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Automated Fault Location Analysis
Data Analysis Method

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SUMMARY

Utilities face significant challenges in locating faults on 110-138Kv systems that are heavily tapped with industrial customers and substations. Typically, faults on these circuits - result in customer outages that impact company performance metrics. To further reduce outage duration, utilities seek to locate the faults more quickly.

One company has developed a process that assists the protection engineer in determining where faults are located. The accomplish this by using a macro that "slides" the fault all along the various taps on the circuit and identifies the location(s) that match the measured fault current. This process helps but still requires many manual steps and calling out a protection engineer in the middle of the night.

If one could automate the process completely, then substantial time could be saved. One company in the USA is undertaking the necessary steps to achieve this complete automation. The major steps include: capturing and categorizing the fault magnitude and type, identifying significant nearby assets that would impact the fault duty such as line or transformer outages, executing the macro and finally displaying the fault locations on a geospatial map of the affected area.

KEYWORDS

Fault Location, Automation, Customer Outages

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Problem Statement
Southern Company, in the United States, desires to improve the accuracy and speed of their fault location process especially for the 115-kV system, which is heavily tapped with industrial customers and substations. The Fault Location team had addressed almost all the elements that have a major impact on the outage duration metric. The primary remaining factor was the need to call out staff to run the fault-location program.

Objective
The overall objective of this effort is to reduce the time to determine where a fault has occurred with sufficient certainty to allow operations staff to begin the process to sectionalize the 115-kV transmission network and begin restoring customers in areas not directly affected by the faulted line section. The expectation is that by automating the analysis, the time previously spent in the off-hours shifts to locate a protection engineer, provide him or her with the needed information, and then perform the analysis would be greatly reduced. This time reduction will improve the performance metrics associated with outage time. [3]

Approach
There are two primary approaches to gather the fault information from the field. In simple terms, one uses a “pull” model while the other uses a “push” model. The “pull” model is based on a system operator initiating the process after an event has occurred by enabling a point in SCADA at the relevant stations. This then enables the process to remotely connect to each site and gather the data from each device based on information contained in a reference table. This table previously captured the relationship between the relays and the lines that are associated with them. Once the data is acquired, the process to extract the relevant data and locate the fault begins.

The “push” model monitors a master fault record table and when an event occurs on a line it sees a new record in the master table and begins the process. Once this process gathers the relevant data the process is basically the same as the “pull” model.

The first step in the automation plan was documenting the existing manual process. Figure 1 shows the relevant process steps for the “pull” model while Figure 2 shows the relevant process steps for the “push” model. The process flow has two paths through it and requires the creation of a new table. The first path identifies the parameters of the fault such as fault type and magnitude. The other path determines what network changes are required to accurately represent the grid elements that are out of service near the fault. The new table was developed to essentially “connect” the operations’ field data historian with the fault study program. [2]

