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A CRITICAL ANALYSIS AND EVALUATION OF FAULTS IN TRANSMISSION LINE USING INTELLIGENT TECHNOLOGY

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ABSTRACT

This paper describes a new concept of automated fault analysis where fault transients and changes in power system equipment contacts are processed on-line. This allows faster confirmation of correct equipment operation and detection of unexpected equipment operations, as well as increased accuracy of fault location and analysis. In addition, the paper gives three independent utility examples that required auto-mating some aspect of the fault analysis process. A highly accurate fault location system for series compensated lines using global positioning sys-tem (GPS) synchronization is presented.

I INTRODUCTION

Development of new technologies such as intelligent systems and synchronized sampling as well as in-creased utility deregulation and competition are leading to the introduction of new applications and solutions in the fault analysis area. The early approaches to fault analysis using intelligent techniques were related to alarm processing in a Supervisory Control and Data Acquisition (SCADA) system [1]. At that time, expert system techniques were utilized to implement an automated analysis of alarms. The SCADA based solutions did not have the capability to calculate fault location, and processing of analog waveforms was not done due to the lack of sampled waveform data. Further improvements of the overall solution were achieved using neural network (NN) implementations [3, 4]. A study of the possible approaches to fault analysis using digital fault recorder (DFR) data revealed some advantages due to the ability to calculate fault location and correlate waveform samples with protective relay and circuit breaker contact operation. This has enabled a new approach to fault analysis to be implemented using expert systems and DFR data [5, 6, 7]. Further developments in this area indicated that a very accurate fault location approach can also be developed using DFRs enhanced with accurate data acquisition interfaced to global positioning system (GPS) receivers [8, 9]. Use of neural nets for fault detection and classification was also investigated to enhance the overall fault analysis solution [10, 11].

II A NOVEL APPROACH TO AUTOMATED FAULT ANALYSIS

The ultimate fault analysis system should provide results of a detailed system-wide analysis of an event to the system dispatchers and protection engineers within seconds after the event occurred. This may not be feasible with the existing SCADA technology. The main reason is the lack of detailed information about transient waveforms and contact changes that are not readily available through Remote Terminal Units (RTUs) of a SCADA system. On the other hand, such information is available through other Intelligent Electronic Devices (IEDs) including DFRs, Sequence of Event Recorders (SERs) and Digital Relays (DRs). A new concept for fast and accurate fault analysis can be developed using this equipment technology, high-speed data communication infrastructure and advanced software techniques.

Various types of users have different needs regarding the time response and/or extent of information provided by the fault analysis system. The system dispatchers are interested in getting the condensed fault analysis information as soon as possible after the valid fault occurs. Their main interest is determination of accurate fault location and switching equipment status that enables them to make decisions about the system restoration. The protection engineer, on the other hand, is more interested in getting detailed and specific in-formation regarding the operation of the protection system and related equipment during the event. The time factor is not as strict as for the system dispatcher.

In this section we present the concept of an integrated fault analysis system that can be built with existing technology and can satisfy both types of users. The subsequent sections give brief presentations of various research and development projects that are an illustration of possible steps towards the final system solution for automated fault analysis.

Figure 1 presents the block diagram of one possible implementation of an integrated system. Each sub-station is equipped with a PC (low end Pentium ma-chine) that collects data from different devices (e.g., DFR, SER, DR), and analyzes that data locally. The results as well as raw data files are communicated to the central file server in a common COMTRADE format. The substation analysis provides fault location and fault type based on the data recorded at this location. This data can be made available to the system dispatcher and protection engineer within a minute after the recording was made by appropriate device. The in-formation is communicated in the form of a fax. After this initial faxing, the substation PC establishes communication with the Central File Server and uploads event data to it. The System Wide Analysis software monitors incoming event files and correlates files coming from different locations based on their accurate time stamps and samples that are synchronously taken at all substations using GPS receivers for synchronization. The system fault analysis is then executed using data from various locations to produce a summary report for protection engineers.

