DESIGN OF A TRIP CURRENT MONITORING SYSTEM

FOR

CIRCUIT BREAKER CONDITION ASSESSMENT

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ABSTRACT

This paper describes a distributed system which supports circuit breaker maintenance and asset management. It uses a Client/Server architecture for propagating expert knowledge from switchgear maintenance experts directly to maintenance operatives for on site circuit breaker condition assessment and diagnosis. Prior research in the field of distribution level circuit breaker condition monitoring has shown the trip coil of a circuit breaker yields a current profile that when tripped, can subsequently be interpreted as an indicator of plant health. Exploiting existing circuit breaker test equipment, a centralized archive of asset condition is built from routine tests permitting experts to examine trends in the data and pass their definition of the operating conditions back out to personnel in the field. This provides diagnostic support to engineers in the field. The system is currently in use as the subject of a pilot study conducted by SP PowerSystems intended to improve their ongoing maintenance and asset management activities.

Keywords: Circuit Breakers, Decision support systems, Power distribution reliability, Power system maintenance

1. INTRODUCTION

Increasing pressure on utility supply companies to reduce consumer charges while improving quality of service has led to rationalization across their core business. One particular area of high costs is the maintenance of supply infrastructure. Sending maintenance personnel out to maintain plant items at regular intervals (time-based maintenance) can be resource intensive and is often performed where a lack of knowledge relating to the plant's behaviour and health exist. Plant failure that leads to customer outages can incur massive penalties from the UK regulator that are in proportion to customer minutes lost. Furthermore, knowledge in maintenance areas is becoming increasingly scarce due to the retirement of experts. Plant assets that date back several decades before privatization have operating idiosyncrasies that could only be learned through years of maintenance experience. Maintenance procedures may have evolved over time using the original equipment manufacturer (OEM) support advice, personal experience and trial and error. A lack of standardization and formalization of these procedures means that this tacit knowledge is not explicit and is subsequently not readily accessible.

Striking a balance between these economic constraints has led to management of assets being driven by reliability and condition metrics rather than time i.e. developing Reliability Centred Maintenance (RCM) and Condition-Based Maintenance (CBM) strategies to provide more focused maintenance. A move away from performing time interval maintenance requires measures for reliability and condition, which can only be obtained through monitoring of the plant. Without this data acquisition, the first indicator of a problem will be at the time of critical failure or during routine maintenance.

Circuit breaker maintenance, considered in this paper, takes a more data centric approach, with the Kelman Profile series of trip test analysis devices [1,2,3] being among the most notable exponents. Although representing a significant improvement over traditional testing methods, the scope for knowledge acquisition is not fully exploited. The present use of the device is as a data capture tool for the Field Maintenance Operative (FMO), with the test being conducted and possibly discarded once its assessment has been acted upon. However, this test record contains a valuable insight to the condition of a given plant item at a given time.

This paper describes an information system for decision support where trip test records are retained by maintenance personnel and archived centrally for future reference and analysis by asset managers and switchgear experts. While trip testing has been practiced for some time now and its value well understood, the place of a single test within the context of the entire asset base is currently not exploited to its potential. Rather than discard records after maintenance on a given plant item is complete, the work carried out here retains them in an attempts to build a general picture of the health of the entire asset population.

Knowledge warehousing is not a new idea, in marketing and commerce such systems have become a business necessity with data being seen as an asset of primary importance in recent years. Moving from time-based towards condition-based maintenance requires plant performance data to be acquired reliably and consistently. Implementing such a system is intended to embrace the emerging asset management methodologies integral to condition based maintenance programs. Extending the life of a heterogeneous legacy asset population is particularly challenging given that plant health is subject to the interleaved influences of substation environmental conditions, mechanical plant properties and ad-hoc maintenance practices. Providing an overall view of asset population condition, fault rate and age permits plant maintenance experts to assess the possibilities of future condition deterioration or failure from collated historical plant test data. This data driven approach not only aids routine inspection of plant items, it advises on the most appropriate maintenance to maximise reliability by providing asset managers and maintenance operatives with dedicated decision support applications. These applications are designed so that they interact automatically to exchange plant health information and expert maintenance advice, ensuring that the system is always aware of the current state of the asset. Asset managers can use these tools to formulate and standardize plant maintenance advice from their existing knowledge which can in turn be used in the assessment of future specific test conditions through electronic dissemination to maintenance staff operating in the field.

The outcome of this development is an ongoing pilot study with several maintenance personnel undertaking an extended service program on 11kV-33kV distribution circuit breakers.

2. CIRCUIT BREAKER CONDITION MONITORING

Circuit breakers are installed to protect parts of the supply infrastructure from damage caused by fault currents. The nature of circuit breaker operation largely explains the potential for malfunction: lengthy periods are spent dormant during normal service while their actual operation, in a fault situation, is a short, violent, release of mechanical energy.

The generic design of a circuit breaker has three constituent elements: the control circuit, the mechanism and the insulation. The control circuit is the part that initializes the trip and activates the mechanism often by means of some kind of electrical mechanical device. The mechanism physically isolates the fault current by opening the breaker’s main contacts. The insulation, while prone to condition degradation itself, is out with the scope of the tests considered in this paper.

Originally, the primary means of testing circuit breaker operation revolved around the simple heuristic that only if the time between trip initiation and current isolation was less than 100 milliseconds then the breaker was deemed to operate satisfactorily. This approach had several shortcomings. Firstly, due to the heterogeneous nature of circuit breaker design, operating times can differ greatly between manufacturers and even between models of the same manufacturer.

This means that a malfunctioning breaker with a normally fast operating time may appear to be in a better condition than it actually is. Again, the nature of the design of a circuit breaker means that this could be incurred by either the control circuit or the mechanism being slower than normal with the mechanism being fast enough to compensate, bringing into question the overall validity of the 100 millisecond rule. Consequently, a slow trip time does not indicate the source of an operating problem i.e. whether remedial maintenance should be directed at the mechanism or the control circuit.