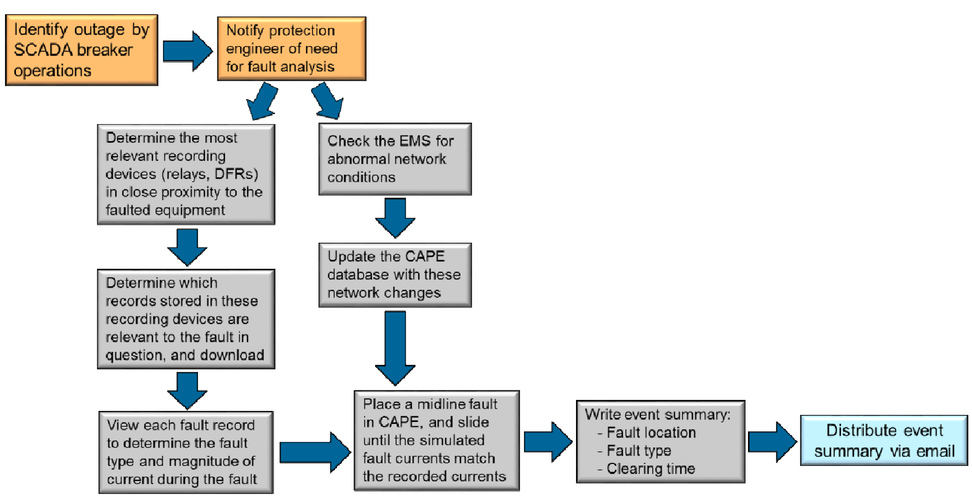

Figure 1
Master fault record table – Pull Model

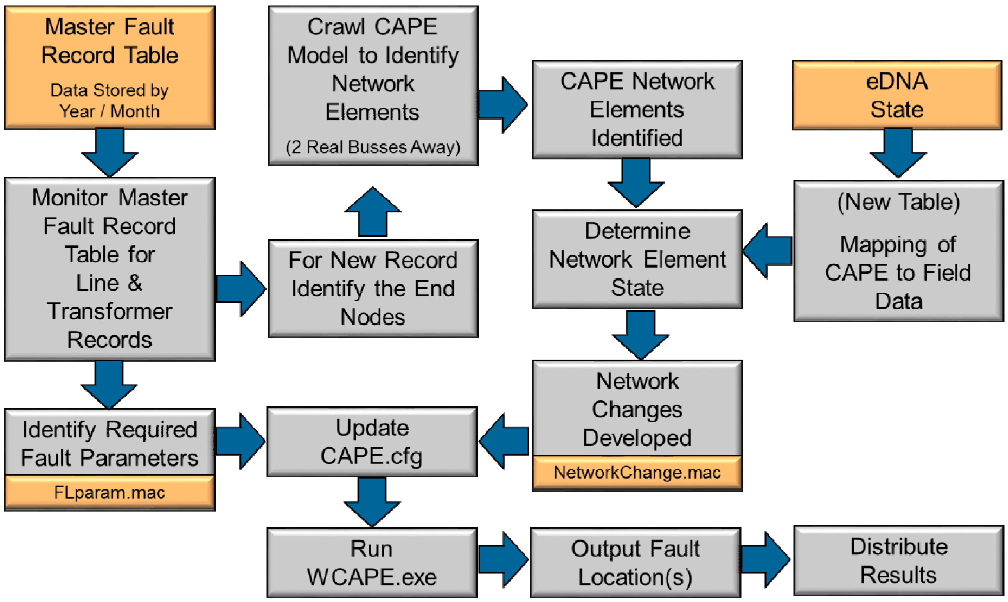

Figure 2
Fault location process flow – Push Model

The fault location process begins with monitoring the Master Fault Record table as shown in Figure 3 for new fault records arriving. Specifically, the monitor looks for faulted lines because it is not a trivial task to determine if the fault event relates to a line or transformer. A watch-dog program will monitor this table for the arrival of relevant fault records and then initiate the process. [1]

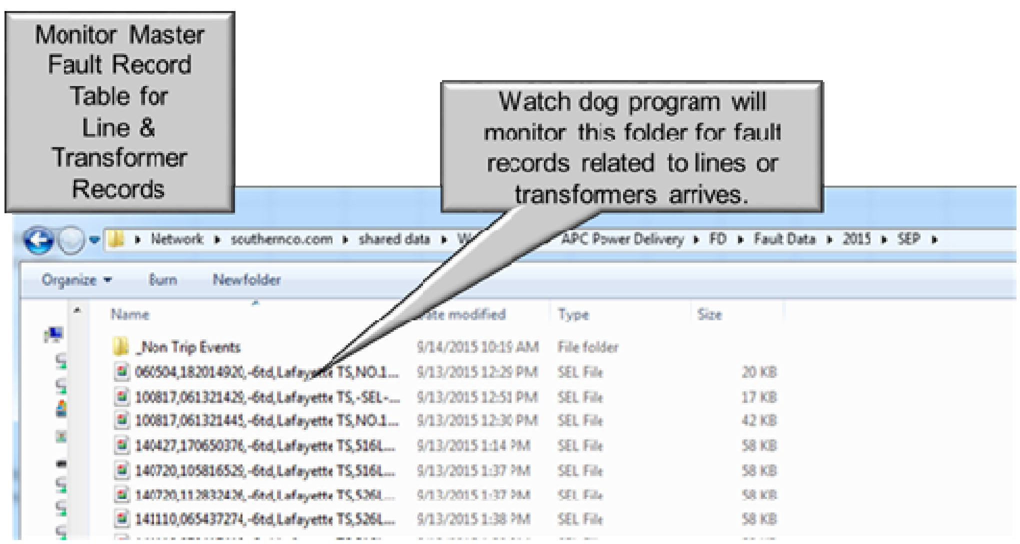

Figure 3
Master fault record table

For the fault parameter path, the following parameters need to be determined from the fault record:

- Fault Time, used in the report text and file name. Use 'NA' if no time is available.
- Bus Number for the "From" bus on the Monitored Line.
- Bus Number for the "To" bus on the Monitored Line.
- Circuit Number for the Monitored Line.
- Bus Number for the "From" bus on the Faulted Line.

