Early fault identification for operating circuit breaker based on classifier model system

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ABSTRACT

The circuit breaker (CB) is used either in the transmission or distribution sections. The fault of a CB is identifed by capturing the trip time; which is the moment of current flow cessation in the load side of the CB. For the maintenance staff of the Iraqi national power board (INPB), their decision is mainly aimed to pinpoint the specific problem of the CB, the breaker parameters, such as latch, buffer, mcon, acon, and end which can be analysed using data mining methods such as K-means clustering and Sammon mapping (KCSM). The advantages of this approach include early identification of faults and saving more cost and time of repairing and replacing damaged CBs as the number of damaged CBs can be decreased. There is one issue of prolonged time of testing the conventional trip as it requires removing the CBs from service and planned outage. Furthermore, the CB may not capture the crucial information that causes slow tripping. Hence, the main objectives of this work are to analyse CB trip coil current data and study the effect and relationship between two different analytical approaches to analyse the data. The result of this technique showed excellent identification of the switch faults.

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1. INTRODUCTION

A circuit breaker (CB) is one of the most important switchgear in a substation whether for the transmission or distribution section. A circuit breaker, as per the American national standards institute (ANSI), is “a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions; it is also capable of making and carrying currents for a specified time and breaking currents under specified abnormal circuit conditions, such as those of a short circuit.” The necrotizing enterocolitis (NEC) defines a circuit breaker as “a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating”. The switchgear functions to protect, control and maintain the electrical network, including the switchgear itself. It is one of the most critical devices that protect the network and works only when there is a fault in the system. Hence, the CB is expected to work within its relay trip time and the main contact opening time to be effectively discriminated from the other CBs and reduce the number of affected users during a faulty operation.

The CB exists in many forms, such as air CB, sf6 CB, oil CB, and vacuum CB [1]-[4]. Furthermore, CBs can be categorized into outdoor CBs and indoor CBs based on their sub-station. Considering the problem of slow tripping time, CBs can also be classified based on their mechanisms into spring-operated CBs, pneumatic CBs, and hydraulic CBs. Currently, the maintenance of CB is determined by capturing the trip time using a handheld device; the trip time is the time from trip initiation to the moment of current flow cessation in the load side of the CB. The maintenance staff of INPB makes maintenance decisions using a simple rule of thumb "If trip time >100 ms, perform the breaker maintenance." However, this approach does not consider the factors associated with the designs of different CBs, and the conditions that affect the timings at different operation stages of the CB during the all-important initial trip that is needed to remove it from service [5]–[7].

2. RESEARCH METHOD

Circuit breaker operator signature analysis-based identification was done [8]–[11]. To explain the shot analysis done by TXU Electric USA, as presented at the international conference of doble clients. It is a process aimed at first pulling up trip shots for a specific CB using the breaker analyzer software. Then, the shots are inspected for compliance with the following measurement criteria:

a. Main contacts are <50 ms on the trip shot (3 cycle breaker).
b. The main contacts are <200 ms on the close shot.
c. Breaker off latch is <17 ms (for 1 cycle for a 3-cycle breaker).

As for the voltage drop, it must be less than 5 V for a 48 V system, while for the 125 V system, it must be less than 10 V. In conclusion, the voltage drop must be less than 10%.

In this method of CB faults detection, two shots are laid on top of one another to compare both of the shots in different ways [12]–[15]. First, compare the same breaker on the first and second shots. The slower first shot can indicate trip latch or/and bearing problems. Secondly, compare the same breaker over time; if bearings and trip latch are in good shape, there should be negligible differences between the two shots. Also, compare the same operator types but for different breakers; the curves should have similar signature and comparable time characteristics. If the trip time is good but close time is slow, the tail spring is out of adjustment and may be masking a bearing problem [16]–[20].

For instance, a CB with a DC supply voltage drop of >10 % could have other issues with the battery chargers or the batteris that could be identified in the shots as a 60 Hz ripple that is superimposed on the signal of the DC trip current. The breaker analyzer shots could also indicate the presence of loose wires in the control circuitry in some other instances. The breaker analyzer can also identify that a tail spring is not properly adjusted (fast trip, slow close). Tail spring adjustment is sometimes used to hasten the trip on a slow CB, but this neglects the main reason for the slow breaker which may be due to faulty lubrication. The analysis can also detect trip coils that are close to failure, as well as inappropriate/dirty auxiliary switch contacts [21], [22].