3. Plant Condition Assessment Through Trip Coil Current Signature Analysis

A potentially useful diagnostic interpretation of the current through the trip coil component of the circuit breaker's control circuit stems from a convenient side effect of normal circuit breaker operation [3].

The trip coil is a solenoid type device used to instigate the mechanism operation upon receipt of the trip signal. The trip signal energizes the coil which causes its ferrous core or plunger to move. The movement of the core within the coil induces a current which rises until gravity abates both the plunger velocity and the current induced. The trip coil plunger then connects with the triggering latch of the mechanism which releases the tensioned spring. Connection with the latch causes a step change in the reduction rate of the current across the trip coil. Once the breaker mechanism unlatches, the trip coil plunger carries on until it hits a buffer to arrest its travel allowing the current across it to increase until its rated value is reached. Being halted by the buffer produces a deep 'V' shape in the current profile as the arrest of the plunger halts the decrease in current. The current across the trip coil of a healthy circuit breaker should then rise to a peak value governed by the coil rating which will be maintained until the supply to it is disconnected. This should occur once the breaker mechanism opens the main contacts disconnecting the supply current. Following this the current across the trip coil should fall to zero indicating the end of supply to the coil. Figure 1 shows an annotated current profile produced by a typical trip test.

Figure 1: Trip Current Test Profile. This is the measured current across the trip coil against the time taken for the trip operation to complete

Aside from analysis of the trip coil current profile, a second test can be executed concurrently to measure the time for the supply current to be isolated – the Main Contact time. Combined, the two tests show how long the control circuit takes to operate the mechanism and how long the mechanism takes to open the main contacts and disconnect the fault current. Several key features in this composite test give an explicit indication of breaker health and possible areas of degradation. These features are extracted from the profile to accompany the Main Contact time. Deviations in these features from what is considered normal suggest the possibility of specific problems. For example:

- The Latch time – delay suggests the obstruction of plunger travel or the plunger being misaligned.
- The Buffer time – delay suggests an absence of latch lubrication.
- The Auxiliary Contact time – delay suggests contacts may defective. If the coil is energized for a prolonged period it may burn out.

SP PowerSystems used the Kelman Profile series of handheld test equipment [2] for trip testing of its population of distribution circuit breakers. This handset contains a small monochrome display for viewing profiles and retains 100 test records in its internal memory for uploading to a PC via a serial connection at the user's convenience. Trip test record profiles are stored on disk in a text file format which also contains additional information about the tested plant item. The following gives a brief summary of the salient attributes of a trip test record as defined by Kelman Ltd:

- Network ID – alphanumeric identifier indicating substation and circuit served by this breaker.
- Test Time/Date – the time stamp of the test to the nearest second.
- Plant Location - this is a text description of the location identified by the Network ID.
- Plant Manufacturer and Model – the name of the manufacturer and model.
- The current and voltage profiles across the Trip Coil during the test
- Test features extracted by the Kelman Handset Software (including but not limited to):
    - Latch Time
    - Buffer Time
    - Main Contact Time (MCON)
    - Auxiliary Contact Time (ACON)
    - End Time

While additional data is provided in the test record, only the above features are useful for the application described here. As identified in [4], the features extracted from the Kelman test records can be collated and used to give an indication of the acceptable timing thresholds associated with these features for a given breaker model and manufacturer.

4. Architecture for Circuit Breaker Condition Monitoring and Assessment

Although trip testing was not new to SP PowerSystems and a condition assessment system had been provided in prototype form [4], routine maintenance of circuit breakers only used the trip test to focus on the performance of the individual breaker in isolation at a given instant rather than considering it within the context of the entire asset base from a historical perspective. Archiving of test data for future reference was performed on an ad-hoc basis using no diagnostic tools to examine this data set and gauge the network wide plant asset condition or compare individual trip tests within the context of the wider asset base. While previous work has been conducted on the development of information systems that collate plant condition data [5, 6], these have both assumed a fairly advanced level of expert knowledge of the user.

Since trip test profiles are most useful when viewed in context of prior performance (i.e. compared with previous trip tests), the following plant test records required to be retained:

- The ‘first trip’ – represents how a particular breaker behaves when first tripped following a significant period of inactivity (i.e. this is representative of how the circuit breaker would operate under a fault condition).
- The post maintenance trip – represents how a particular breaker behaves immediately following maintenance (note: assuming effective maintenance the breaker should operate satisfactorily).

In the prototype circuit breaker decision support system [4], an element of expert knowledge was incorporated, offering more diagnostic advice to maintenance personnel. One of the main problems with the testing of circuit breakers is that little is known about the acceptable temporal range associated with each trip test feature. Heterogeneity in construction methods between breaker manufacturer, model and model variations mean that the ‘normal’ operating time can vary so significantly that there is no generic asset wide mean value that could be deemed applicable to all circuit breakers irrespective of model or manufacturer. Furthermore, the novel nature of the trip coil current monitoring technology means that no reference trip profiles or data relating to this aspect of the breaker operation is readily available from manufacturers. This paper proposes a mechanism whereby asset managers and switchgear experts can analyse the temporal features extracted from the population of captured trip test current profiles, and subsequently define the feature thresholds representing the acceptable and unacceptable limits of operation and condition associated with breakers of specific model and manufacturer. These thresholds are then exported to field staff for on-site condition assessment of trip-tested circuit breakers.

These requirements dictated that a distributed information system was required primarily for the collation of test records into a central repository from which they could be analysed and knowledge could be extracted by switchgear experts. This knowledge could then be disseminated to the maintenance teams in the field. The distinct requirements of the two user groups (switchgear experts and FMOs) dictated that separate applications were required for each with associated data storage: an Analysis Server, facilitating maintenance experts in the discovery of diagnostic knowledge from archived trip test data and a Field Test Client, using this discovered diagnostic knowledge to advise field operators on appropriate maintenance action. Figure 2 shows how these components interact in practice.

