CONTROL-CENTER-BASED AUTOMATIC FAULT ISOLATION AND RESTORATION SYSTEM FOR RURAL MEDIUM VOLTAGE NETWORKS

Jukka KURU
Tekla Corporation – Finland
jukka.kuru@tekla.com

Turo IHONEN
Elenia Oy – Finland
turo.ihonen@elenia.fi

Juha HAIKONEN
Tekla Corporation - Finland
juha.haikonen@tekla.com

ABSTRACT

In severe weather conditions when many fault interruptions are simultaneously ongoing in overhead line networks, control center operators are overworked because of heavily increased dispatching tasks. At the latest when outage statistics reveal that the first corrective switching actions repetitiously take too long, a new cost-effective distribution automation tool to pursue SAIDI reduction should be introduced. This paper presents the principles of a new control-center-based automation system (called FLIR) for rural medium voltage networks. A proof of concept is enclosed to provide an overview, key results and user experiences of the first implementation at Elenia Oy.

INTRODUCTION

Various algorithms [1] and technologies have been attempted in the area of automatic fault isolation and supply restoration. Many of the recently implemented solutions, e.g. [2], are based on modern intelligent electronic devices (IEDs) utilizing local automation and therefore not applicable in large scale without making significant investments on network assets and data communication.

The main objective is to reduce outage times by speeding up fault location, isolation and restoration. The study assumed that automation is exploited in typical current Finnish rural networks, having some remote-controlled load sectionalizers, some tie points for interconnections, and only few fault indicators, if any. As a starting point, FLIR is expected to work without any additional network asset investments, such as upgraded IEDs.

In software architecture, further development of existing distribution management system (DMS) and SCADA was considered to be the key to the solution. By minimizing the efforts of modelling because required information is already available. The roles of these subsystems were defined clearly: DMS composes switching sequence proposals and SCADA deploys them into real actions in the field and substations, either by being supervised by operators or fully automatically. Automation process requires detailed information of network assets to be integrated, not only with the real-time status of the network but also, with the status of remote control. Especially in a multi-vendor system environment, the communication between DMS and SCADA is essential to success. A Web Service interface, called FLIR WS, was developed to enable seamless interoperability. FLIR WS provides many advantages when compared to traditional two-way-communication based on immediate execute or check before execute type of control commands (available in standard protocols).

In an interconnected circuit, FLIR is able to isolate the faulted zone of the network and the supply for remaining parts can be restored via top-rated back feeds. In radial circuits, automation can only use the main feed route for restoration.

CONCEPTUAL MODEL DYNAMICS

FLIR creates two simplified run-time models from the actual faulted feeder and its surroundings: switch model and area model. These models are dynamic in order to enable FLIR to adapt its functionality to different kind of changes while automation is running. When composing the proposal of isolation sequence, the focus is only on the area model. Switch model (figure 1) enables SCADA to perform required evaluation (both precondition and post condition) steps while executing the sequence.

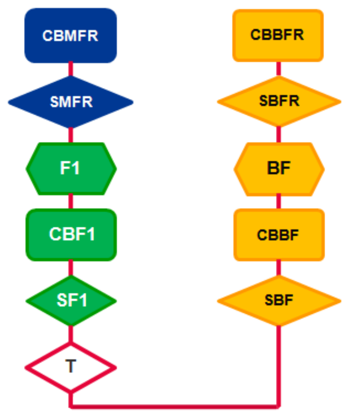

Figure 1. Switch model of a sample feeder F1

Switch model is basically a list of all related remote-controlled switches from the faulted feeder F1, including the feeder circuit breaker (CBF1), load sectionalizers (e.g. SF1) and tie points (e.g. T). The switches in the main feed route, e.g. circuit breakers (CBMFR) and busbar disconnectors (SMFR) of the main transformer are included. The corresponding switches of all possible back feed routes are presented in the switch model as well.

Figure 2 emphasizes the dynamics of the area model. On the left, sample feeder F1 is presented in a pre-fault situation (tie points T4 and T5, zones from A1 to A8 energized and a distributed generation DG1 connected). In the middle, the same feeder is presented after being faulted (CB1 in open state, DG1 disconnected and the zones de-energized).