3. OBJECTIVES OF ARTIFICIAL INTELLIGENCE-BASED CLASSIFIERS FOR CIRCUIT BREAKER MAINTENANCE

The objectives of this analysis are:

- To analyze CB trip coil current data obtained from INPB population in service distribution CB.
- To investigate the relationship between the parameters of the CB, as well as perform condition assessment and defect diagnosis of 11 kV and 33 kV Tamco distribution CB.
- To determine whether the system is applicable for circuit breakers in Iraq.

The main objective of this work is to study the relationship between the useful domain knowledge (which is the parameters) and perform condition assessment (through data mining) and defect diagnosis of 11 kV and 33 kV Tamco distribution circuit breaker (which requires expert interpretation). The basic idea of artificial intelligence-based classifiers for circuit breaker maintenance is to analyze the obtained data from the CBs in the field using data mining methods (such as kinetically constrained spin models (KCSM)) to pinpoint the real problems or symptoms of the failure of the CBs [23]-[25].

Figure 1 showed that the testing process starts with obtaining and recording the trip testing data. After that, the obtained data is evaluated and the significant parameters in this process are isolated for analysis. Then, the data for the time and current of the breaker are also isolated to form a Trip coil profile. The next step is to calculate the K-means clustering and get the Sammon map. The map must be compared with the K-means cluster and if both are synchronized, proceed to the C5.0 rules description. The data is then sent to INPB Research for expert interpretation. Lastly, the results are achieved and the conclusion(s) can be made.

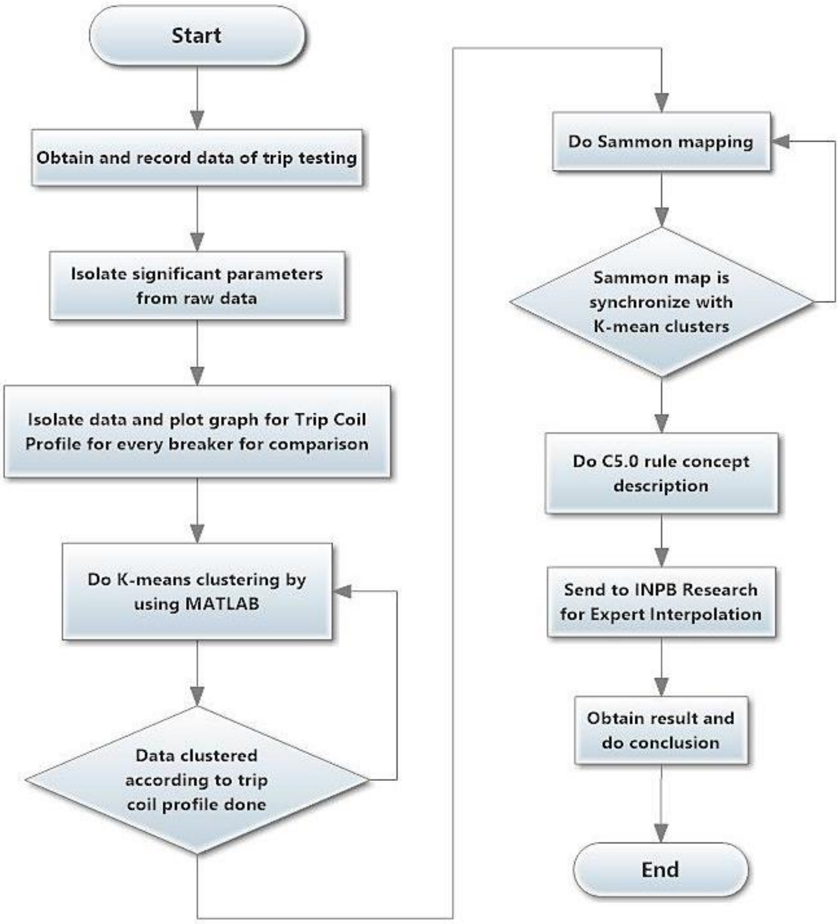

Figure 1. Flowchart of the testing process

4. RESULT AND DISCUSSIONS

To analyze the circuit breakers, the process involved is as Algorithm. The algorithm process to analyze the faults of CB, first obtain the record of the CB trip testing data then look for the raw data and select the most significate ones. The next step is to plot the graph of the coil profile, after that using MATLAB to calculating the K-means then to draw of Simmon map. Then the use of C5 rule for descripting the case, finally send to INBP experts to conclude the result of data to indentfy that the CB is fault or not. There are three main parts in the methodology of this project; the first part is to obtain the data by using the device known as Profile P3 which is used by the INPB Research industry to record the data of the trip test conducted by the INPB maintenance staff. The second part is to analyze the data obtained by using K-means clustering and Sammon mapping (KCSM). This is the longest process in this project as it involves mathematical methods related to data mining. This process requires consultation with mathematics experts. The third part is to send all the analyzed data to the INPB Research industry switchgear expert, such as those that specialized modeling for expert interpretation. As the data has been interpreted, conclusions can be made.