Figure 2: Knowledge flow in the proposed system

4.1 ANALYSIS SERVER

The main part of the system serves a dual role as asset database and test repository. This application is aimed at the switchgear maintenance expert working in an office environment. SP PowerSystems maintains an asset repository which contains asset network position and manufacturer data. A subset of this data containing all salient distribution circuit breaker data is held in the Analysis Server repository and associates it with test record data. This subset of asset data is used to validate trip test records ensuring that their network location corresponds to one of the unique asset identifiers, which in turn will provide the manufacturer and model details for a given plant item. With this data subset in place, the central repository contains relevant plant information for all SP PowerSystems' distribution level circuit breakers installed in primary and grid substations, and has been extended to include condition monitoring data for every plant item tested. Trip test data is imported from the field test clients and gathered into a central repository, where every plant item is given a unique identifier when commissioned. Coupling this identifier with the timestamp in every test record associated with the breaker allows the test to be uniquely identified. Although the repository holds all tests ever conducted, the two most important tests are the most recent 'first trip' test and the subsequent post maintenance trip test. Only two parts of the test are retained for further use: the current profile and the five extracted features. The profile is retained for expert inspection and the features are required for evaluation of the thresholds of acceptable breaker trip performance. The Analysis Server acts as a front end to the central data repository giving the user access to the following:

- All Primary and Grid Substation Information
    - Circuits Served

    - Plant Type Installed (per circuit)
    - Tests Conducted
        - Current Profile
        - Extracted Features
- All Breaker Manufacturer and Model Information
    - Locations in Service
    - Numbers in Service
    - Numbers Tested

The Analysis Server user interface, shown in Figure 3, permits the browsing of the hierarchically arranged asset data with selected trip test current profiles, feature frequency distributions and overlaid Red, Amber, Green condition thresholds displayed in the main part of the interface. Data items displayed in the tree can be queried using context menus to display plant, substation, test or threshold specific data. Examples of this might be the number of tests conducted on a particular model of breaker, the last time a substation was visited and the switchgear installed in a particular substation. In use, this is expected to be an essential feature of the system, with users alternating between test feature frequency distributions and trip test current profiles taken at particular locations on given dates.

Figure 3: The Analysis Server user interface

The Analysis Server takes knowledge derived from inspection of the data set and applies it to the setting of thresholds defining acceptable operating times associated with each of the five breaker test features. This is done using an interactive graphical display superimposed on the frequency distribution for each specific feature. ‘Red’, ‘Amber’ and ‘Green’ condition thresholds are intended to be applied to named breakers, either specific manufacturer, model or if required a particular plant item. It is in the creation of these condition thresholds that the unification of expert knowledge and data driven asset condition occurs. Using the density function of the extracted test features gives an indication of the most likely operating times for the test feature under consideration. Switchgear experts have a feel for these values from experience which can be used to corroborate those evident from the density function.

Creating a contextual picture of test results can be achieved by adopting a statistical approach to modelling past breaker performance. The probability density function of a given random variable may be approximated using an established density estimation technique such as a Parzen Window [8] to obtain a smoothed histogram from a set of observed data points. Here, these data points represent times for particular test features. Simply considering the mean of a given feature is insufficient as the distribution may be multimodal and individual modes may characterise different faults. The main part of the interface shown in Figure 3 depicts the probability density function for the latch time on a South Wales C4X circuit breaker, with the feature time displayed on the x-axis and its corresponding likelihood of occurrence on the y-axis. Note that the distribution is not unimodal i.e. it has a number of peak values throughout its range. Domain experts can selectively partition this data by specific manufacturer, model or plant item using the pull down lists provided in the interface, which updates the frequency distribution accordingly.

The notion of condition thresholds was introduced in [4] as a means of encoding expert knowledge into a test feature condition assessment. Although the entire test profile is retained, the condition is inferred on the test times extracted from it by the Kelman handset software. For each test feature, the user is presented with a colour coded condition assessment indicating the extent to which the particular feature has deviated from the acceptable operating time. The condition states associated with this 'traffic light' condition assessment scheme are defined as follows:

- 'Green' - predictably indicates the timing for a test feature was acceptable, suggesting no maintenance action is required at present (i.e. until the next planned maintenance).
- 'Amber' - indicates signs of deterioration, suggesting a developing problem requiring maintenance at the earliest opportunity.
- 'Red' - indicates the feature is far out with the expected operating range, suggesting immediate maintenance is required.

Setting of the condition thresholds defining these condition states, is a two part iterative process that requires the user to set the bounds of the 'Red', 'Amber' and 'Green' condition then assess the coverage of these condition categories across a selected subset of data. This is repeated until the proportion of assessed breakers assigned to each category is closely aligned with the expert's expectations. Condition thresholds are set on density functions compiled from post maintenance trip tests, the reasoning behind this being that these should be most representative of correctly functioning breaker operation. The thresholds are assessed using a random subset of the available test data relevant to the application criteria, with the size of this subset selected by the user. Assessing the condition thresholds in this way provides a measure of the proportion of test records and consequently circuit breakers currently in service, that fall within the different Red, Amber and Green condition categories. It is at this point the domain expert's knowledge of the asset base is required. Using their experience, the expert will have some inclination of the approximate proportion of breakers they would expect to be assigned to each condition category by the system, for a given threshold setting. If these expectations deviate from system results (i.e. number of breakers in Red, Amber and Green categories for a given threshold setting appear greater or less than expected), the expert may then revisit the thresholds, adjusting them accordingly until the system results are more closely aligned with their expectations. Alternatively, the system may serve to highlight unexpected results e.g. more breakers appear in the Red condition category than expected for a given test feature or the most frequently occurring time value associated with a particular feature may be higher or lower than expected. This may prompt the expert to investigate further the reason behind this outcome, before defining the corresponding thresholds for that feature. Although automated learning of feature condition thresholds may be possible in the future given a comprehensive data set, for now a convenient heuristic for setting thresholds is to bound the highest peak of the distribution, representing the most frequently recorded time value for a given feature, with the 'Green' region and use the 'Amber' region to bound any turning points on the distribution. If the distribution exhibits pronounced bimodal or multimodal characteristics, this may indicate breakers that have been retrofitted with parts that differ significantly from their OEM counterparts or may indicate breakers that have been returned to service in an unsuitable condition. Again, it is at this stage that the knowledge of the expert is of value in making such distinctions. Additionally, the user may specify advice to the maintenance operative at this point regarding where to direct maintenance attention or possible remedial action. Having the switchgear expert or asset manager specify explicit maintenance advice removes ambiguity in defect interpretation and supports consistent rectification of switchgear condition. It is through this feature that maintenance procedures are expected to become standardized removing the need for ad-hoc procedures and therefore reducing the overall maintenance time of plant items.