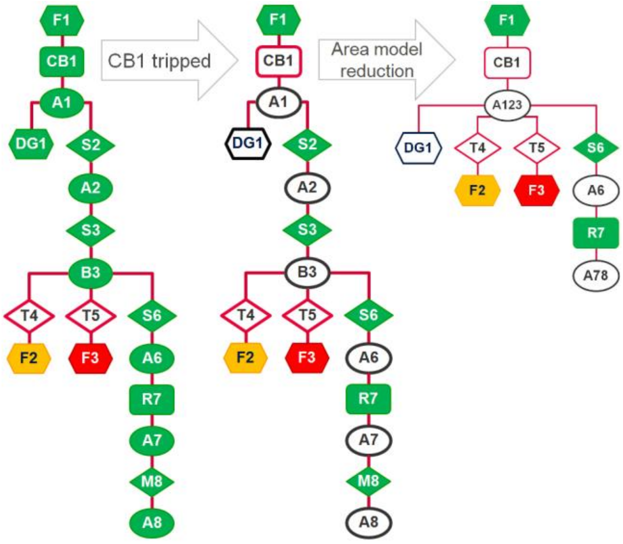

Figure 2. Dynamics of area model

On the right, the same feeder is presented after a precondition evaluation that revealed (this time) two sectionalizers (S2 and S3) being inoperative. To prevent control actions for these switches, zones A1, A2 and B3 are merged into zone A123. Thanks to this area model reduction procedure, which naturally covers manually operated switches (e.g. M8) as well, the composing of sequence proposals takes place in a simple and consistent manner but not forgetting adaptation to recent changes. This increases the degree of success in the long run.

Zone B3 presents a sectionalizing station. It can be assumed that, like in with reclosers (e.g. R7), the switches of these stations are assembled with more reliable communication compared to single pole-mounted remote controlled switches in the field. This division affects the operation principle of the sequence proposal (figure 4), which enables FLIR to split the rolling sequence in to a sparse phase (more reliable – less accurate) and dense phase (less reliable – more accurate).

The conceptual model dynamics enables SCADA to execute simultaneous FLIR cases, even when having shared objects in the main/back feed routes, without harmful interactions as long as the area models do not overlap.

PRINCIPLE OF AUTOMATION

The response of an electricity distribution system to corrective switching actions cannot be determined in advance. There are always some factors of uncertainty, which means that the final state can vary a lot. Figure 3 highlights this dilemma with an area model of a small-scale feeder.

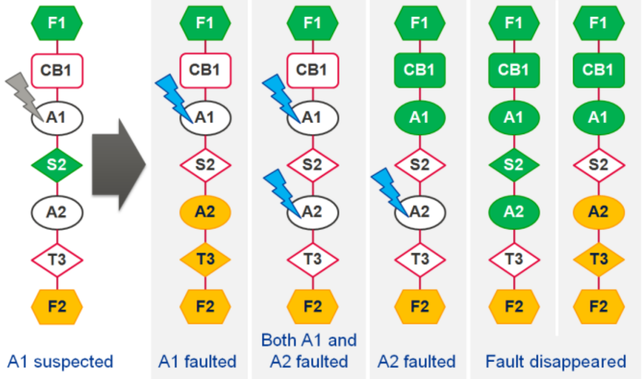

Figure 3. Alternate final states of automation

After estimating possible benefits, drawbacks and performance issues of different approaches, it was decided that the composing of switching sequence proposal should take place in two phases:

(1) The first phase starts immediately after having a switch model shared between DMS and SCADA. This phase results in a proposal dealing with the isolation of the faulted zone and restoration (if possible) via the main feed route.

(2) The second phase takes place after the execution of the isolation sequence has completed. This time the proposal is focused on back feed restoration only.

The approach leads to the following conclusion: It is not enough to compile a straightforward sequence that contains only the most probable path of execution. Instead, the proposal must include check points (for evaluating the result of the previous action) and conditional paths after each check point. By using this principle, FLIR is able to react to various changes in the switching state of the related network while automation is running, even when having a reliable hypothesis about the faulted zone.

Before composing the isolation sequence, FLIR performs a fault location analysis, which results in one the following as a starting point for the execution of the proposal:

(1) Reliable hypothesis about the faulted zone. This can be reached when there are enough reliable fault detectors mounted at the line crossing points where remote-controlled switches are located.

(2) One suspected zone. This can be reached by using a computational fault location method based on actual measurements in the substation. Another method is to calculate fault probabilities for each zone based on fault frequency data of each network component in the feeder. FLIR introduces a probability calculation method that

combines the results of the computational fault location method and the fault frequency method.

(3) Faulted zone unknown. This happens when the methods described above are not available or the results of them are not good enough. Earth faults are examples of cases where the faulted zone is typically unknown.

Figure 4 presents the operating principle of the proposal.