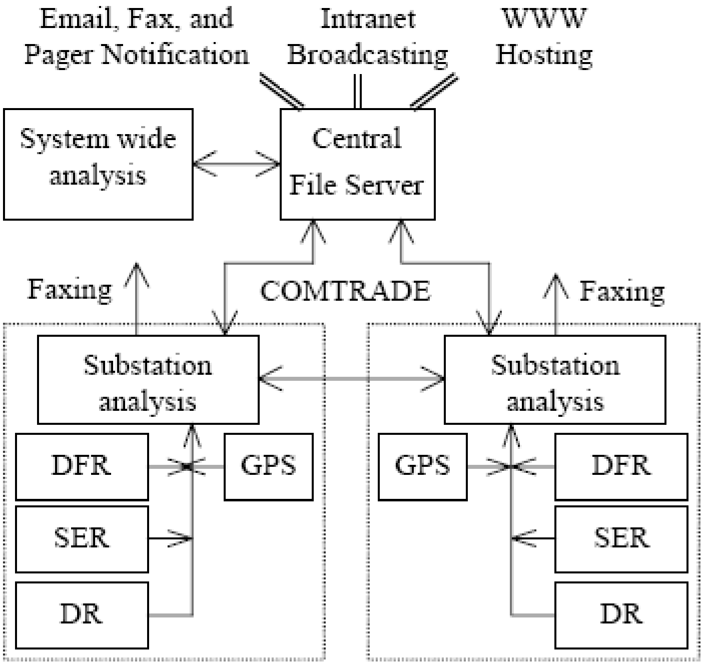

Figure 1. Conceptual diagram for the new fault analysis approach

It is important to note that such an integrated solution is not yet available since the design provisions to implement the synchronized sampling for all substation data acquisition systems are not readily available [13]. In addition, utilities are still researching various options to provide standard communication architecture allowing high-speed substation-wide data acquisition and transfer to the centralized substation and system level location [14]. An assessment of the existing technology reveals that future developments in the IEDs for substation metering, control and protection are leading to the following expected improvements [13]:

- Increased accuracy of the A/D subsystem
- Synchronized sampling on all input channels
- Multiple communication interfaces for high-speed data transfer
- Availability of extensive signal processing for calculation of various measuring quantities

Combined with on-going developments in the utility communication architecture, it is expected that the substation IEDs will provide an impressive level of detail of the data needed to perform automated fault analysis. In the meantime, some solutions that are less involved can be implemented using the technology that is readily available. In particular, DFR data analysis can be automated using expert system technology. In addition, fault location accuracy can be improved using GPS receivers to synchronize customized data acquisition units located at two ends of a transmission line. The remaining sections of this paper illustrate how several different approaches can be undertaken using the existing technology. It is expected that in the future, the substation equipment will have all the required design provisions so that an optimized use of the technology can be achieved maximizing the cost/performance benefit.

III GPS BASED HIGH ACCURACY FAULT LOCATION

As noted earlier, the accurate and timely information regarding fault location, after a transmission line fault has occurred, is most important to system dispatchers. They need to confirm and isolate the faulted section before any system restoration is attempted. Then dispatch maintenance crews directly to the fault site.

Most of the existing fault location algorithms use data from one line end, due to the large cost of additional equipment involved in obtaining the data from the other end as well [15, 16]. Recently, the cost of the necessary hardware is rapidly decreasing, which makes implementation of two ended fault location algorithms cost effective for critical transmission lines. The two ended fault location algorithms are inherently more accurate and robust than single ended ones [8, 17].

The fault analysis system presented in Figure 1 incorporates design features needed for implementation of an advanced fault location technique based on synchronized sampling. Figure 1 shows the case where two neighboring substations are equipped with GPS receivers. The GPS receivers are used for accurate synchronization of recording devices. Two substation PCs communicate with each other via dial-up modem lines and exchange fault waveform samples taken synchronously.

One of the most important requirements for this fault location algorithm is a fast, reliable and accurate data acquisition subsystem. This can be achieved either by using separate data acquisition with customized signal conditioning hardware, or making improvements in the existing data acquisition subsystem built in the customized DFR [18]. The first approach increases the cost and complexity of the hardware installed in the substation. The second is preferred if the existing DFRs can be upgraded.