4.2 FIELD TEST CLIENT

The system architecture complements SP PowerSystems' Mobile Workforce initiative. This decentralized approach reduces maintenance time and resources by devolving the responsibility of maintenance decisions and actions to field operatives conducting routine trip testing of switchgear. SP PowerSystems' Mobile Workforce project equips field staff with portable computing devices to minimize their time away from the field and improve the response time for directing appropriately skilled personnel to fault occurrences. As part of this larger initiative to provide maintenance personnel with mobile IT, field operatives were equipped with 'ruggedised' tablet type PCs. A limited number of fitting teams conducting an intensive switchgear maintenance program were equipped with these tablet type PCs with the Field Test Client software installed for use in the substations. These devices are primarily stylus input driven given the field based operating environment in which they are deployed.

Figure 4 shows how the test records enter the system. Although Kelman hardware was chosen by SP Power Systems for their current switchgear maintenance activities, the system developed here has no direct dependence on this equipment.

Figure 4: The intended use of the field test software

Typically, an FMO would connect the testing device to the plant item and inform grid control to send the trip signal to the associated network location. After the breaker trips, the FMO would return to the handset, disconnect it from the breaker and connect it to a tablet PC where the test record would be transferred through a serial or USB cable. As stated earlier, the test record contains both the trip current profile and the set of test times provided by the feature extraction software embedded within the handset.

The choice of user interface was driven by both the hardware available and the need to maintain data integrity, requirements that placed a strong emphasis on the need for simplicity and ease of use of the software. The Field Test Client user interface is of the 'Wizard' variety that has become ubiquitous in simplifying potentially complex tasks [7]. Interaction is driven by the application, with the user only having to consider the process one step at a time. As with other applications of the 'Wizard' type interface, information is presented in manageable increments and all operations can be undone by backtracking. An additional benefit is that 'sanity' checks can be implemented at every step. Data integrity is a key issue for both the current and future objectives of this application so addressing data quality issues and raising them to end users is done in a manner that permits only fail safe operation. The Field Test Client contains a local database storing historic test data for the entire population of distribution circuit breakers maintained by SP PowerSystems. Each asset record gives the plant details as well as the network position details allowing the end user to verify that the plant item being maintained is the correct one. Since this relationship is crucial the user is given every opportunity to amend the record or confirm that it is indeed correct and the test procedure will not continue until the user has explicitly specified that this is the case.

The 'Wizard' style interface handles this stage of testing particularly well, since the user is constantly made aware of his/her actions and can at any time undo them by stepping backwards through the pages that led to them. Finally, since there is no means in the Kelman record of specifying that the trip test is a first, post maintenance or final trip, the user must again specify this explicitly - the interface design assists this task by halting the test progress until this has been dealt with. As noted previously, the Kelman handset has the ability to display trip test profiles albeit on a small monochrome display of significantly lower resolution than that of the tablet PC. The major problem with viewing the trip current profile on its own is that it requires a domain expert with significant experience to interpret the profile or even gauge the acceptability of the features' times [5]. When displayed in the test wizard the test profile is presented to the user through an interactive display that shows both the profile superimposed with the expert defined condition assessment for the selected test feature (selected via the radio buttons) as shown in Figure 5. This page displays the current profile for the trip and where the extracted features sit within the expert specified condition thresholds. In the profile display (Figure 5), the condition indicator and the range it spans is overlaid on the profile. A marker for the actual value of the feature is provided to give an indication of the extent to which the feature lies in its categorical condition assessment. The example shown in Figure 5 shows the Auxiliary Contact (ACON) time lying within the acceptable 'Green' region, but close to the maximum threshold value of this range.

Figure 5: Profile display page from Field Test Client

After viewing the trip profile, the user is then shown the condition assessment for the plant item on its own. Along with each of the five condition assessments, a pop up maintenance advice caption is included containing text provided by a switchgear expert to direct the efforts of the maintenance operative to the potential causes of the poor performance. An example of this might be the occurrence of slow latch time. This would cause a red or amber condition assessment for that feature which would in turn display a dialog informing the user that the trip coil may have become contaminated with aerosol lubricant and to remedy the problem, the coil plunger must be removed, cleaned and dried. This feature is intended to standardize circuit breaker maintenance procedures for particular defects.

In practice, a minimum of two trip tests are conducted during routine circuit breaker maintenance, those being the 'first' pre-maintenance trip, any subsequent pre-maintenance trips, and a post maintenance trip. In order to build knowledge on the effects of circuit breaker maintenance on the shape of trip profiles, three additional pages for logging conducted remedial maintenance are provided. The page specific to the maintenance of the control circuit is shown in Figure 6. Although the user is restricted to selecting from pre-defined categorical options elicited from circuit breaker experts, this has the benefit of implicitly labelling each test profile with the set of remedial actions required. Again the primary business driver for this design decision was the need for data to be captured by the system as robustly as possible with the minimum possible effort required from the end user. The interface guides the user through the three general maintenance areas: the control circuit, the mechanism and the auxiliary control circuit. In the short term this provides an implicit representation of presently undetectable profile features such as battery problems that are of significance but cannot be interpreted from extracted features alone. In addition it will improve the understanding of the causes of deviations in the times of the extracted features. It is envisaged that the knowledge captured through this facility will enhance our understanding of the linkage between the trip current profile shape and its characteristics, and their physical causes. This can then be incorporated into the system, providing maintenance field staff with even more detailed diagnostic advice in future.

