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SGEM

Conceptual model of an automatic fault isolation and restoration system for rural MV networks

Report

Description	This paper is a report for SGEM Task 4.2.7 (Field proven network management IT support for smart grids). The task includes a study of a new control-center-based fault isolation and supply restoration automation system for rural MV networks. This paper presents the conceptual model of the required system integration.
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1. ABSTRACT

This paper presents a recent study of a new control-centre-based fault isolation and supply restoration automation system for rural MV networks. The main objective of the system is to reduce average outage times by speeding up the starting of the isolation and restoration processes. Starting point for the study was that the automation should be exploitable at first in typical Finnish rural feeders having some remote controlled load sectionalizers and only few (if any) fault indicators. On the other hand, the system should tolerate different active resources and new hardware with intelligent electronic devices that the evolution of smart grids will breed.

This paper is focused on the conceptual model of the system. Remaining aspects of the project will be presented in other documents including a paper to be concentrated on automation principles and proof of concept.

2. BACKGROUND

During bigger storms or other severe weather conditions lots of fault interruptions are ongoing simultaneously in overhead line networks and the dispatchers are overworked. At the latest when outage statistics reveal that first corrective switching actions repetitiously take too long time, it is high time to introduce more effective tools to enhance distribution automation.

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3. OBJECTIVES

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4. APPROACH

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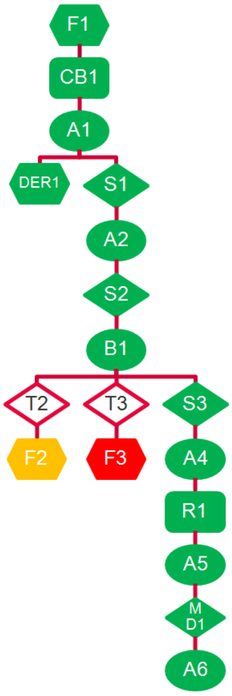
4.1 Conceptual model dynamics

The following picture presents the conceptual model of a sample network, named as feeder F1 according to its main feed.



Picture 1 Sample feeder F1

Here CB1, i.e. the feeder circuit breaker, is in close position as well as the remote controlled load sectionalizers S1, S2 and S5. Also the remote controlled recloser R1and manually operated disconnector MD1 are in close position.

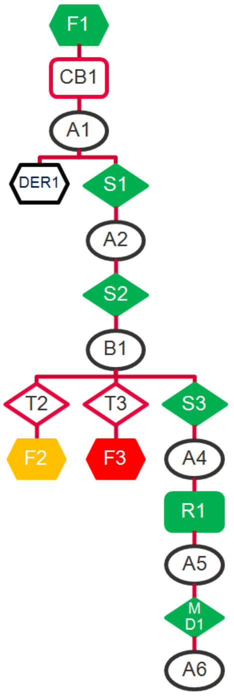
The network sections and the loads between the switching devices form zones (i.e. areas) like A2 between S1 and S2.

B1 presents the bus bar of a *load sectionalizer station*. Bus B1 is a special zone from the FLIR automation point of view.

There are two back feed alternatives in the sample feeder, one from feeder F2 via tie switch (open point) T2 and another from feeder F2 via tie switch F3.

FLIR automation assumes that the network is operated in radial mode, i.e. each load has normally a connection only to the main feed. The only exception regarding interconnected networks deals with distributes energy resources like DER1 in the sample feeder. The number of DER units is not limited by FLIR nor is the number of zones.

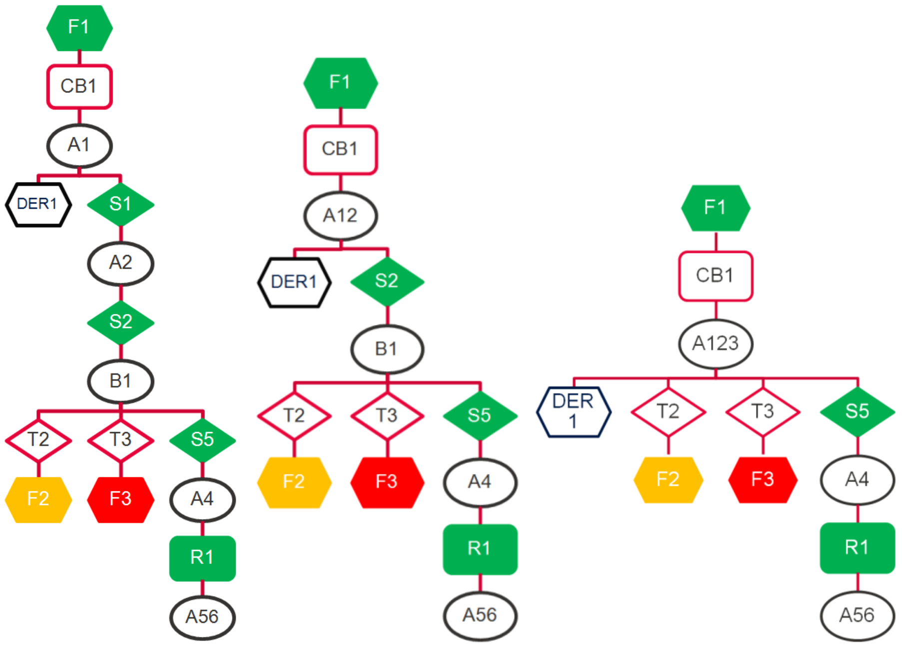
The following picture presents the conceptual model of the same feeder when a sustained fault takes place.



