TOWARDS SELF-HEALING POWER DISTRIBUTION BY MEANS OF THE ZONE CONCEPT

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ABSTRACT

This paper presents the zone concept, a systematic method of dividing distribution networks into manageable areas based on loads, load criticality and disturbance vulnerability. The self-healing functionality is achieved by utilizing intelligent network nodes and their seamless cooperation with substation and control centre systems. The paper presents a real case where the planning considerations are described.

INTRODUCTION

System self-healing is not a new issue in the field of power distribution, where auto-reclosing and auto-reclosers have been used for decades. In the past, however, self-healing was dealt with on the individual feeder level. With the increasing demand of uninterrupted power urged for by an ever growing group of consumers, it is necessary to have a broader view of the whole distribution network and its capability to limit the impact of disturbances to as small areas and as few consumers as possible.

The Zone concept provides a model for dividing distribution networks into zones, separated by active and intelligent components, in order to handle fault situations in an optional way. Optimal in this context means as few affected consumers as possible, fast power restoration and, finally, as little need of personnel as possible. The active and intelligent node components, the data communication between these nodes and the substation, and the control centre systems with appropriate software form the corner stones of the Zone concept.

The fast development of especially feasible communication technologies have made it possible to build the needed applications. This is particularly important for power utilities, as they are faced with the increasing demand for a more reliable power supply and lower operational costs.

THE ZONE CONCEPT

The lay-out of the power distribution network is affected by the density of settlement, power consumption and its criticality, legislation, environmental concerns, weather conditions, philosophy of the distribution network owner etc. Dominating driving forces today are the needs to **improve the supply reliability and voltage quality** as well as the requirement to **improve the operational efficiency** of the network company. Additionally, the increased use of distributed energy resources complicates the network operation but it also provides additional means to secure the power supply. **In such a situation the zone concept will provide a useful model for planning and upgrading of distribution networks**.
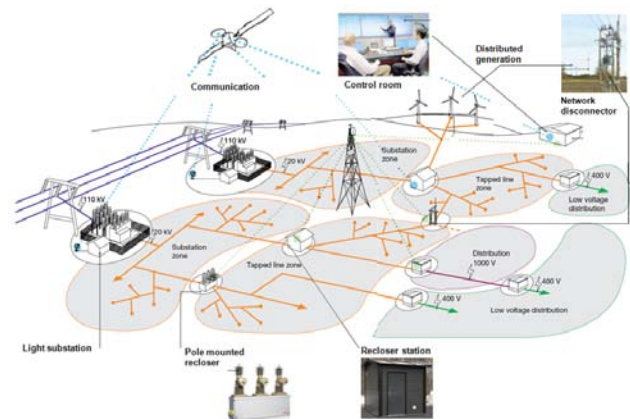

Figure 1: Main principles of the zone concept

Figure 1 shows the various zones downstream of the substation as shadowed areas. Between these zones **zone dividers** with protection and breaking/reclosing or only disconnecting capabilities are located. All zone dividers are provided with facilities for remote communication for transfer of status indications, control commands, measurements, etc. required by the application. Depending on the capability of the zone divider equipment the zone on the downside is either a **protection zone** or a **control zone**. Today the ongoing increase of distributed energy resources put special demands on the flexibility of the equipment functionality and adaptability.

Dividing networks into Protection and Control zones

The capability of the zone dividers, the differences in fault vulnerability between the areas and the criticality of the consumption within the areas are main issues for defining zone border locations. Needless to say that differentiating areas with low fault probability from those with high fault risks is worthwhile. Another zone divider criterion is the need to secure the supply to areas with substantial and/or critical consumption. The same criteria are used when determining whether a zone shall become a protection zone or a control zone.

