Advanced automation with zone dividers deployment in distribution networks

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Summary

The driving forces for increasing automation in all distribution network levels are the need to improve the reliability of the power supply for customers and requirement to improve the operational efficiency of the utilities. In addition, the increased deployment of distributed energy resources makes network operations harder to manage. In this scenario, higher level of distribution automation will provide a useful approach for planning and upgrading of distribution networks.

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 optimal way. Optimal in this context means as few affected consumers as possible, fast power restoration and reduction of personnel needs. The active and intelligent node components, the data communication between these nodes and the substation along with the control center systems with appropriate software form the corner stone of the zone concept. The main reason for introducing the zone concept is the need to improve the supply reliability, reduce outage time via precisely calculating distance to fault, significantly reducing fault isolation time, voltage quality and economic benefits as well. In addition, an improvement of the operational efficiency of the network would be a result.

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. Zone dividers with protection and breaking/reclosing or only disconnecting capabilities separate the zones in the concept. All zone dividers are equipped with capabilities of communication for transfer of status indications, control commands, measurements, etc. required by the advanced application such as fault detection, isolation and restoration. Today the ongoing increase of distributed energy resources put special demands on the flexibility of the equipment functionality and adaptability.

This paper presents an approach on how the operation of the distribution network improves with deeper automation in the distribution network in a cost-effectively and future-proofed way. Integrating fault passage indicators to detect in a fast way the faulty zone and isolate it by manual and/or automatic operations. Adding protection and reclosing functions deeper into the network directs reclosing functions and interruptions selectively to the problematic parts of the network. Thus, distribution interruptions on other sections of the network are avoided. To do this, the feeder is divided into sections, or zones to minimize the affected area of fault. The fault probabilities can be minimized by focusing on the construction of the primary network, e.g. by replacing overhead lines with cable feeders. To maximize the benefits of these efforts, investment can be completed by implementing the zone concept. The investments can be made in phases starting from the actions most critical to the consumers. The zone concept solutions provide in the continuous improvement and creation of long-term development programs.

Introduction

The main long-term objective for the development of the power distribution network is to increase the quality of the electricity and the continuity of supply in a cost effective way. With its intelligent equipment solutions, the zone concept creates a solid and flexible basis for this comprehensive development work.

Uninterrupted power distribution is the primary element of the quality of power distribution. The reliability of the supply can be improved in a fast and cost-efficient manner through increasing automation and adding primary distribution substations, zone breakers and zone disconnectors to the existing network. This solution benefits both the consumers and the distribution network companies.

The zone concept also adapts to situations where distributed power production or new important consumers become a part of the network. The zone concept grows along with the requirements, offering a solution both for today and for the future. The reliable and accurate fault detection and location of re-striking and permanent type of faults with directional information is a key importance to the zone concept deployment in different types of network grounding methods. Measuring the fault current at the deployed recloser enhances the fault localization provided by the substation devices and the Distribution Management System (DMS). With this described approach and deployment of the zone concept as an advanced application in distribution automation, an advanced automation in the distribution network is proposed.

Zone concept – enhancement through automation and optimal grid use

The main principle of the zone concept is to confine the impact of a network fault to as limited an area as possible. A fault in the distribution network often interrupts distribution along the entire feeder and to all the consumers connected to it. Integrating protection and reclosing functions deeper into the network directs reclosing functions and interruptions selectively to the problematic parts of the network. Thus, distribution interruptions on other sections of the network are avoided. To do this, the feeder is divided into sections, or zones. Each zone should be equipped with communication for transfer of status indications, measurements, control commands etc. as required by the secondary distribution application [1].