Algorithm:

```
A.   Obtain and record the trip testing data.
B.   Isolate significant parameters from the raw data.
C.   Isolate data and plot the graph for Trip Coil Profile for every breaker for comparison.
D.   Calculate the K-means clustering using MATLAB.
E.   Draw the Sammon Map.
F.   Do C5.0 Rules Concept Description.
G.   Send to INBP Research for expert interpretation.
H.   Obtain results and make conclusions.
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To get the initial result regarding the breakers that belong to the same cluster, the trip coil profile of each circuit breaker can be compared. The trip coil profile requires the data of the current changes during tripping over time. So, the data of current and time are isolated from the raw data and recorded in a new

Microsoft Excel file. After that, a graph of the trip coil profile can be plotted using MATLAB application software. The same principle of recognition is used for robot vision analysis applications.

As mentioned earlier, there are several important parameters of a circuit breaker that must be considered in this analysis; these include the time taken at certain points of tripping of the circuit breaker (which are latch, buffer, acon, mcon, and end time). These parameters must be isolated and compiled in a new Microsoft Excel file [12]. In this project, there are five important parameters during tripping that are considered; these are latch, buffer, acon, mcon, and end. The definitions of the parameters are as shown in:

– Latch: The time taken for the trip coil to release the latch and initiate the mechanism.
– Buffer: The time taken for the CB to come off the latch and the operator mechanism to start moving.
– Acon: The time taken for the auxiliary contact to open.
– Mcon: The time taken for the main contacts separation.
– End: Time taken that the coil current reaches zero.