Primary components, i. e. zone dividers

Circuit breakers and disconnectors are naturally among the most essential components in the distribution network. However, based on the need to secure the supply and reduce losses there is also an increasing use of distributed compensation equipment. Furthermore, there is, partly based on the need to have easy access and weather protection, an increased need to have ground mounted

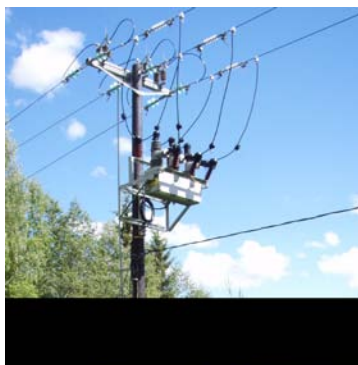equipment, even if the network otherwise is built as an overhead line network.

Figure 2: Traditional mounting of vacuum circuit breaker in an overhead line distribution network. **(Pole-mounted Recloser)**

In the application in Figure 2 the secondary equipment housed in a weather-proof enclosure is pole-mounted close to the ground level. The equipment handles protection, auto-reclosing, control and carries out versatile measurements. Communication with an upper level system is required in order to gain the full advantage of the automation.

Figure 3: Ground mounted vacuum circuit-breaker application with one incomer and two outgoing feeders (**Recloser Station**). The network is either an overhead or a cable network.

The application in Figure 3 is used when a weatherproof solution is required, and it is especially feasible when more than one circuit breaker (ref. recloser in Figure 2) is needed at the same location. A typical situation like this is when the main feeder has to be branched off into two feeders. The secondary equipment has versatile functionality for protection, auto-reclosing, control and communication.

Alternatively, a ground-mounted air-insulated load-break switch application with one incomer and two outgoing feeders (Load-break switch Station) is used. Figure 4 shows an application with both recloser and load-break switch stations. Load-break switches can be used further out in the network and the load-break capabilities are especially useful in network reconfiguration situations. As the load-break switch station is provided with the same secondary equipment as the recloser station extensive measurements and control capabilities are available.
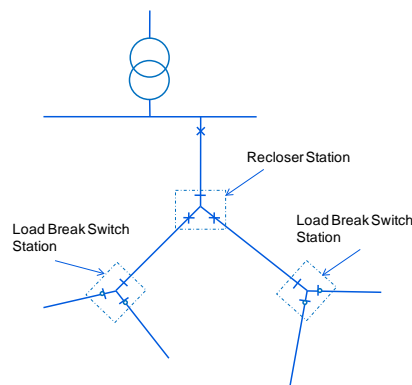

Figure 4: Principle location of the Recloser Stations and the Load Break Switch Stations in a main feeder

Secondary components, i.e. intelligent zone dividers
With the development of electronics it has been possible to provide grid distributed secondary equipment with enhanced functionality. In addition to protection, versatile measurements supporting both operation and asset management are provided. Local and remote control and automation features as well as communication and auxiliary functions are also found in these "all-in-one units". Thus the zone dividers can be selected and provided with exactly the functionality considered viable.

Communication
Communication is a central part of the zone concept, as it is essential to know the status of the zone divider equipment and to control it. With the development of capable wireless communication it has become feasible to arrange communication to most of the nodes in a distribution network. This has been made possible by the development of public wireless networks. In the selection of the communication methods not only communication features but also availability and security issues have to be addressed.

Substation and control centre software
As said in the beginning local automation has been a part of the distribution network for quite some time. The deve-lopment of communication and the need to have an improved overview and control of the whole distribution network from the control centres gave rise to centralized control and automation. The latest development has made it possible to locate such functionality also to the substation level.