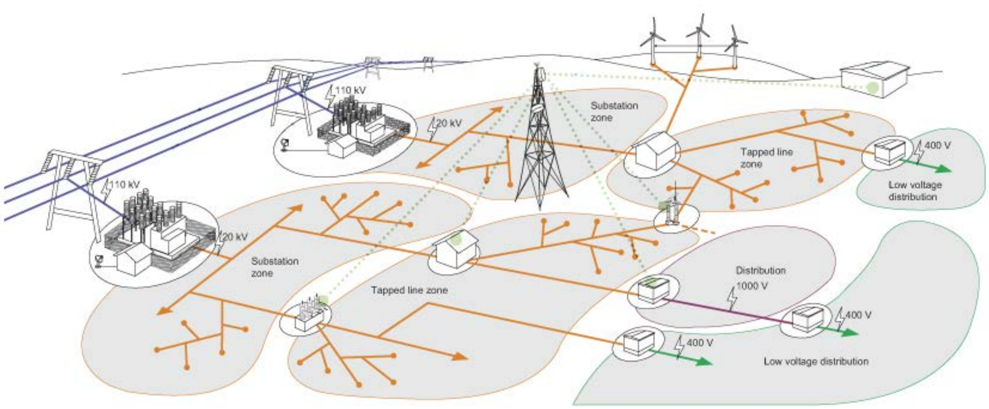

Figure 1. Main principle of the Zone Concept

According to research, the number of consumers experiencing interruptions is cut by as much as half compared to the case of no zone division. In the zone concept, an outgoing main feeder is divided into zones using line reclosers, automatic sectionalizers and remotely controlled disconnectors as zone dividers. Depending on the capability of the zone divider, the zone is either a protection zone or a control zone. Each main feeder zone, typically a protection zone, has a number of lateral feeders or branches, which can form their own protection and control zones.

A distribution network can be divided into zones in many different ways. The most traditional way is to increase the HV/MV substation density, or divide the network into sections fed by several substations. With this approach, even the nuisance caused by voltage dips in the distribution grid is restricted to a small part of the network. On long, lightly loaded feeders, the latter part of the feeder can be galvanically isolated from the beginning of the feeder using an intermediate transformer introducing e.g. a 1000 V distribution zone near the consumption points. Thus, the effects of any disturbance occurring at the end of the feeder are limited to the 1000 V zone of its own. Largely, the 1000 V zone can be designed using material intended for the standard LV distribution network.

The zone concept presented in this paper demonstrates the technical solution to accomplish the above mentioned constrains by utilizing communication network with minimum outage times. Adding communication and remote control functions into the deeper in the network e.g. in the disconnector and secondary substation is the first step of this concept. In this step, fault indication information and position indication statuses of the switching equipment are provided over communication network. This can also include some level of medium voltage measurements and connections to the low voltage metering and measurement devices. All the transferred data must be cyber secured.

The second step adds accurate energy measurements to the secondary substation. The high-accuracy energy measurements based on fault detection equipment enable a detailed power flow analysis in the distribution network. When entering into the power flow management, remote control disconnectors and secondary substations provide better operation of the increasingly dynamic distribution network.

The third step of the approach is adding the automated fault restoration capability. In addition to the previous steps, the power is restored to the healthy part of the network based on the fault passage indication and switching equipment position statuses in distribution network. With fault detection, the switching operations can be minimized and the efficiency of automatic restoration can be maximized.

The fault probabilities can be minimized by focusing on the construction of the primary network, e.g. by replacing overhead lines with cable feeders or by equipping transformers with surge arresters. To maximize the benefits of these efforts, the investment can be completed by implementing the zone concept.

If a fault occurs near the substation ahead of a zone breaker, remote control is used to restore the supply in the feeder section behind the fault location, using an alternative supply route. It is not practical to install breakers on all the branches; a disconnector is often enough. On a dead feeder, the branch is isolated either using remote control or automatically, if the disconnector provides fault current measurement (automatic sectionalizer). On a live feeder, the fault spot can also be automatically isolated using load break switches and local automation.

Fault indication in distribution network

As utilities today concentrate on continuity and reliability of their distribution networks, accurate fault indication has become an important supplementary function. One solution for this requirement is to apply computational fault distance estimation. Such functions are available in primary substation relays, and they are typically based on the calculation of impedance utilizing locally measured currents and voltages. The physical fault distance (in km) is derived by conversion from ohms to kilometres using the entered setting values. This can be done in the relay, but more accurate and informative results are obtained when the fault reactance value is further processed in DMS and possible fault location(s) are visualized in a map-view.

The fault indicators must work in an extensive MV network that consists of both cables and overhead lines, and whose earthing system is either compensated or isolated from ground. Challenge of the compensated networks comes mainly from the small fault currents that makes it difficult to detect faults reliably.

Accurate fault location brought up to SCADA and DMS makes it possible to send better fault information to the service personnel in the field. Accurate fault location helps also contractor to decide from which direction the fault location should be approached from and which spare parts should be taken along from the warehouse [2].