- Bus Number for the “To” bus on the Faulted Line.
- Circuit Number for the Faulted Line.
- Fault Type:
    - PHASE_1_2,PHASE_1_2_G,PHASE_1_G,
    - PHASE_2_3,PHASE_2_3_G,PHASE_2_G,
    - PHASE_3_1,PHASE_3_1_G,PHASE_3_G,
    - THREE_PHASE
- Fault Current Magnitude, in amps.
- Monitored phase/value (1=‘Phase 1’, 2=‘Phase 2’, 4=‘Phase 3’, 8=‘Residual’).

Once these parameters are gathered from the fault record, the process will automatically generate the Flparam.mac file. (See Figure 3) This file is one of two input files used by the fault-location macro executed within the fault study program.

```
Sample Flparam.mac file

This file is used to load the parameters for running a fault location.
% The parameters are entered into the array "fl_inputs" as follows:
%
% 1 (string) : Fault Time, used in the report text and file name. Use 'NA' if no time is available
% 2 (number) : Bus Number for the "From" bus on the Monitored Line
% 3 (number) : Bus Number for the "To" bus on the Monitored Line
% 4 (number) : Circuit Number for the Monitored Line
% 5 (number) : Bus Number for the "From" bus on the Faulted Line
% 6 (number) : Bus Number for the "To" bus on the Faulted Line
% 7 (number) : Circuit Number for the Faulted Line
% 8 (string) : Fault Type
% PHASE_1_2,PHASE_1_2_G,PHASE_1_G,
% PHASE_2_3,PHASE_2_3_G,PHASE_2_G,
% PHASE_3_1,PHASE_3_1_G,PHASE_3_G,
% THREE_PHASE
% 9 (number) : Fault Current Magnitude, in amps
% 10 (number): Monitored phase/value (1='Phase 1', 2='Phase 2', 4='Phase 3', 8='Residual')
```

Figure 4
Sample content description of Flparam.mac file

The other path requires the development of a process to “crawl” through the fault study program database to determine the connectivity to the next 2 “Real” busses in the network. This allows the identification of grid elements that are out of service near the fault. The purpose is to develop a listing of relevant network elements related to the fault and then to determine their state at the time of the fault. A new table that links the fault study program to the field historian is needed to build this relationship. From this table, the state of the network elements can be established.

Once the state of the network is established, the result is passed to the ‘Network Changes Developed’ step where the file NetworkChanges.mac will be created. As seen in Figure 5, the changes consist of opening of branches or breakers, taking a generator out of service, or changing the state of a bus tie or switch.

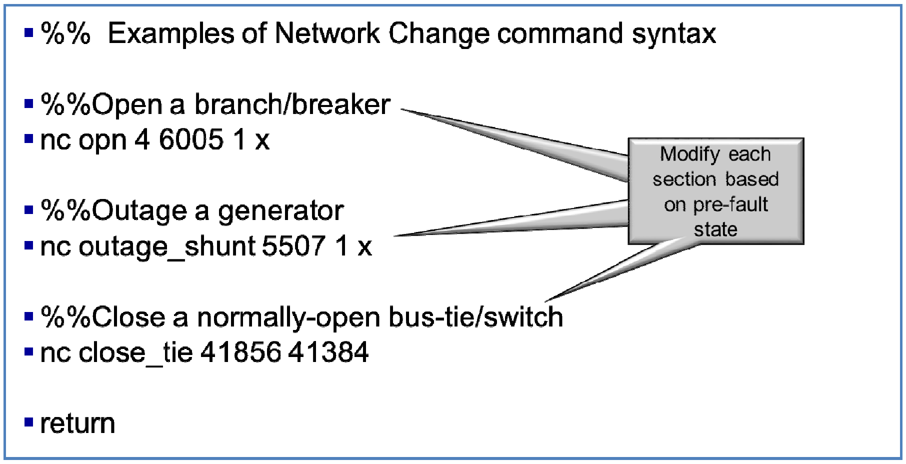

Figure 5
Example network changes

Once the above steps are completed, the process updates the fault study program.cfg file as needed and runs the fault study program to locate the fault. Thereafter, the process outputs its results and distributes the output to the appropriate staff.