In the type of system shown in Figure 5 control and automation functions are to be found at both local, substation and control centre levels. A system which takes into account the existing loads at various locations and the supply capability of alternative network configurations makes it possible to implement fast, fully automatic fault localization, fault isolation, network reconfiguration and power restoration functionality, i.e. to create a self-healing power distribution network.
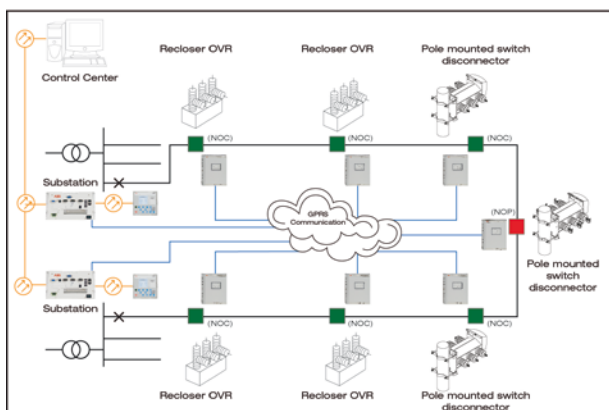
Figure 5: Automation functionality at different locations in a distribution network

THE PILOT CASE

The concept is being piloted on two rural area feeders in Kirkkonummi, Finland. The target of the pilot project is to verify the functionality of the concept. The pilot project is divided in three phases. In the first phase, **4 new disconnectors** and **2 new reclosers** are installed into the distribution network and a **local substation system into the primary substation**. The devices are equipped with **current sensors,** which can supply **data for the local substation system and for the distribution management system,** for determining fault locations. The locations for the new devices were decided by feasibility calculations made with LuoVa, ABB's reliability analysis software and on the basis of historical fault data.

In the second phase the pilot is scheduled to also cover other feeders of the same substation. In the third phase also a neighbouring substation is due to be included into the pilot so that the co-operation and backup functionalities would also be tested.

Background and objectives

The original target is, besides verifying the functionality, to reduce the SAIDI index by 50%. Currently the SAIDI is above 200 in the area, even though the automation level in the area is quite high.

The determination of the most suitable locations for the zone dividers, i.e. breakers and switches, was done using both the earlier described LuoVa reliability analysis software and historical outage/fault statistics from the DMS system.
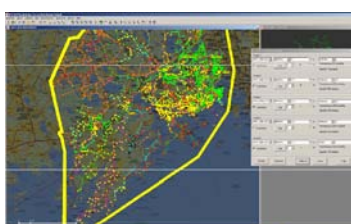

Figure 6: Example of historical data available from the DMS system. The figure shows the outages in 2009 for all transformer districts, fault test switching included.

The DMS system can provide both the number of outages and their duration. Based on this historical data, as well as the fault probability based LuoVa analysis, the zone borders were determined for the Kirkkonummi pilot installation.

Divisions into zones and selection of zone dividers

The piloted feeders have been divided to 20 remote controlled disconnector protected areas and 2 remote controlled recloser areas.
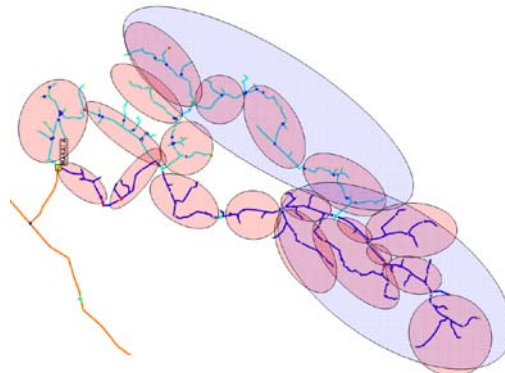

Figure 7: Protection areas of the piloted feeders. Red zones indicate disconnector protected areas and blue zones recloser areas.

The feasibility of the concept pilot was analyzed with LuoVa, ABB's reliability analysis software. The program calculates Customer Interruption Costs (CIC). Based on the Finnish regulation model 50% of the reduced disturbance costs can be regarded as regulation income for the distribution company.

The results show that the phase 1 would pay off after 6 years, with an interest rate of 8%. The asset-based income, allowed by Finnish regulation was not taken into account in the calculations, since there are no regulation definitions for smart grid related new devices. With asset based income, the pay-back time would be even shorter. Nor does the program take SAIFI reduction into account.