Figure 6: Field Test Client Maintenance Reporting. This allows maintenance activities to be associated with specific tests

The control structure of the Field Test Client application permits tasks to be undertaken continuously, allowing multiple tests to be conducted, compared or assessed while maintaining or investigating potentially defective circuit breakers. Comparisons between the test profiles can provide an indication of how the breaker normally operates or has malfunctioned in the past, but again requires a significant amount of domain expertise for interpretation. The Field Test Client permits a number of comparison options that allow the user to superimpose profiles from the first trip test, the post maintenance trip test, the most recent trip test or any two tests.

4.3 CENTRALISING PLANT DATA

Any information system is only going to be as good as its data and since the validity of data deteriorates with time, this must be dynamically updated to reflect the current state of the asset. A key requirement of this system was that as knowledge was gained on circuit breaker maintenance it would be re-circulated to progressively improve plant diagnosis and maintenance direction. To achieve this, maintenance operatives are expected to dock their tablet PCs to allow the upload of test records across the network and update of the expert specified condition thresholds from the Analysis Server. Docking the tablet instigates the communication sequence with the central data repository and ultimately the transfer of test records. Switchgear experts may at any time update the condition thresholds or provide additional maintenance advice based on recent experiences and/or analysis of the newly acquired test profile data. The periodic Field Test Client updates also comprise the latest relevant subset of SP PowerSystems' asset database and the latest historical test record/profiles from the central data repository to support plant condition assessment.

5. CONCLUSIONS

This paper has detailed the architecture for a data acquisition and analysis toolset facilitating circuit breaker maintenance. The objective of this development was to enhance circuit breaker health management with prognostic and diagnostic methods through the application of data mining technologies to operational data and maintenance records. This application has provided the framework for data acquisition and analysis that will inform and support a condition-based approach to distribution circuit breaker maintenance. It is intended that, in the longer term, the adoption of this technology will lead to improved operating efficiency and a reduction in maintenance costs associated with circuit breaker plant through the provision of more focused maintenance. Coupling the knowledge gathered from this set of analysis tools to other data sets (e.g. costs, maintenance, critical failures, customer minutes lost, customers served by the asset) may enable cost and benefit metrics to be developed and used to gauge the effectiveness of maintenance procedures and establish a return on investment measure for longer term maintenance programs as part of developing a successful RCM strategy. The implemented system is presently in use with SP Power Systems FMO teams in Central Scotland, assisting the company with the ongoing maintenance and asset management of more than 5000 distribution circuit breakers. It is the long term intention of this work to look for visible signs of circuit breaker reliability at the end of SP Power Systems 3 year maintenance cycle as indicated by a significant reduction in costs incurred by circuit breaker plant failure to clear faults satisfactorily through the availability of:

- Fast automated condition assessment enabling early recognition of incipient circuit breaker degradation
- Identification of circuit breaker type specific faults
- Archiving of reliable, representative information detailing current asset condition
- Reduce maintenance costs and downtime associated with unnecessary maintenance
- Auditable records and verification that maintenance has been carried out satisfactorily

FMO teams from both of SP Power Systems major maintenance bases have been trained to use the software with a deployment to all UK operations envisaged in the near future. A study of the use of the software is expected to be the subject of a future publication.

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References

1. Speed, W.R. “Circuit Breaker Operator Signature Analysis”, Proceedings of the International Conference of Doble Clients, Sec 4-4, 2000.
2. Watson, R. “Diagnostic technique facilitates timing and condition monitoring of circuit breakers”, Proceedings of Engineering Asset Management Conference, Oct 2000.
3. Beattie, S. “Circuit Breaker Condition Assessment by Vibration and Trip Coil Analysis”, IEEE Colloquium on Monitors and Condition Assessment Equipment Digest No. 1996/186, Leatherhead, 1996.

4. Strachan, S.M., McArthur, S.D.J., McDonald, J.R., Leggat, W., Campbell, A. "Trip Coil Signature Analysis and Interpretation for Distribution Circuit Breaker Condition Assessment and Diagnosis". CIRED 2005, Turin, 6-9 June, 2005.
5. Kezunovic, M., Ren, Z., Latisko, G., Sevcik, D.R., Lucey, J.S., Cook, W.E. and Koch, E.A. “Automated Monitoring and Analysis of Circuit Breaker Operation”, IEEE Transactions on Power Delivery, July. 2005.
6. Glickman, R., Frimpong, G. and Taylor, T. “Informed Planning: A Web-Based Solution for Integrating Electric Utility Asset Information”, ABB Corporation Technical Report, January. 2005.
7. van Welie, M. and Trætteberg, H. “Interaction Patterns in User Interfaces”, Proc. 7th. Pattern Languages of Programs Conference, Allerton Park Monticello, Illinois, USA, August 2000.
8. Parzen, E. “On the Estimation of Probability Density Function and Mode”, Annals of Mathematical Statistics 33. 1962.