Picture 2 Faulted feeder F1

After tripping and auto-reclosing trial, the feeder circuit breaker CB1 remains in open position and, as expected, DER1 is also disconnected. All zones of the faulted feeder are de-energized. This is the starting point of the preparation for FLIR automation.

Next steps deal with simplification efforts. The idea is to remove all those switches from the conceptual model that cannot be used in the upcoming FLIR sequence. The following picture presents some alternative versions of the conceptual model based on different occasions.



Picture 3 Simplified models

First, in the left, we have the model after removing manually operated disconnectors. As we can see, zones A5 and A6 are merged into a new zone A56.

In the middle, we have the model with merged zone A12 as a result of the sectionalizer S1 being temporarily in control lock (or in local control or in any special state preventing its control in SCADA).

In the right, zones A12 and A3 are merged into zone A123 due the reason that the sectionalizer S2 is also currently in control lock. Note that the bus B1 is excluded from the model in this case. Actually, this kind of modification affects quite strongly to the sequence proposal as described later in the paper.

After simplification efforts we have finally reach the conceptual model of the faulted feeder to be used as the main element of the FLIR automation. The sequence proposal composed by DMS does include control actions only for the switches in that model. This also means that FLIR can isolate the actual fault and restore the supply into healthy network sections by means of the zone division.

Naturally operators can see all the manually operated disconnectors and all temporarily unavailable remote controlled switches all the time in DMS. This information is necessary when planning further actions after FLIR automation is completed.

There are two important details left when exploring the conceptual model: the properties of feeds and zones.

Both the main feed and all possible the back feed alternatives contains certain information about the exterior networks. A property called main feed route contains a list of switches located in the route from the main transformer down to the feeder circuit breaker. A property called back feed route contains a list of switches located in the route from back feed circuit breaker down to preceding sectionalizer before the tie switch. SCADA requires this information when evaluating that all prerequisites are fulfilled before executing a restoration action i.e. closing the feeder circuit breaker or a tie switch.

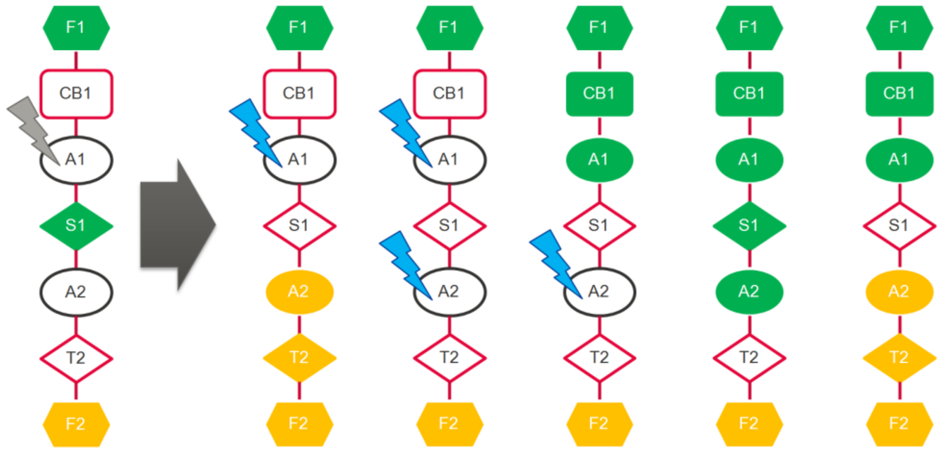
There is another property for back feeds that affects already when DMS is composing the sequence proposal for restoration. Certain feeders can be so important that it is decided not to use them as back feeds for the neighbouring feeders. The feeder F3 with red colour in the picture FIXME illustrates that kind of feeder. In case of a fault in zone A1 or A2, it is not allowed for FLIR to use feeder F3 as a back feed for the healthy zones of feeder F2.