Data Integration
The integration of the fault study model database which contains the pre-fault system state and the database containing the prevailing state of the grid at the time of the fault is critical to the success of this process. This requires the development of a new database table that maps the fault study program bus names to the associated EMS bus. The database was created and an automated historian script was developed that allowed elements in the database to be queried, based on their relationship to the facility in the relay fault record.

Challenges/Solutions
There were a few challenges in this effort. The first was to properly identify the fault records that needed to be analyzed because more than one record may come in after a fault occurs. Properly discriminating among the fault records to eliminate false process triggers is challenging and requires additional work.

Another challenge was linking the fault study program branches and bus names to the actual EMS names so that the state of the grid elements could be determined. As stated previously, this requires the creation of a new table that needs to be maintained as the grid changes through physical grid modifications.

Automation
A critical factor in the success of the effort was the addition of a function to the watch-dog program which automatically distinguishes line faults from other system events which show up as records in the Master Fault Record Table. The old procedure required a human in the loop to determine whether the event record was a line fault or not and initiate the fault location process. The new watch-dog program automatically initiates the fault location process and notifies appropriate personnel of the fault's estimated location.

Results
This process is still in development and additional steps are needed to get the script that has been developed to initiate the executable that queries this fault database. Work remains to complete this process.

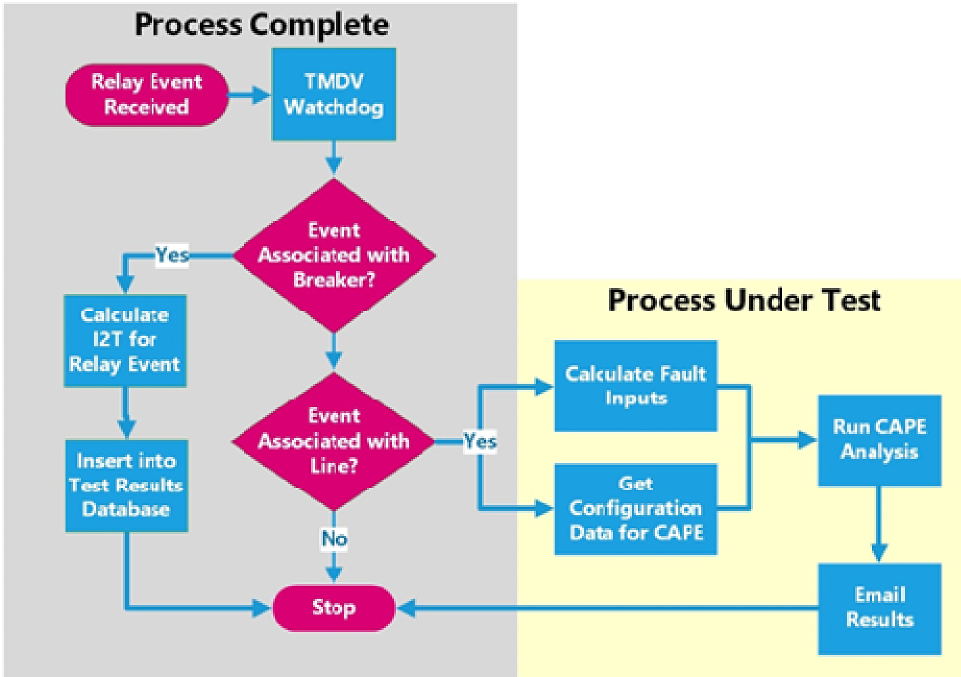

Figure 6
Fault Analysis Process in Progress

There are 10 test cases identified and the modelling for these affected lines in the mapping database. The next step was to run a non-automated version of the process against those test files and compare the results to the known fault. The area shaded in yellow in Figure 6 above is the part of the process being tested. Once this proven to be successful the automated process will be run against real-time events.

Conclusion
This effort is in its final stages with work underway to complete testing of the automation and then transition via a phased implementation within System Operations. It is expected that this will result in a significant reduction in man-hours necessary to locate faults and the duration of line outages.

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