ESTABLISING AND OPTIMISING AN AUTOMATIC FAULT ANALYSIS SYSTEM FOR ESKOM TRANSMISSION

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ABSTRACT

It is electric utilities' aspiration to maintain network integrity and stability. To support this, automatic protective relay systems are enhanced, wide area protection systems (sometimes called special protection systems) are implemented and quality of information available to human operators in network control centres is improved. By improving the speed, validity, completeness and accuracy of information to control centres, serious network disturbances can be alleviated significantly. It has been proposed to establish an Automatic Fault Analysis (AFA) System which will be a server system that will perform expert system rules and formulaic analysis on fault records or report files posted on its entry folders by Fault Recorder Master Stations. This proposal was developed into a detail user requirement specification and a business case, eventually leading to project execution. The purposes for such a system are multiple, including recognising and categorising faults that occur, be they short circuits or other types of faults. Other purposes are to determine fault locations and to record data about fault level and fault resistance. A particular purpose that has not developed to the desire of most utilities is to accurately evaluate the correctness of power system protection operations for short circuits or other types of faults. By means of an openly coded expert system with a robust rule-base and algorithm-base, it is possible for the supplier of the system to retain secrecy of some algorithms and heuristics while still allowing a utility to optimise the expert system for accurate analysis using their own configuration. While much detail is omitted from this paper, we would like to involve the reader in the intricacies of such activities as the configuration of the communications network, the optimisation of the power system description, adaptation of the system for lack of fault recordings during events, the writing of specific automatic analysis rules in a computer coding language, and some examples of anomalous results produced by the system. In each case we present a problem that needs to be solved, the initial solution that was innovated, the resulting outcome and some corrective measures that were then implemented.

INTRODUCTION

Eskom places a very high premium on Power System Reliability which is sometimes also understood to be synonymous with Power System Integrity. A failure of Integrity would be a partial failure of Reliability, or a failure of reliability on only certain parts of the Power System. In turn, Power System Reliability depends on Power System Adequacy and Power System Security.

Adequacy relates to the existence of sufficient facilities (generation capacity & transmission capacity) within the system to supply the consumer load. Security relates to the ability of the system to maintain supply to the consumer despite disturbances or perturbations.

Both Adequacy and Security is essential to ensure Reliability, while a lack in Adequacy may cause a continuous concern of relatively small magnitude a lack of Security will seldom be revealed. However, a lack of Security is unfortunately most often brought to light by catastrophic events that lead to severe outages of enormous proportions (large percentage of the consumer load disconnected) and long duration (hours to days).

Power System Security is almost always a more demanding requirement than Power System Adequacy. For example, if a Power System is supplying the maximum load that it possibly can in a steady state condition, it is most likely not Secure, since a single disturbance or contingency will reduce the amount of load that it can supply (load shedding), or may even lead to disconnection of complete parts of the Power System (islanding), which are both Reliability failures due to insufficient Security.

To be Secure, the Power System often requires some redundant equipment (over and above what is adequate) and/or some remedial action schemes, such as Islanding, Out-Of-Step-Tripping, Underfrequency and Undervoltage load shedding schemes and so on. Unfortunately, almost all of these already imply a reduction in Power System Reliability; by simply re-defining what is adequate (shedding of consumers), so as to restore Security margins after contingencies or stability problems.

It is clear that Power System Security can be influenced by Power System Stability and Power System Contingencies. Power System Stability is a combination of dynamic phenomena affected by angular stability between synchronous generators, and voltage stability between automatic voltage regulators for transformers, generators and variable reactive compensation devices.

Power System Contingencies are understood to be temporary conditions that reduce the margin of Security, and therefore may lead to eventual failures of Power System Integrity (local blackout) or failures of Power System Stability, which in turn may lead to even worse consequences.

In order to improve Power System Security, a utility can either invest heavily in additional EHV network equipment, or attempt to apply various Power System Control enhancements. The first option would cost orders of magnitude more than the second, and therefore many utilities choose to improve the handles of control that they have on the existing power system first, before additional capital expenditure is incurred to expand it. Many attempts are made to enhance automatic protective relaying systems such as implementing wide area protection systems (sometimes called special protection systems) and improving the quality of information that is made available to human operators in network control centres.

By improving the speed, validity, completeness and accuracy of information provided to human operators, much may be achieved to alleviate serious network disturbances.

It is the aspiration of every electric utility to maintain network integrity and stability throughout, and to continue power supply to customers without interruption. To support this aspiration, many attempts are made to enhance automatic protective relaying systems, to implement wide area protection systems (sometimes called special protection systems) and to improve the quality of information available to human operators (let us call them “controllers”) in network control centres. It is on this last option that this paper and the work behind it are focused. This may be done by using data which is made available through the SCADA system, such as the Expert Systems described by [1], [2] [3], [4], or [5], the last of which proposed using only circuit breaker alarms.