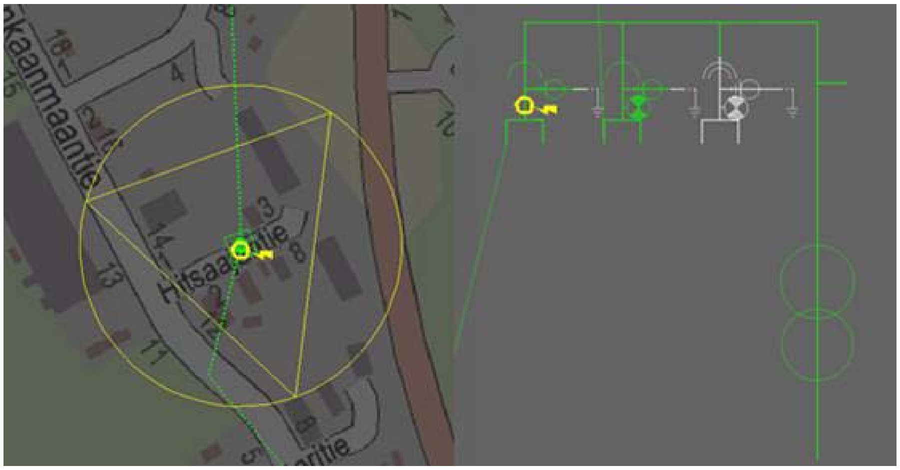

Figure 2. Remotely controlled CSS with fault indication in DMS system

Fault information with type and direction is available and visualized in used SCADA system. Figure 2 shows a remotely controlled compact secondary substation (CSS) with fault indication. The yellow arrow indicates earth fault.

Application of computational fault distance estimation in compensated networks is currently limited to short-circuit faults. Commercial solutions for computational location of single-phase earth faults is not yet available, regardless of the research and development work done in recent years [3]. Due to lack of solutions for computational fault location of earth faults, application of Fault Passage Indicators (FPIs) is a promising alternative [4, 8]. The purpose of FPIs is to point out whether the fault current has passed the location in question in forward or in reverse direction. Combining the directional information from FPIs in upper level systems (DMS), the faulty line section can be determined to enable effective and fast fault isolation and supply restoration, Figure 3.

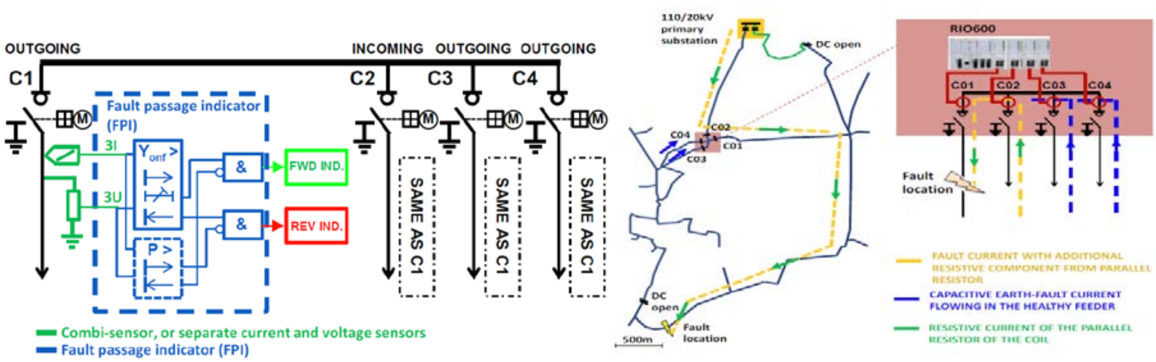

Figure 3. The principal concept of FPIs in compensated MV-networks

Similarly as computational fault distance estimation, earth fault indication in compensated networks is a very challenging task. Due to the compensation effect of the Arc Suppression Coil (ASC), the fault current magnitude itself cannot be used for indication of the faulty feeder.

Furthermore, the reactive component of the residual current can have the same direction in the healthy and faulty feeders. This implies that the directional evaluation requires dedicated algorithms [5, 9]. Attention should also be paid to intermittent earth faults, e.g. a special fault type that is often encountered in compensated cable networks.