As total cost of implementing this advanced fault location system decreases over time, we expect wider acceptance of the technology by utilities that want to gain comparative advantage by having accurate and upto-date information regarding their transmission grid. High sampling rate requirements are imposed on the data acquisition system due to the fact that the fault location method is based on discretization of Bergeron's traveling wave equations or lumped parameter line equations [19, 20]. In order to derive these equations we can consider the unfaulted long transmission line shown in Figure 2. A transmission line longer than 150 miles can be represented as an L-C circuit, since the contribution of the resistance and conductance to the series impedance and shunt admittance can be neglected. The length of the line is *d*. The *l* and *c* are the series inductance and shunt capacitance per unit length. The voltage and current at the point *F*, at distance *x* from the sending end *S* is given by

$$v_F(t)=\frac{z}{2}\left[i_S(t-\tau_x)-i_S(t+\tau_x)\right]+\frac{1}{2}\left[v_S(t-\tau_x)-v_S(t+\tau_x)\right] \qquad (1)$$

$$
\begin{aligned}
i_F(t) = -\frac{1}{2}\left[i_S(t-\tau_x)+i_S(t+\tau_x)\right] - \\
\frac{1}{2z}\left[v_S(t-\tau_x)-v_S(t+\tau_x)\right]
\end{aligned}
\qquad (2)
$$

These equations follow directly from Bergeron's traveling wave equations. Here, *z* is the characteristic impedance of the line and is the travel time to point *F* from *S*. They are defined as

$$
z=\sqrt{\frac{l}{c}} \quad , \quad \tau_x = x\sqrt{lc} \qquad (3)
$$

The voltage and current can also be written in terms of the receiving end *R* voltages and currents by replacing the subscript *S* with *R* and changing the travel time J*x* to J*d-x*, which is the time to travel from end *R* to *F*. Now, if a fault occurs at *F*, then the voltage at point *F* due to the end *S* voltages and currents will be the same as the voltage at *F* due to the end *R* voltages and currents. Thus the fault location equation becomes

$$
\begin{aligned}
&\frac{z}{2}\left[i_S(t-\tau_x)-i_S(t+\tau_x)\right. \\
&\qquad \left.-i_R(t-\tau_{d-x})+i_R(t+\tau_{d-x})\right] \\
&+\frac{1}{2}\left[v_S(t-\tau_x)+v_S(t+\tau_x)\right. \\
&\qquad \left.-v_R(t-\tau_{d-x})-v_R(t+\tau_{d-x})\right]=0
\end{aligned}
\qquad (4)
$$

The distance to the fault does not appear explicitly in the equation. When the equation is discredited based on the sampling interval, the travel times to the point *F* from either end will not be exact any more. The right hand side of Equation 4 will have a finite non-zero value. Now, based on the sampling time step, the line can be divided into a number of discrete points, and Equation 4 can be used to compute the error voltage at each of those discrete points. The point that yields the minimum error value is the estimate of fault point.

This method is strongly dependent on the sampling frequency. To reduce this requirement, the approximate point is used as a guideline. Once the mini-mum error point is obtained, the voltages and currents at the points adjacent to this point can be computed using the discredited versions of equations 1 and 2, the single end equations.

The line section between the adjacent points is now modeled as a short transmission line and the fault location is calculated more accurately. Further accuracy improvements can also be achieved for mutually coupled lines if the synchronized measurements are avail-able from the terminals of the coupled lines [21].

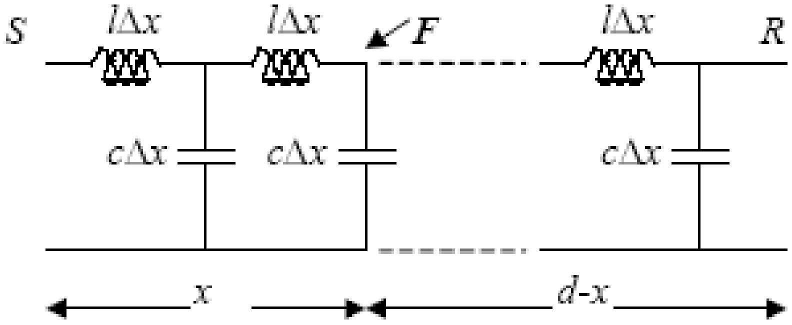

Figure 2. Unfaulted long transmission line

IV CONCLUSIONS

This paper has introduced a general concept of automated fault analysis utilizing data collected by various substation data acquisition equipment, and synchronized using GPS receivers. Since the technology for a full-blown solution is not yet readily available, a variety of solutions can be implemented using existing advanced technology. Accurate fault location utilizing synchronized samples from two ends of a transmission line using GPS receivers.

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