Figure 2 to Figure 8 showed the results of the data analysis using K-means clustering. Figure 9 shows the standard fully operational trip coil profile of circuit breaker. Figure 10 and 11 show the identification was correctly done based on Figure 9 and KCSM showed capability as a good intelligent system for problem identification. Figure 10 shows the plotted trip coil profile for comparison of five circuit breakers, all these circuit breakers are healthy. The signature of the curves related to how far are healthy. When the signature looks in got difference in curve similarity means the circuit breaker is lower healthy than the standard ones.

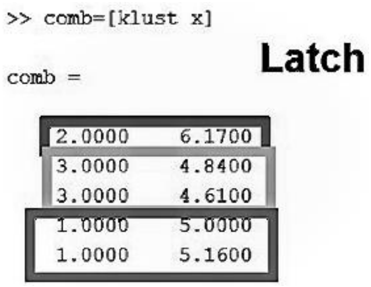

Figure 2. K-means clustering for latch parameter

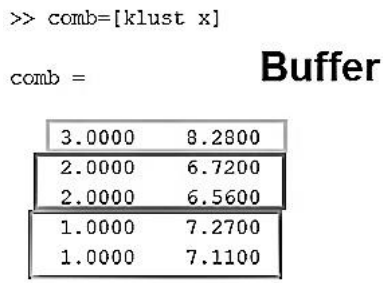

Figure 3. K-means clustering for buffer parameter

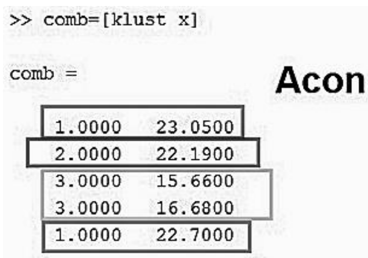

Figure 4. K-means clustering for auxiliary contact parameter

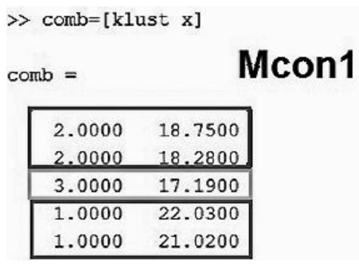

Figure 5. Clustering for main contact 1 parameter

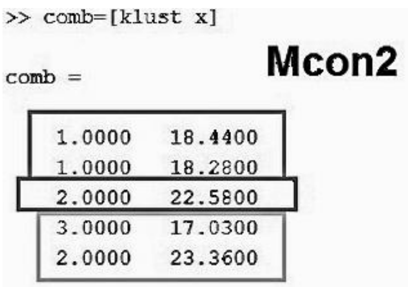

Figure 6. Clustering for main contact 2 parameter

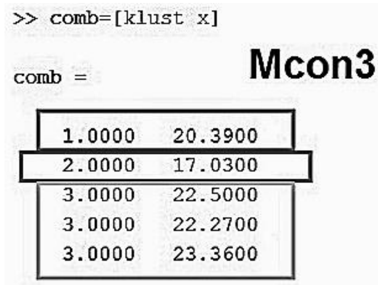

Figure 7. K-means clustering for main contact 3 parameter

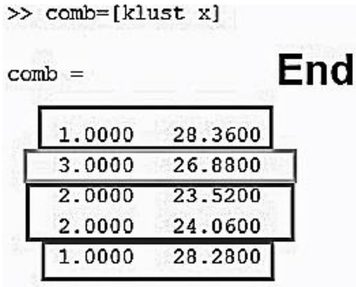

Figure 8. Clustering for end parameter

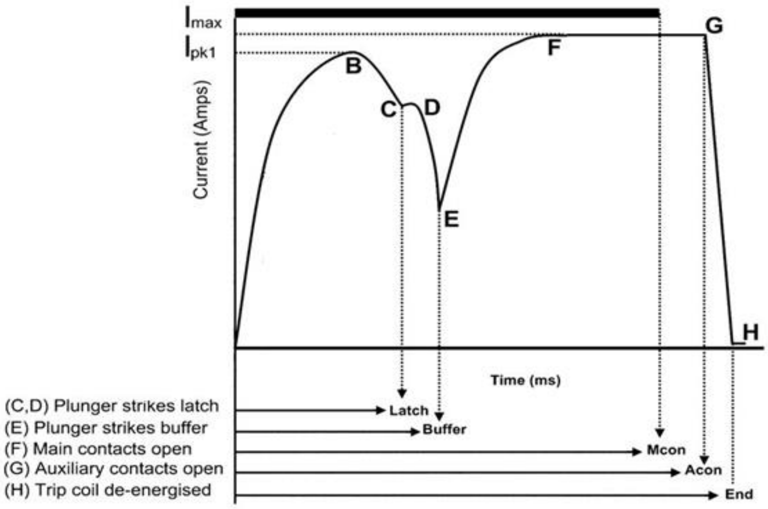

Figure 9. Standard trip coil profile of circuit breaker

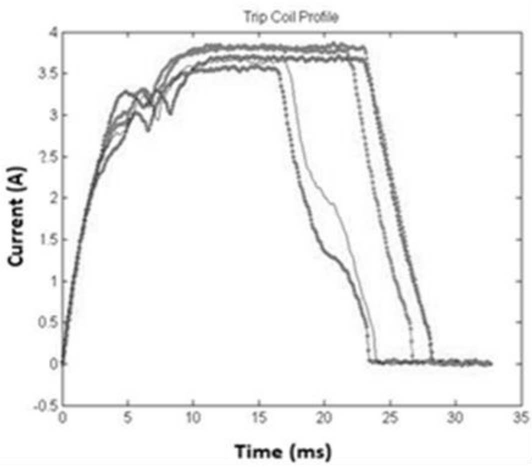

Figure 10. Plotted trip coil profile for comparison of five circuit breakers

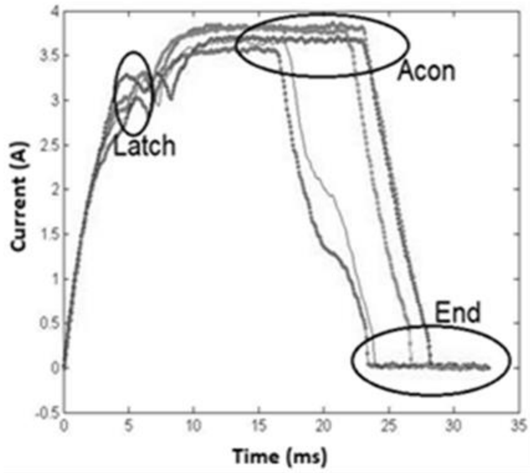

Figure 11. Labeled graph of trip coil profile of five circuit breakers

The examples of the comparisons based on Latch and Acon. As shown in Figures 12 and 13. The relationship between the breaker parameters and condition assessment and defect diagnosis of 11 kV and 33 kV, Tamco distribution circuit breaker was also reported.

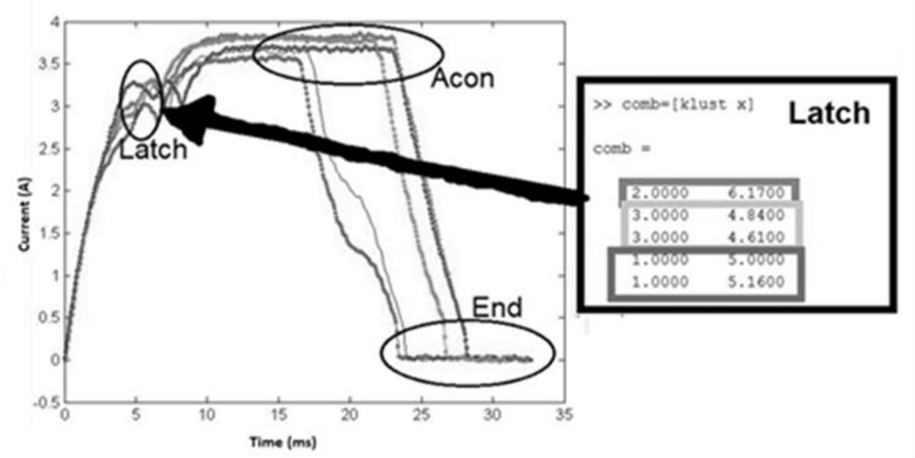

Figure 12. Example of comparison of clustering and TCP (Latch)

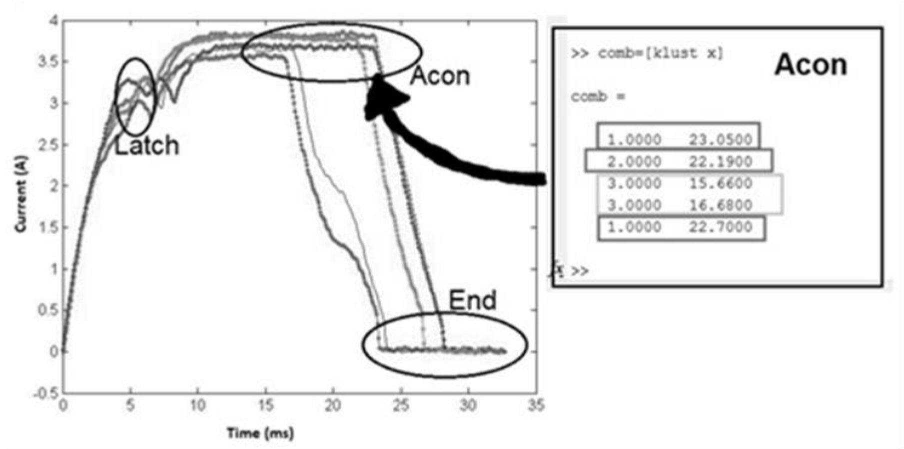