DMS can produce many useful properties for the zones by using the NIS database as the information source: total number of customers, customer criticality index regarding dependence on power supply and total cost of energy not supplied (CENS). Two separate values are presented for each quantity, one for the zone itself and another presenting the total behind the zone. DER units are also managed as properties of zones.

4.2 Final state after automation

The following picture presents the initial state of a very simple feeder having (in the left) zone A1 as the suspected one. After automation is completed, five different states of the feeder can be seen also in the picture:

- Zone A1 confirmed as faulted and zone A2 restored from the back feed
- Two separate faults, one in zone A1 and another in zone A2 confirmed
- Zone A2 confirmed as faulted and zone A1 restored from the main feed
- Fault is disappeared and both zones are restored from the main feed
- Fault is disappeared, zone A1 is restored from the main feed and zone A2 from the back feed



Picture 4 Final state after automation

Actual feeders are typically much more complicated than sample F1, so, the number of alternative results is substantially bigger. Various (both unexpected and well-known) technical and logistical problems e.g. with remote terminal units are always possible to take place, so, the number of different paths and sub sequences (in the sequence proposal) as well as the number of different final states (after automation) can be quite high if all exceptional cases are also supported.

For example, the final state of the feeder can be same as the initial state due to reason that SCADA, when trying to isolate the suspected zone, is temporarily not able to control the sectionalizer S1 or the control command is passed but the device responses with error or middle status.

4.3 Automation steps

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4.3.1 Fault detection (step F)

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4.3.2 Fault location (step L)

There are three different categories regarding fault location results:

1. Reliable hypothesis about faulted zone. This can be reached when there are enough fault detectors mounted at the line crossing points where the remote controlled switches are located. Naturally it is also required that the indications are reliable. Unfortunately this is the case only in few feeders.
2. One suspected zone. This can be reached by using computational fault location method based on actual measurements in the feeder IED (intelligent electronic device for protection and control). Another suitable method is to compute fault probabilities for each zone based on collected fault frequency data of each network component in the feeder. In addition, FLIR automation introduces a probability calculation method that combines the results of the computational fault location and the fault frequency method.
3. Faulted zone unknown. This is the case when the methods described above are not available or the results of them are not good enough. Typically earth faults are examples of cases where the faulted zone is unknown.

More detailed description of the fault location methods are to be presented later in another paper.

4.3.3 Fault isolation (step I)

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4.3.4 Supply restoration (step R)

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4.4 Operating principle of the sequence proposal

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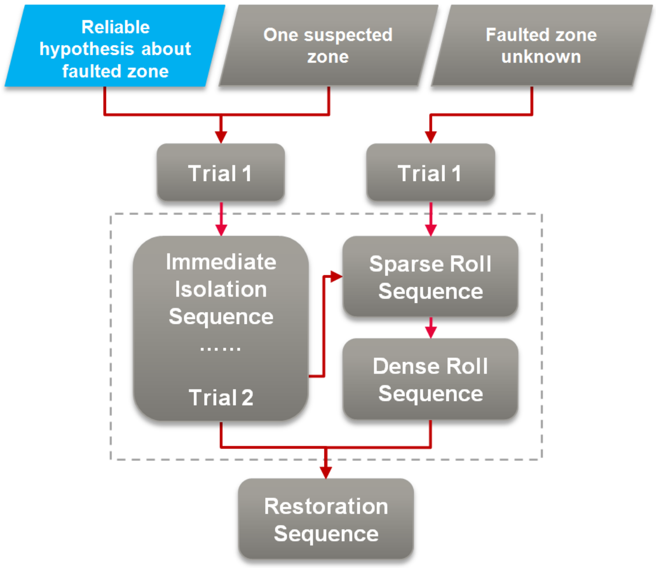
The following picture presents the operating principle of the sequence proposal.



Picture 5 Operating principle of the sequence proposal

The three different categories of fault location results (of step F) are presented in the top.

Which sub-sequences are to be included in the proposal, depends on the fault location result and some sequence settings that either enables or disables certain sub-sequence types.