In the work presented here, it is intended to improve the completeness and accuracy of the analysis of the protection operations and their correctness, by adding data available from Digital Fault Recorders (DFRs) that include oscillographic recordings of voltages and currents, as well as binary signals from protection relays. [6] Correctly highlighted that while most protection systems are designed to discriminate accurately and operate only for the particular conditions which they are set to trip for, unfortunately, protection relays that are designed to prevent excess damage to equipment may often contribute to network instability or loss of network integrity.

ADAPTATION AFA SYSTEM DUE TO THE LACK OF INFORMATION (FAULT RECORDS MISSING DURING AN EVENT)

In several cases obtaining the fault recordings from the devices at or very close to the time of the incident has always been a challenge. The telecommunications network (X25 for fault recorders) together with problems the interfacing between the LAN and Serial conversions and the fact that at the time of the incident the older fault recorders might fail for unknown reasons means that we do not always get to the correct conclusion because of the limited information. This problem is very common to our daily operation in trying to provide accurate feedback to the National Control Centre. The adaptation feature that is proposed does not focus on assessing the protection as such but serves to provide fast and helpful information to the standby personnel.

One goal in using the AFA system is to build a set of rules based on the Power System (PS) event which in turn will provide us with an acceptable answer in a very short time after the incident even with limited information. The NC centre is particularly interested in short circuit location as well as area of the fault so as to restore other parts of the network faster. During an event where more than one piece of equipment trips due to single disturbance (May it be primary plant or secondary plant errors) knowing in which area the disturbance is and what the impact is becomes important. The faster we have the information the faster the restoration process can begin. When limited information is available some definite conclusions can still be made such as: which phase the fault is on, what the duration of the fault is and on which areas we do not have a fault. This is done by way of elimination. On many occasions the disturbances occur on the distribution lines not being monitored by this system. Certain SCADA alarms are raised in such cases and recorders trigger due to binaries or analogue disturbances. This detail may indicate a primary fault on the system in which case other equipment are subject to the fault and an operator or maintenance engineer has interest in the fault. If we cannot get accurate distance but isolate the problem as soon as possible we can restore the healthy equipment in a short time or flag equipment for inspection. The system allows us to use the information captured in such a PS event to create tags and conclusion based on the logic and analogue information. We also have SCADA Alarms as an input to the AFA system. The SCADA alarms are used to provide additional certainty and accuracy in the conclusion that is reached but is not used as a trigger for analysing a disturbance on the system.

DEVELOPING A RULE TO RECOGNISE A NON SYSTEM FAULT USING DATA PROVIDED BY THE AFA SYSTEM'S DEFAULT OUTPUTS FOR EVENTS

This section describes motivations and solutions for using the Automatic Fault Analysis System software to assist in classifying the system faults as per the ESKOM classifications. In a proposal by [7], they demonstrate how SVMs can be used in a Fault Classifier. The ambition to obtain an automatic fault analysis system is not unique to Eskom or South Africa. In fact, [8] demonstrated how that a similar system was configured and tested for Reliant Energy HL&P in the USA. One of the main drivers for this aspiration is highlighted by [9], namely the conflict between intensifying requirements for performance assessment versus an ever increasing shortage of relevantly skilled man-power. .One of the features that is not available in the default package of the current AFA system is the ability to classify abnormal incidents according to ESKOMs own guidelines. As pointed out in [10] we could implement an exhaustive search where the solution or Non System Fault (NSF) will be located using the information already provides by the basic AFA system. This would require processing time and will increase the result output time. This paper party focusses on developing logic based rules or programmed algorithm using the default outputs from the AFA system. This rule will help in identifying a NSF. A NSF is the classification used by ESKOM to an abnormal incident where the protection operated when there was no primary fault or short circuit on the system but some protection operation has occurred.

The benefit of having such a rule is that it runs directly after all default processing has been done and provides an answer before a manual assessment can be made. It is critical that controllers are informed of protection operating when there is no fault on the network since this directly speaks to the reliability criteria of protection. Knowing when a specific relay has maloperated can decrease the outage time and inform the protection department of a possible problematic relay far sooner than the current way of detecting these maloperations. The existing, manual method, may take a day or two before a problematic protection relay is detected.

The result of the program as represented in Figure 1 is a *tag* produced that adds to the conclusion of record or records that was processed. This tag is used as the handle for categorising a NSF which can now be highlighted as protection not operating correctly. Having this rule means we can isolate the record earlier in the fault investigations process.