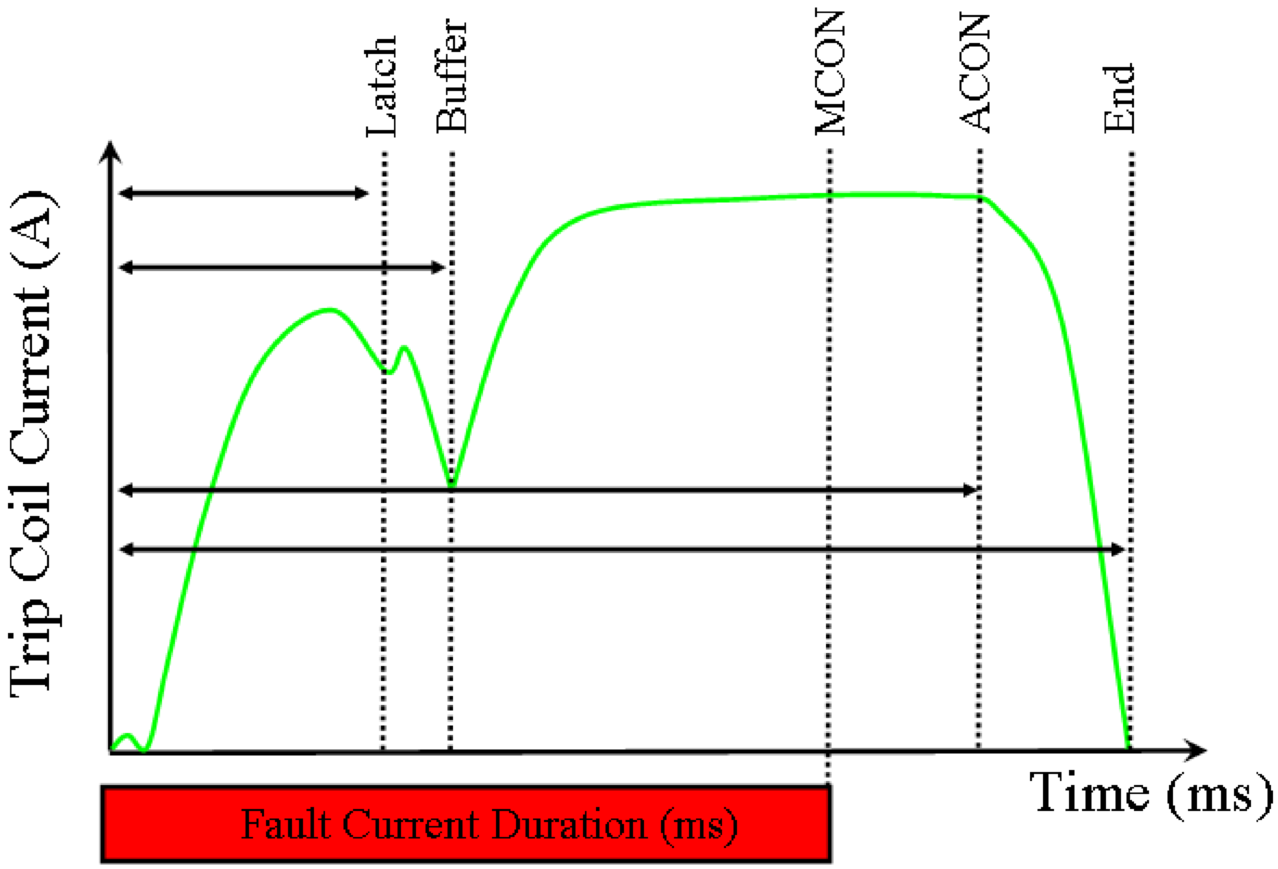

Figure 1: Trip Current Test Profile. This is the measured current across the trip coil against the time taken for the trip operation to complete.

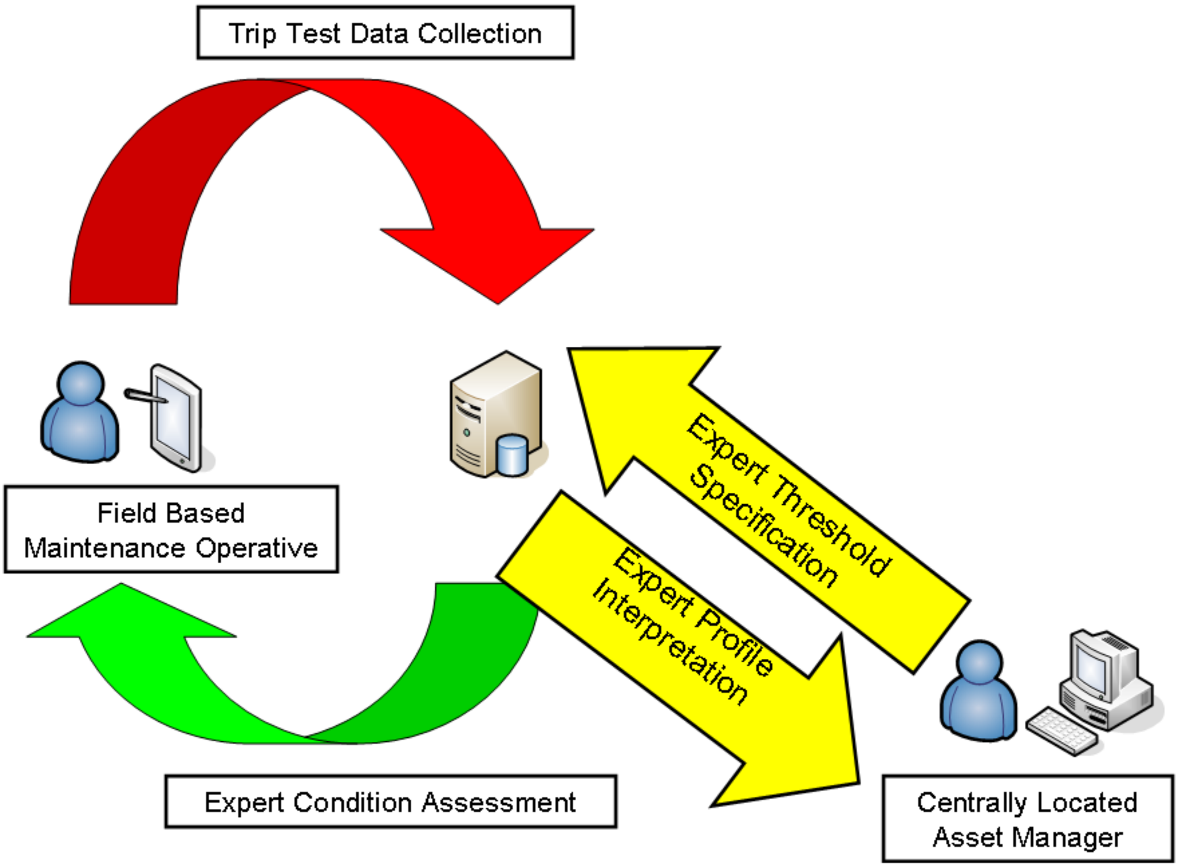

Figure 2: Knowledge flow in the proposed system.