Table 1: Feasibility of the concept pilot investments

Years	Total CIC savings, k€	Investment, k€	Profitability, k€
1	28	134	-106
2	55	134	-80
3	79	134	-56
4	101	134	-33
5	122	134	-12
6	142	134	7
7	159	134	25

Choices of communication means

The network automation devices use the public network (GPRS) for communication with the substation computer. The substation computer communicates with the SCADA system, which is cooperating with the DMS systems. The coverage of the public network was measured in the planned disconnector and recloser locations for verification of the availability of the network. Since the communication

network depends on power supplied from the distribution network, it is important that there are several communication link stations available for the network automation devices and that some of the link stations are supplied from a different distribution feeder.

Fault localization
Experience by other network companies show that the main challenge of the automatic fault localization is to get the location of the fault with high accuracy. The reason for this is most likely that the majority of the faults in the network are earth faults, which cannot be located with earlier equipment. In the pilot installation this problem has been addressed as follows.

Firstly **an "intelligent" fault location package for the DMS is developed already at the substation**. This package includes:
- Localization of earth faults by using new algorithms and most probably also graphical methods
- Disconnectors provided with current transformers are used as fault indicators
- Utilization of the fault indicator information in the DMS fault localization functions
- Trigging of the fault recorder including the FLOC (Fault Locator) function **and combining it with the protection start signals**. This would mean that **possible fault locations are got to the DMS system before the faults cause an auto-reclose function and/or breaker trip**.

Secondly the DMS system will be provided with additional functionality, such as:
- Localization of the auto-reclosings (e.g. all auto-reclosings in a week will be localized simultaneously).
- Display of the auto-reclosing frequency by feeder and by time period.
- Calculation of the FLOC (Fault Locator) parameters.

Automatic Fault Detection, Isolation and Restoration (FDIR)
In the DMS system (DMS600) **the FDIR function has been included already for years.** The operation sequence is as follows:
The SCADA system provides the DMS system with the "fault package" and the status of possible fault indicators. The DMS system locates the fault and creates a switching sequence for isolation of the fault and for restoration of the power supply utilizing alternative supply routes (back feed). The switching sequence is sent to the SCADA system for realization and the SCADA system puts it automatically into reality. This is done step by step, i.e. the sequence does not proceed to the next step until the position indication has been received from the switching device. Tripping of a breaker during the sequence will stop the sequence.

Where is the FDIR functionality to be included?
In the first phase of the pilot installation the DMS system has a central role in providing the FDIR functionality. The DMS system provides accurate and reliable information about the network situation. When a switching sequence is created facts like network loads, open connections, occasional earthings, ongoing construction work, etc. have

to be taken into account. Solutions in networks including DER (Distributed Energy Resources) and demanding data maintenance issues are somewhat easier to handle in a reliable and dependable way in the centralized DMS system.

In the second phase of the pilot, however, the feasibility of running the FDIR functionality in the substation system (COM600) is tested. With this decentralized DMS/FDIR approach the central system does not need to be directly involved in the process related to a specific substation. The feasibility of such a solution depends on the capabilities of the selected systems as such and their ability to work together.

CONCLUSION

The ability of the system to locate the earth faults with a high enough accuracy is a key issue when striving to reduce SAIDI figures. The reduction can be achieved when the fault locator functionality of modern protection relays is combined with information from network distributed fault indicators. With a DMS system capable of creating reliable switching sequences automatically and of cooperating with SCADA systems in place, further improvements will be focused on the division of the network into zones and the selection of the zone dividers.

One important issue is also the amount and quality of the data transferred to the control centre. Advanced station level fault management reduces the amount and improves the quality of the data sent to the operators. Thus the control centre can focus on more important issues and overall coordination tasks.

The payback time of the pilot is expected to be 6 years. The concept will be piloted in a network, which already has a relatively high level of automation. The payback time would have been even shorter in a network with a lower automation level.

The pilot project is one of the first steps towards an automated and self-healing network.

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