The rule is done using the following flow diagram as per the pseudo code:

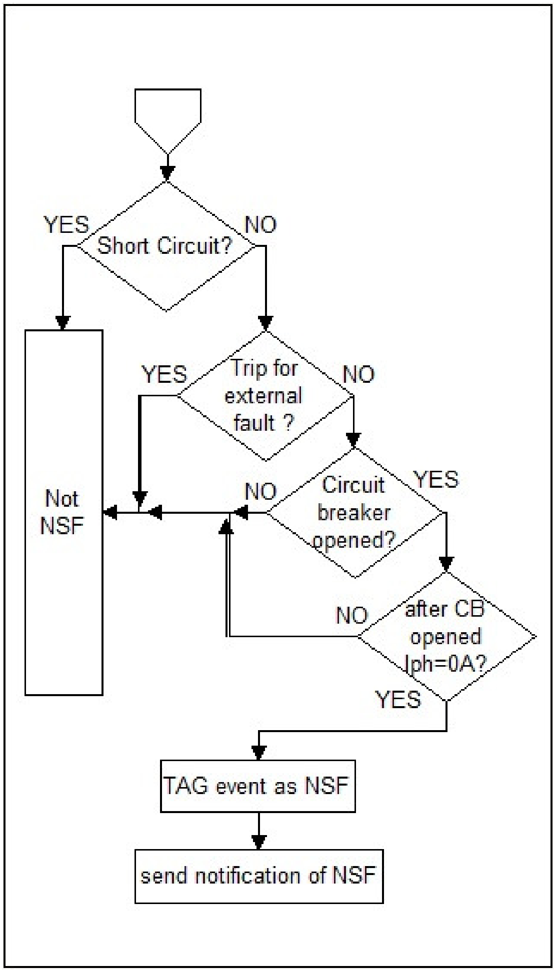

Figure 1: Flow Diagram for Pseudo code of the NSF rule

CONFIGURATION OF THE COMMUNICATIONS NETWORKS

In order to establish a recorder retrieval system that would be able to retrieve fault records from all relevant fault recorders concurrently, a setup was devised by which fault recorders are polled or scanned by 14 different fault recorder master stations. These are industrialised PCs, running the necessary proprietary software to communicate to each type of fault recorder. On each of the 14 master stations, a list of recorders was set up to be polled by that master station, in such a way that no two adjacent substations, or even neighbours of neighbours, would be polled by the same master station.

When we say that we want to retrieve all relevant fault recordings concurrently, we are making the assumption that any given incident will only trigger relevant fault recordings in a localised region of the country-wide power system. We expect that a short circuit in the vicinity of Johannesburg will only trigger fault recordings on the two ends of that transmission line on which the short circuit takes place, and perhaps on neighbouring substations to those two substations (connected through adjacent transmission lines). For a good collection of information to work with, we want the AFA system to have simultaneous and concurrent access to the fault recordings from both ends of the transmission line on which the short circuit has taken place. However, if any protection devices on adjacent transmission lines should operate in an unwanted fashion, we would also want the AFA system to have simultaneous and concurrent access to the fault recordings that recorded those protection operations also, which would be from “second” neighbours.

To ensure robust communications, we ensured that there are dual-redundant communication cables, switches and routers. However, we wanted our human-machine interface to be web-based, to enable wide portability, and therefore we had to take into account that communications with substation networks and communications with office networks have to be separated from each other by means of firewall installations. The separation is achieved by means of two concurrent mechanisms, namely a hardware-based firewall-gateway, combined with authenticated virtual private network (VPN) connections to that hardware-based firewall-gateway. To enable transfer of the fault recordings from the master stations to the AFA servers, however, VPN tunnelling was required. Fortunately, VPN tunnelling can be set up in such a way that only other devices on the same switch can obtain access to the VPN tunnel. And since we occupy both dual-redundant hardware switches to full capacity, we can be certain that our VPN tunnels are exclusive to the AFA system, except if physical access is gained to the high security building where the AFA system is housed.

OPTIMISATION OF POWER SYSTEM DESCRIPTION

The power system description used in the AFA system consists of a detailed electro-magnetic simulation model, with models for transmission lines that include effects such as mutual coupling between transmission lines, as well as series capacitors that are employed to reduce line reactances and thereby improve dynamic stability margins.

In order to provide information to the AFA system on how the power system description is configured, engineers compile a set of tables with long lists of components, linked to references of connections.

These tables include lists of substations, bays, feeders, lines, line sections, mutual couplings of transmission lines and series capacitors. Another set of data-table types also included are devices (fault recording devices and protection devices – of various types) fault recorder analogue channels and fault recorder binary channels.

As such it may appear as a misuse of the word to speak of "optimising" the power system description. What is meant by the term 'optimising' is that we need to optimise the accuracy of the approximation of the power system description to the actual reality of the physical power system that it represents – and this we may call error-minimisation or accuracy-optimisation. Also included in the meaning of the term is the trade-off between time and effort spent on correcting errors in the PSD, and the resulting accuracy achieved by that amount of time and effort spent – and this we may call labour-efficiency optimisation.