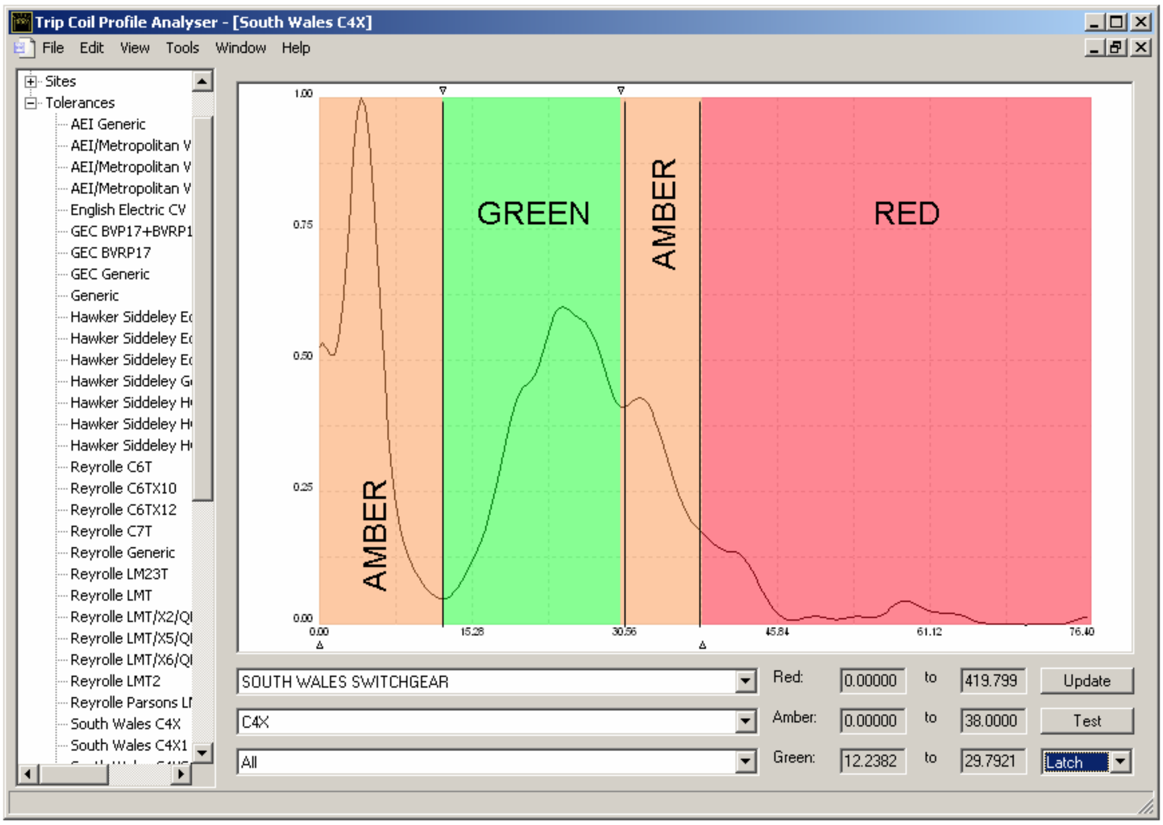

Figure 3: The Analysis Server user interface.

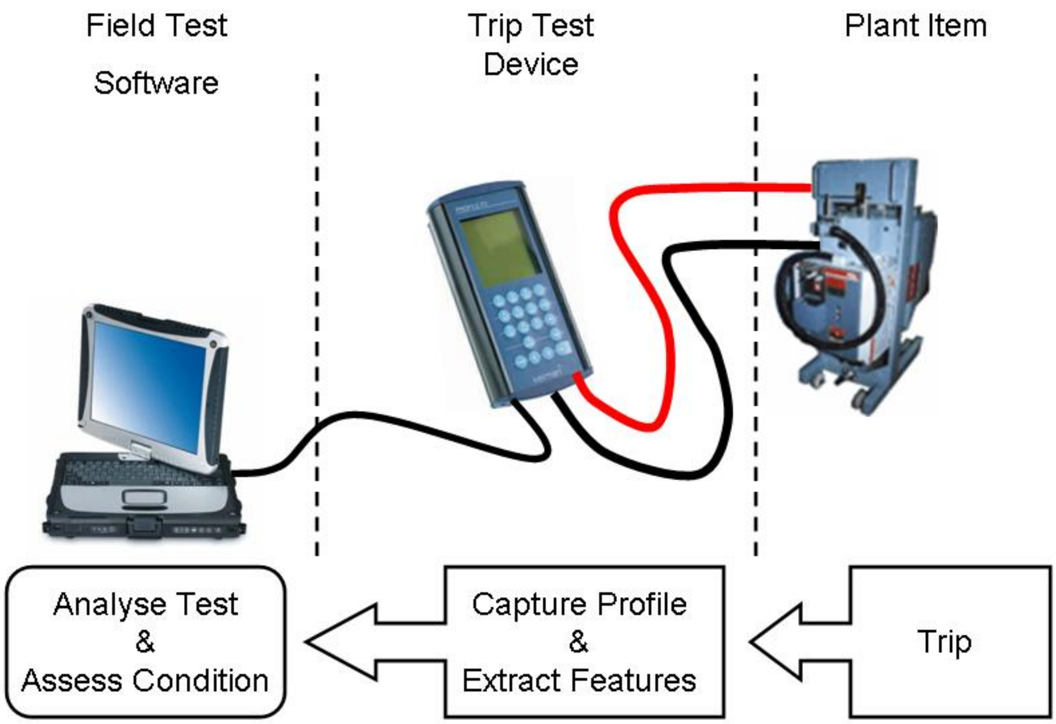

Figure 4: The intended use of the field test software.