Novel concept for fault indication in distribution network

From earth-fault indication perspective, the performance target for the development of a novel fault indicator was to productize a solution, which fulfils the following requirements:

- It can detect continuous (stable) earth faults with fault resistance up to 10 kohms
- It can detect and operate selectively during restriking/intermittent earth faults
- It can operate correctly during various compensation levels of the system, from unearthed to fully compensated operation
- It should have as few settable parameters as possible with easy setting principles

In order to meet the above requirements, multi-frequency admittance (MFA) - based earth-fault detection method was chosen. The MFA-function consists of two main elements: the directional element and the current magnitude supervision element, which are shown in Figure 4.

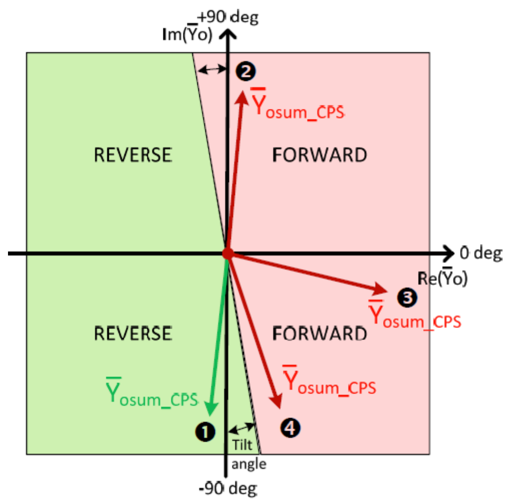

Figure 4. Illustration of the operation characteristics of the MFA-function

The novel algorithm combines optimal transient and steady state performance into one function. The operation of the algorithm is based on multifrequency neutral admittance measurement using the cumulative phasor summing technique. The main advantage of the used concept is that it provides valid measurement results regardless of fault resistance value and fault type, whether the fault has permanent, transient or an intermittent character. It also simplifies the applied fault indication scheme, as there is only one earth fault function to protection engineer [6].

Pilot tests and usage has shown advanced and accurate fault indication covering the demanded requirements of detection up to 10 kohm fault resistance (low touch voltages) and intermittent earth faults in a selective manner. This is done independent of degree of centralized or decentralized neutral point compensation or active network connection status.

Full benefits, economical and operation efficiency are taken when commissioned secondary distribution station is factory installed, full FPI functionality together with remote control and communication. Factory worked CSS enables easy and fast installation and commissioning. Fleet management of the FPI equipment is especially important when it is installed in a large scale and therefore this topic needs to be addressed. System wide fleet management for FPI's needs to be implemented centralized within DMS where device configuration, settings, health and communication status can be monitored and managed at all time.

Furthermore, with novel algorithm within fault indicator is possible to improve fault detection, isolation and restoration (FDIR) functionality. Using FDIR and fault indicators it is possible to minimize the outage times in different distribution network levels and to avoid trial switching operations and isolation but also restoration can be done very fast. Then customer effects are minimized and outage information to faulty area customers are improved further [7]. Additionally accurate fault location speeds up the fault repairing actions in the field. Customers benefit from the precise outage time information.

Conclusion

The aim of a distribution power utility is to offer the consumers high-quality electricity in a reliable and cost efficient way. Regulatory changes and other alterations in the operational environment have brought new challenges for achieving the targets. The zone concept offers a solution for proper allocation of development actions. The concept combines sensible topology of the primary network, appropriate primary equipment and intelligent protection, control and automation features into an optimal functional entity.

A novel concept for fault indication shows that the concept provides universal earth-fault indication that detects reliably all types of earth faults regardless type of distribution system grounding, and that the multi-frequency admittance criterion has a high potential to become a standard and widely used functionality in the zone concept.

The investment costs related to the zone concept are typically rather low. However, the investments have a wide impact on the distribution network and have an immediate decreasing effect on the costs related to power distribution interruption. In practice, this means rather short payback times for the investments.

To have the full benefits of investments in reliability of the critical network components, such as cables, zone circuit breakers can be used to restrict the impact of the faults to the components outside the network of enhanced reliability.

Zone concept solutions decrease the stress on the network and thus increase the life cycle of the network components. Improved asset management through use of device condition monitoring functions adds to the benefits of the zone concept implementation.

Due to the zone concept, the average interruption time experienced by the consumers is shortened as the zone disconnector isolates the faulty zone in case of a permanent fault e.g. in network reconfiguration for power restoration.

The benefits of the zone concept can be fully utilized by using remote-controlled switching devices in combination with the DMS. Measuring the fault current via fault passage indicator at the network breaker and secondary substation enhances the fault localization provided by the substation devices and DMS.

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