Figure 13. Example of comparison of clustering and TCP (Acon)

5. CONCLUSION

This study focused on the analysis of the trip coil current data of a circuit breaker that obtained from the INPB population in service distribution circuit breaker. This technique shows good and simple way to identify the faulty of a circuit breaker (it can be used to estimate for long it will take a circuit breaker to get faulty as future study). The result of this analysis helps in supervising and assessing circuit breakers for the need to either conduct regular maintenance or to replace the circuit breaker. In addition, the number of broken circuit breakers that need replacement can be reduced as the required maintenance can be done when the incoming problem can be detected. In conclusion, the companies that are related to circuit breakers can gain from using this classifier model. The study of the relationship between the breaker parameters and condition assessment and defect diagnosis of 11 kV and 33 kV Tamco distribution circuit breaker was also reported. The differences in the clusters of the parameters showed that there are a few things to be changed to obtain the desired results. The expected result is to come out with only one value to represent each breaker for clustering purposes, but there is still no exact solution. The system was also evaluated for usability in circuit breakers in Iraq. For the time being, only five breakers are randomly chosen to be profiled and clustered. The total number of data is about 20 to 30 breakers. In the future a trip coil profile must be done and compared among the breakers to determine the breakers that belong to the same cluster. Additionally, the data is clustered by parameters for now, but the desired result was achieved. Thus, extended research must be done on how to come out with a single value for each breaker as it will be much easier to be clustered and more accurate results can be achieved.

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