Use of DFR and PQ Data for Automated Restrike and Trip Coil Energization Analysis

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***Abstract*— This paper will describe analytic developed to characterize breaker performance based on trip coil energization current and restrike events. The analytic was developed as a component in the open-source disturbance analytic software and is capable of detecting restrikes and reignition parameters such as restrike duration, transient over voltage and transient recovery voltage. If a DFR is used to monitor trip coil energization currents, the analytic is also able to determine pickup time, trip time and change in inductance of the trip coil.**

Automatically determining these parameters allows utilities to trend any changes in breaker performance over time and identify breakers likely in need of maintenance or inspection. An Open source visualization tool is also developed as part of this project allowing protection engineers to look at these parameters over an extended period and set notification limits to detect abnormal breaker conditions.

Keywords—Asset Health, Breaker Monitoring, DFR Data, PQ Data

I. INTRODUCTION

With the recent introduction of new power quality meters (*PQMs*) and more advanced digital fault recorders (*DFRs*) there is an opportunity to use the measurements obtained from these devices to monitor condition of assets without the need to take them out of service. Historically, assets, such as breakers, are maintained on a fixed schedule. During maintenance they are taken out of service, disconnected from the grid and subjected to a number of tests to determine operating characteristics. This paper describes an Open-Source Disturbance Analytic Software (*OSDA*) that can obtain these same operating characteristics based on measurements of the trip coil energization current during normal breaker operation. The OSDA is a production grade software designed to analyze disturbance records from DFRs and PQMs in a real time fashion [1]. This allows the trip coil energization (*TCE*) analysis described in this paper to run on most breaker actions and monitor the operating characteristics over longer time periods. Section II describes the TCE current signature and associated breaker operation in more detail. Section III describes the algorithm developed to obtain operating characteristics from the TCE signature. Finally, Section IV describes the system implementation in a production environment and the lessons learned at the Tennessee Valley Authority.

II. BREAKER OPERATION AND TRIP COIL ENERGIZATION

The trip unit of a breaker transforms the trip command into a breaker opening action. Mechanically, the trip coil consists of a wounded coil wrapped around an iron plunger. By energizing the coil a magnetic field is generated to move the plunger. A mechanical latch is used to unlock the operating shaft once the plunger has moved far enough. This results in the opening spring discharging and opening the main and auxiliary contacts. Fig. 1 shows the mechanical process from the trip coil energizing to the main contacts opening [2].

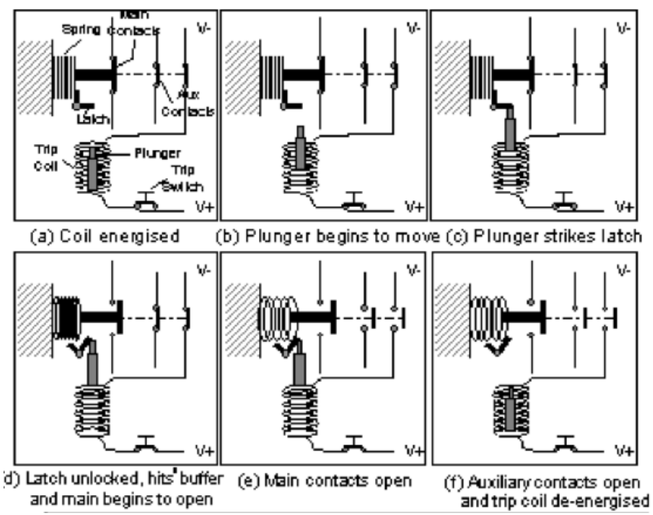

Fig. 1. Breaker trip unit mechanical operation

By monitoring the energization current in the trip coil, it is possible to determine the breaker's operating characteristics. As the trip coil is energized (a) the current rises and the magnetic field builds up. Once the force exerted on the plunger exceeds the force of friction the plunger starts to move resulting in a change of inductance of the coil (b). As the plunger continues to move it reduces inductance affecting the energization current in the coil. Once the plunger hit's the latch (c) a sudden reduction in velocity occurs which results in a sharp reduction in the increase in energization current. The current continues to rise at a slower rate until the plunger hits the buffer (d). With the plunger at rest the energization current is at a maximum, and once the auxiliary contacts open, the energization current gets interrupted (e and f). The only stage of the breaker operation that is not visible in the TCE current is the opening of the main contacts (e). However, since the current on the main contacts is usually monitored by the same DFR with the same clock and sampling frequency, it is possible to relate the two measurements with a reasonably high accuracy, and use the current measurements to determine the time at which the main contacts open. In addition it is possible to use the digital breaker status signal provided by the same DFR.