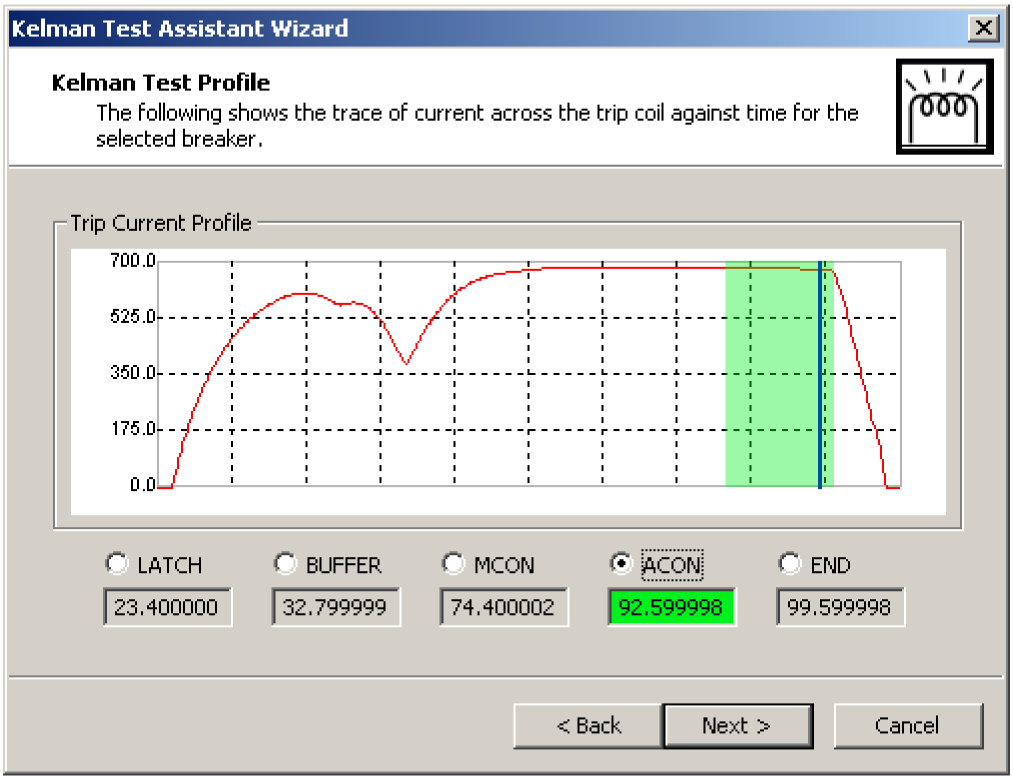

Figure 5: Profile display page from Field Test Client.

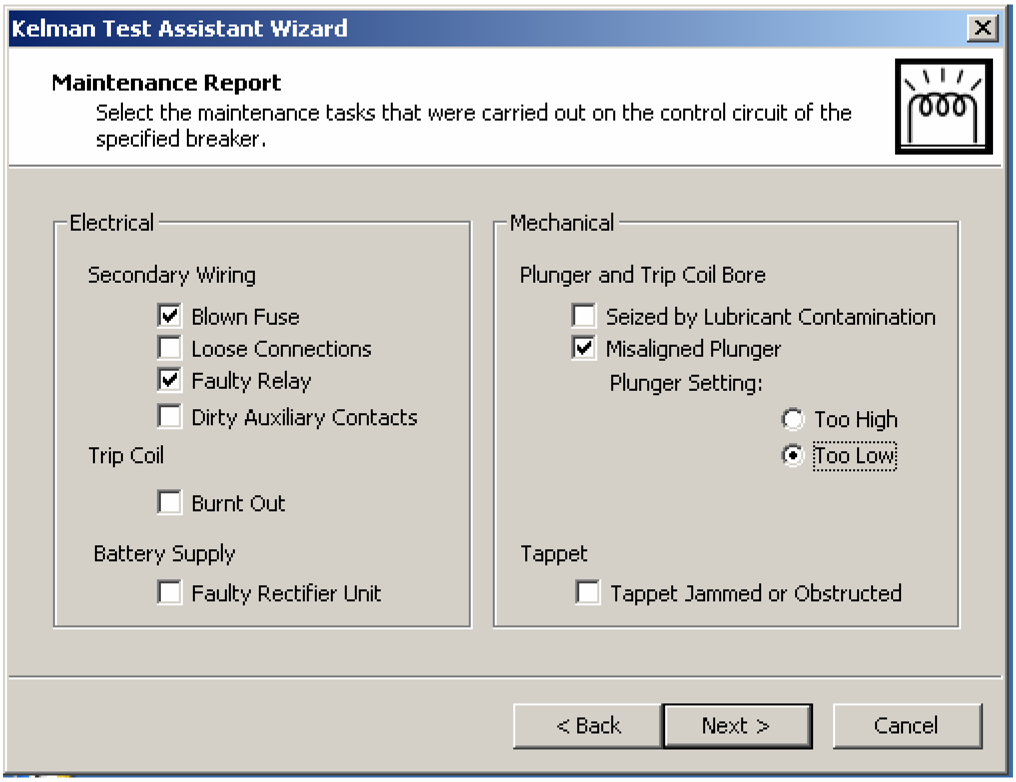

Figure 6: Field Test Client Maintenance Reporting. This allows maintenance activities to be associated with specific tests.