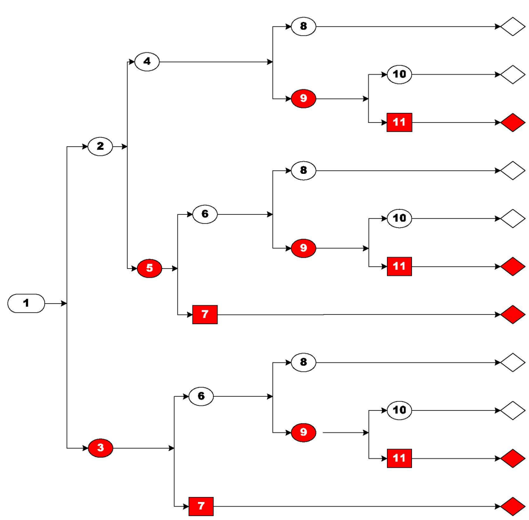

Fig. 5. Event tree analysis for assessing relay operations

We have designed a group of generic event trees for a typical relay when it faces different kinds of disturbances [11]. Those event trees can be easily modified to cope with different relay system configurations. The event tree analysis provides a self-explainable, easy-to-use tool for real time monitoring of relay operations. The design of event trees predefines a remedial action in the case of the relay misoperation or unintended operation to help operator make the corrective controls.

IV. ACKNOWLEDGMENT

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