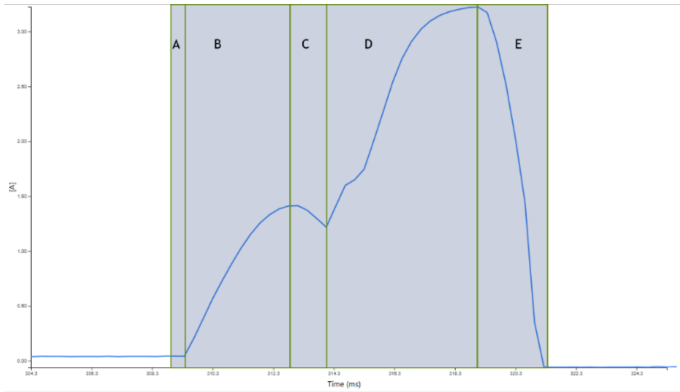

Fig. 2. TCE current duing a breaker open operation

Fig. 2 shows the TCE current measured during breaker open operation. The timing for each of the previous steps can be identified on this curve. Based on these points it is possible to compute the pick-up time (T_{pick}), the transient time ($T_{Transient}$), the Arcing Time (T_{arc}), as well as the trip time (T_{trip}) and the fall Time (T_{fall}). In addition, the change in inductance can be estimated during the initial movement of the plunger (b). These parameters are used to track the operation of the breaker across multiple openings and any change can indicate a deterioration of the Breaker [2].

The following section describes the algorithm used to identify each point as well as some general steps taken to improve accuracy of the results.

III. Algorithm for Identifying Breaker Operating Characteristics

This section describes the algorithms used to identify the points indicated in the previous section.

The first point identified (T_A) is the start of the TCE which corresponds to (a) in Fig. 1 and A in Fig. 2. In order to exclude any noise in the measurement it is important to check against a non-zero threshold rather than any deviation from 0.

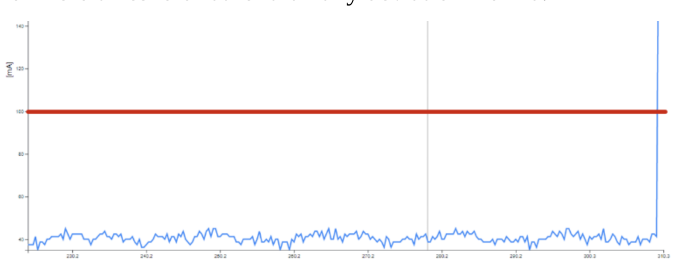

Fig. 3. TCE current with noise threshold and trip time

Fig. 3 shows a section of the TCE current where the energization starts. Once the current exceeds the threshold the start of the rise is determined by going backwards to the last measurement at which the current decreases. This allows the threshold for noise to be relatively high without causing the timing to be off due to the time it takes for the current to rise above the threshold.

The first local maxima (T_B) is found by moving forward in time until the TCE current decreases again. This corresponds to the time at which the plunger hits the latch. During the initial movement the change in current is approximately linear and can be used to estimate the inductance of the coil by (1).

$$L = \frac{\Delta I}{\Delta t} \quad (1)$$

The following local minima (T_C) is determined, which corresponds to the time at which the plunger hits the buffer and stops. At this point the pickup time and transient can be computed as (2) and (3) respectively.

$$T_{pick} = T_C - T_A \quad (2)$$

$$T_{Transient} = T_C - T_B \quad (3)$$

The next local maxima, which also corresponds to the global maxima is found, to identify the time at which the coil is de-energized (T_D). Finally, the time at which the TCE current returns to near 0 (T_E) is identified using the same noise threshold. This allows the computation of fall time, arcing time and trip time as (4), (5) and (6).

$$T_{fall} = T_E - T_D \quad (4)$$

$$T_{arc} = T_D - T_C \quad (5)$$

$$T_{trip} = T_D - T_A \quad (6)$$

The timing parameters as well as the inductance are saved and tracked across multiple breaker open events. A system protection engineer can set thresholds, such that any timing parameters exceeding these thresholds trigger an email notification from the OSDA.