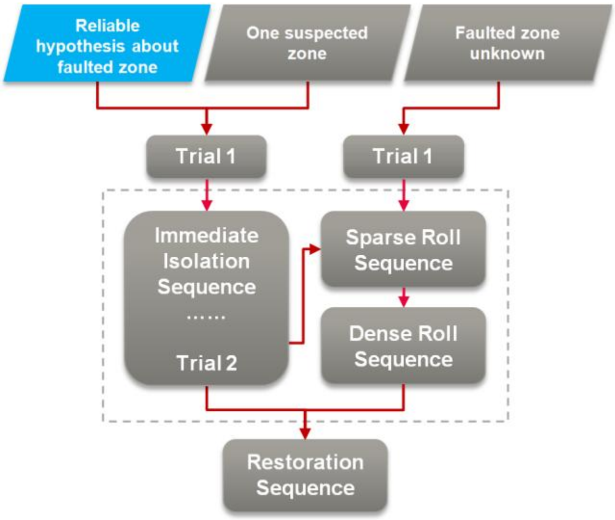

Figure 4. Operating principle of the sequence proposal

As a prologue (if not disabled by system configuration), automation begins with a simple trial sequence, called trial 1, containing only one control action, which closes the feeder circuit breaker. The purpose of the trial is to check if the fault exists. If the fault disappears, the execution of more complicated actions is avoided. Trial 1, like any closing action in a sequence proposal, may precede a computed waiting period to avoid constraint violations regarding the short-time thermal withstand of conductors.

The next sub-sequences (inside dashed rectangle) form the isolation sequence. If a reliable hypothesis about the faulted zone exists or when one zone is suspected, the isolation sequence contains two paths to end up: either the straightforward path via an immediate isolation sequence or via a fallback path to rolling sequences (sparse and dense). The rolling sequences are the only possible route if the faulted zone is unknown.

In straightforward path, the immediate isolation sequence includes not only the isolation of the suspected zone but also restoration to possible zones via the main feed route. When enabled by system configuration, the sequence continues with another trial sequence (trial 2) to guarantee the isolated zone to be the faulted one. In practice, trial 2 causes an extra outage period to zones already restored.

Fallback path is chosen if the immediate isolation sequence fails i.e. if another zone is detected as faulted when trying to restore power via the main feed, or if trial 2 disproves suspected zone to be faulted. Rolling is started with sparse-roll sequence by means of sparse-roll sectionalizers, e.g. S3 and R7 (figure 2). Rolling takes place downstream and switches are closed having upstream side energized. Sparse-roll sequence is successful when all zones are restored or, more evidently, when the fault is located in a section between two consecutive sparse-roll sectionalizers and when the supply is restored to possible zones via the main feed route. If necessary, automation continues with dense-roll sequence. This time, rolling is performed by means of dense-roll sectionalizers, e.g. S2 and S6. Dense-roll sequence is successful when all zones are restored or, more evidently, when the fault is located in a single zone and the supply is restored to possible zones via the main feed route.

The last part of the sequence proposal contains closing actions for tie points (e.g. T4 in figure 2) to restore supply from back feeds to the de-energized zones located behind the faulty zone. The stage takes advantage of power system analysis to evaluate alternate back feed situations. Possible limit violations regarding load grade and voltage drop are detected. In addition, the protection condition regarding the minimum phase-to-phase short circuit current is checked.

WORK FLOW

The work flow in FLIR (figure 5) lets SCADA execute each sequence without the need for non-stopping communication between the subsystems.

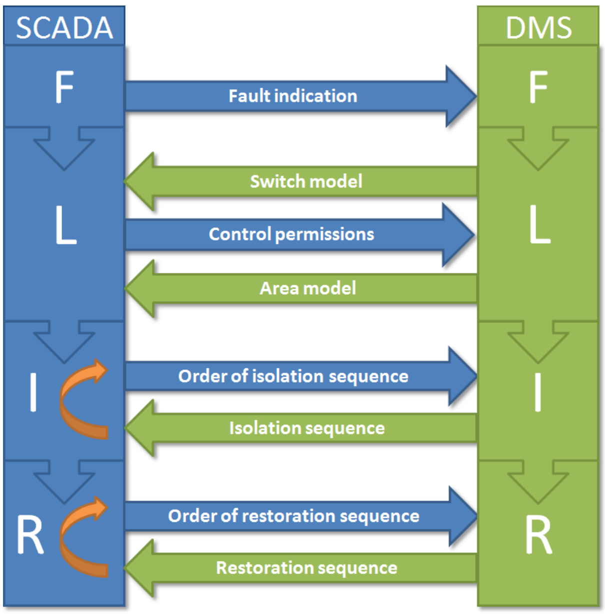

Figure 5. Work flow and data exchange communication

The data exchange communication via FLIR WS is used to manage the life cycle of each FLIR case synchronized on both sides. For IT security reasons, FLIR WS requests are always initiated by SCADA. Beside FLIR WS, a standard protocol is used to transmit timely indications about switch and fault indicator state changes and fault measurements.