Originally, the PSD data tables were constructed from scratch using extracts of data from three independent sources.

- Firstly, the data model of the power system simulation software package used for fault studies to perform protection setting calculations with.
- Secondly, the database of the proprietary fault recorder configuration and communication software package.
- Thirdly, the database of protection setting revisions issued.

The added benefit in having the equipment parameters of the AFA system the same as our simulation data model increases our performance assessment of the accuracy of our simulations. The AFA System, setting and fault investigation sections heavily rely on an accurate simulation data model. Conversely, the simulation data model can be verified and improved by means oscillographic fault recording information for actual incidents, which can be extracted from the AFA system.

However, in the meantime, our experience has been that the amount of initial data manipulation to fit the data to the correct format is too demanding to be repeated frequently. Instead, we have learned to focus on common errors highlighted by incidents. Typically, the result for a particular incident will be erroneous, and we would be able to identify the reason for the incorrect result, which is often an incorrect data representation in the PSD data tables. When the error in the PSD data tables has been identified, we will then compare other cases and establish a pattern of errors, which we can then correct all at once, very efficiently. In such a way, the PSD is improved incrementally, as opposed to be re-created repeatedly.

From experience, the most common category of corrections that had to be performed to ensure correct identification of fault locations, was where analogue channels of fault recorders were incorrectly labelled or not labelled at all, based on errors that pre-existed in the fault recorder software database. The second most common category was where topological information had changed, with a destination for feeders on either side of a pre-existing line due to a new substation cut-in. However, for the purpose of correct identification of protection behaviour, the most common category of corrections that had to be performed was where binary channels of fault recorders were incorrectly labelled or not labelled at all, once again based on errors that pre-existed in the fault recorder software database.

EXAMPLES OF ANOMALOUS RESULTS AND THEIR EVENTUAL OUTCOME

Under some circumstances, it has happened that causes for anomalous results could be confused. For example, for several months, only the PSD on the Main 2 server was updated, after its software was upgraded. Because the Main 1 upgrade was imminent, its PSD was left un-changed. At one stage, the fault location for a series compensated line would not be displayed on the Main 2 server, but it was displayed on the Main 1 server. Because corrections to the series compensation values and topology were recently made in the Main 2 PSD, it was obvious to suspect this updated PSD of containing newly introduced errors. However, after multiple double-checks, the nature of the suspected errors could not be determined, and a service-request was logged with the supplier to provide assistance in determining what the error was. The supplier returned with the answer that the logic of the software upgrade on the Main 2 server was different from that on the Main 1 server, specifically with respect to fault locations on series compensated lines. Because series capacitors alter the fault location for faults beyond the series capacitor, fault location with a series capacitor in the middle of the line is often uncertain. For this reason, the supplier had chosen to re-classify series compensated line fault location results as "provisional", in effect hiding it from view unless specifically sought out. It turned out that the corrections to the PSD were not responsible.

In a similar vein, somewhat later, after both Main servers had been upgraded (albeit not to the exact same version of the software), it was noticed that the Main 2 server would repeatedly provide fault locations for a certain relatively short line, while the Main 1 did not (exactly opposite from the previous example). This time, the PSD on both Main servers was identical, and besides, there was not any series capacitor nearby. As a result, the different version of software on the Main 2 was suspected, and a service request was logged with the supplier. After investigation, the supplier agreed that it was partly caused by a difference in the software version, but also stated that it was intended, and that the outcome could be influenced by a variable in the so-called "Agents" input parameter file. The particular variable was a threshold for the quality of results. As fault location calculations are performed, the software also calculates a statistical certainty as a percentage, indicating how good the qualities of the fault location calculations are. The default threshold was selected to be 40%, and any fault location with a statistical certainty below 40% would be rejected and erased by the software, and therefore then not be displayed. At Eskom, it was decided that it is preferred to get indications of fault locations, even if their quality is poor, and therefore the threshold was lowered until the results for this particular incident was displayed. At this stage the threshold stands at 27.5%, but Eskom will experiment further to see if a lower or higher threshold is more advantageous. If a threshold that is too low causes incorrect fault identification, it will be increased. Conversely, if the threshold that is too high causes fault location results to be omitted, it will be decreased. For the purpose of experimentation, the threshold on the Main 1 server will be increased to 35%, while the threshold on the Main 2 server will be decreased to 20%. Differences between the two servers will be evaluated to see which option is more effective.

CONCLUSION

Because of the need for restoring the network adequately and monitoring protection operation in order to securely protect the network, Eskom has started using:

- An automatic fault analysis system that provides speed by reducing manual human involvement
- Customised rules that incorporates expert knowledge of engineering professionals accumulated through years of experience

The system will be continually improved by correction of its Power System Description, corrective changes to custom rules in response to incorrect results and by experimentation.

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