IV. TVA Use Case

The algorithm described in the previous section was implemented as part of an open-source software suit, which also includes the OSDA and tools to automatically obtain disturbance event records from DFRs in the field, as well as visualization and notification tools.

Effectively, TVA now has a system in place that automatically downloads disturbance records from DFRs in the field and moves them to a location in the central IT infrastructure [1]. Once the files are downloaded, they are automatically processed by the OSDA which includes a number of analytics described in [1] as well as the breaker TCE analysis if appropriate. Once the analysis is complete the results are saved and can be viewed in a data exploration tool. An example screen is shown in Fig. 4 including the voltage on the connected Bus, the current through the main contacts, the digital breaker status as reported by the DFR, and the TCE current.

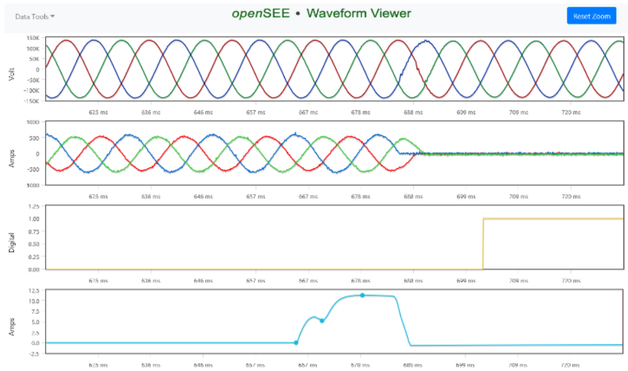

Fig. 4. Open source visualization tool for protection engineers

System protection and asset management staff can go back to any event previously processed and compare various TCE current curves as seen in Fig. 5. If a breaker has multiple tripcoils that are analyzed and trended individually they can also be compared using the data exploration tool.

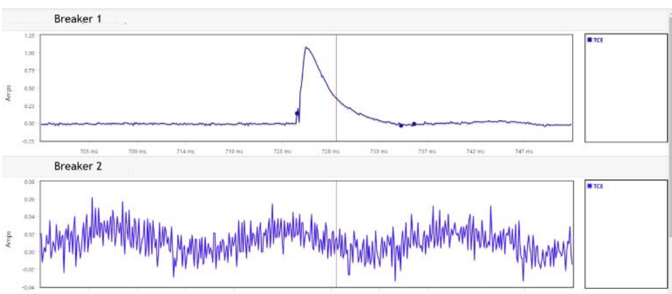

Fig. 5. Open source visualization tool comparing various TCE current traces

In addition, the open-source tools installed at TVA include a Trip Coil Report where the timing characteristics can be visualized across longer time frames and any trends in these characteristics can be easily identified. Fig. 6 shows a report for a trip coil across one year.

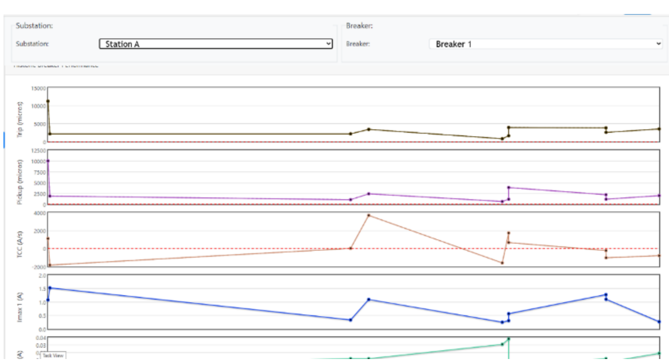

Fig. 6. Open source visualization tool trending breaker operating characteristics over time

V. Conclusion

This paper introduced an algorithm to determine operating characteristics of a breaker during a normal breaker open event. The algorithm was implemented in a production grade open-source software application and is used at the Tennessee Valley Authority to track breaker performance without having to disconnect and test the breaker. TVA expects this tool to provide additional information to protection engineers and eventually lead to more targeted breaker maintenance.

References

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