After detecting a sustained fault, SCADA creates a new FLIR case and sends a fault indication message to DMS. DMS responds by sending the related switch model. After evaluating the switch model, SCADA sends (via the control permissions message) the latest information about interlocked or disabled switches. After this stage, DMS creates the final area model, computes fault location(s) and compiles the isolation sequence proposal, which is sent to SCADA for execution. After completed isolation, DMS compiles the restoration sequence proposal, which is sent to SCADA for execution.

Regarding each step in the sequence, SCADA evaluates its preconditions, executes the step (automatically or after confirmation by operator) and evaluates the post conditions of the step. In the first implementation, automation is aborted in specific error and exception conditions but the solution could be extended to overcome adversity by re-ordering new proposals as presented in figure 4. The condition evaluations are not limited to standard algorithms and rules regarding the associated process object, in addition, by checking the status of the objects in the switch model, SCADA is able to detect changes in the “external” circumstances that should force the FLIR case to stop.

DMS user interface provides visualized information about the faulty feeder and its automation status. This helps operators to take action after completed or aborted execution of the FLIR case in question.

IMPLEMENTATION CASE STUDY

Elenia’s distribution network is a rural network consisting of 1 024 km of 110 kV lines, 135 pcs of 110/20 kV primary substations, 22 050 km of 20 kV lines, 21 523 pcs of 20/0,4 kV distribution transformers and 38 626 km of 0,4 kV lines. In addition to remotely operated primary substations, Elenia’s network is equipped with 3500 remotely operated disconnectors and breakers to enable efficient and centralized outage management. Elenia has 408 000 customers, and of these approximately 374 000 are connected to FLIR automated network.

Case Elenia, the first implementation of FLIR, is presented here as a proof of concept. At Elenia, FLIR is used in the entire medium voltage network apart from few specified feeders with, e.g., critical industrial customers.

Elenia’s DMS has a powerful engine for geospatial data management and applications to streamline network operation and to integrate it into DSO's other business processes, e.g. outage communication [3] and workflow management. Elenia’s SCADA system is the solid backbone of network operations with hot standby backup for the safety and security of operations and time critical data. SCADA provides functionalities for alarms, measurements and remote operations for network automation components. SCADA is the master system for real time network switching state in medium and high voltage components.

After site acceptance testing period of six months, FLIR has been in production use at Elenia since October 2011, at first in manual confirmation mode and switched to auto confirmation mode already in December 2011. Since then DSO operations have dealt with numerous power outages, both occasional incidents and major disturbances, even with hundreds of simultaneous medium voltage outages.

The first year experiences are very encouraging. Firstly, no hazardous situations detected in consequence of the automation. In total, 382 FLIR cases were executed successfully in 2012. As expected, quite a large number of other cases were aborted during the execution because of recurring problems in the mechanics and telecommunication of old dense-roll sectionalizers. Occasionally, execution of the sequences revealed data quality issues (either on the SCADA or DMS side). These become naturally less frequent after corrective actions by DSO personnel. Elenia is determined to increase the utilization, efficiency and reliability of the automation by further developing the functionality together with software partners.

CONCLUSIONS

User experiences about FLIR have been very positive. Operators have been pleased when the automation takes care of the first critical isolation and restoration steps, especially during simultaneous outages because of storms or heavy snowfall. At the same time, operators have been able to concentrate on dispatching and customer service oriented tasks. FLIR has made a significant impact on improving the outage management of medium voltage networks, overall efficiency and customer satisfaction.

REFERENCES

[1] B. Akduman, B. Türkay, 2011, "Service restoration in distribution systems using an evolutionary algorithm", *The 21st International Conference on Electricity Distribution (CIRED)*

[2] F. Mekic, K. Alloway, C. Angelo, R. Goodin, 2011, "Fault detection isolation and restoration on the feeder (FDIR): Pick your technology", *The 21st International Conference on Electricity Distribution (CIRED)*

[3] J. Kuru, J. Haikonen, J. Myllymäki, 2009, “Innovative system integration for outage communication”, *The 20th International Conference on Electricity Distribution (CIRED)*