If assuming that all types of sub-sequences are allowed (refer section FIXME for more information), the sequence proposal starts always with a simply trial sequence called as trial 1. It contains only one control action, close the feeder circuit breaker. The purpose of use of trial 1 is to check the existence of the fault. If the fault is disappeared, the execution of more complicated actions is avoided.

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4.5 Sequence settings

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4.6 Elementary sequences

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4.7 Principle of FLIR message exchange between SCADA and DMS

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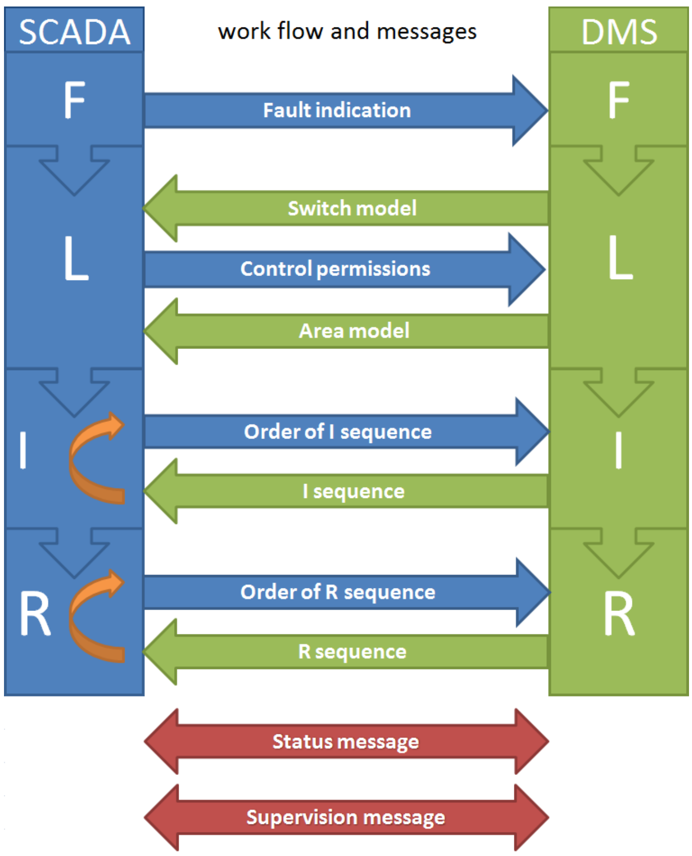

Picture X Work flow and message exchange

4.8 Information security

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5. RESULTS

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5.1 Conceptual FLIR network model

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5.2 Web Service messaging patterns

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5.3 Sample use case

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5.4 FLIR model from an actual network

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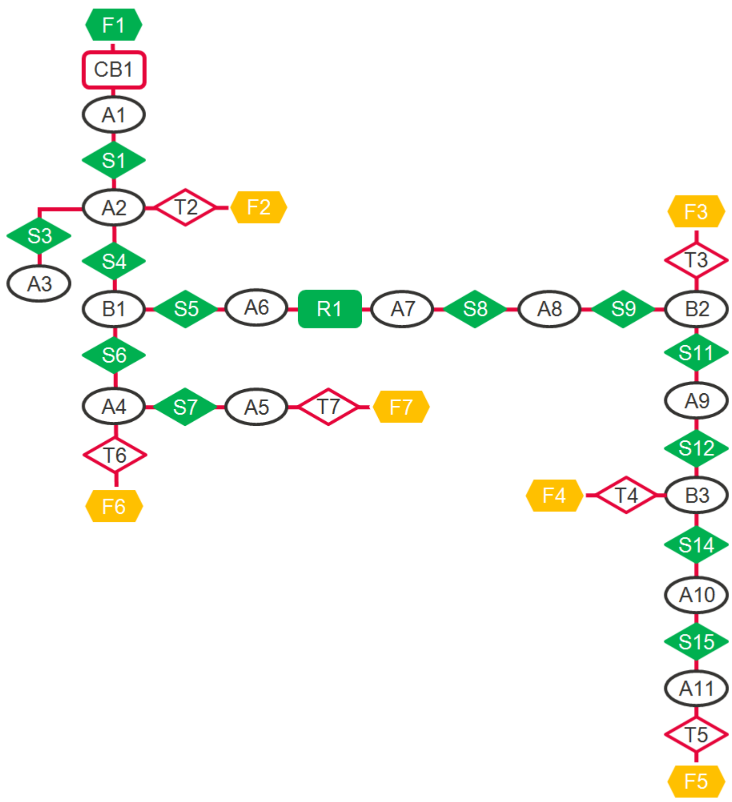

6. REFERENCES

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