ADVANCED FAULT DETECTION IN COMPENSATED NETWORKS

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ABSTRACT

The driving forces for increasing automation in all distribution network levels are the need to improve the reliability of the power supply for customers, requirement to improve the operational efficiency of the network company and the increased amount of distributed energy resources. This paper presents an approach how operation of the distribution network is improved with the increasing of the automation level in secondary substations. The paper presents also a method for reliable fault indication and restoration in compensated and high-ohmic networks.

INTRODUCTION

The starting point for the secondary distribution cable network is the manually operated Ring Main Unit (RMU) that is a part of the Gas Insulated Switchgear (GIS), which is typically located in the Compact Secondary Substation (CSS). An RMU is typically equipped with manually operated load break switches.

Secondary substations are unmanned and normally up to one hour of driving distance for the power utility's service personnel in case of rural area distribution utility. In an open ring type of distribution network, fault location, fault isolation and power restoration to the healthy parts of the power network requires operation of several RMUs and this is the main reason for the power interruption times to be in range of several hours.

The automation concept presented in this paper demonstrates the technical solution to accomplish the above mentioned actions by utilizing existing public mobile communication network with minimum outage times.

Adding wireless communication and remote control functions into the 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 public mobile 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 are 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 level smart secondary substations provide better operation of the more and more 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.

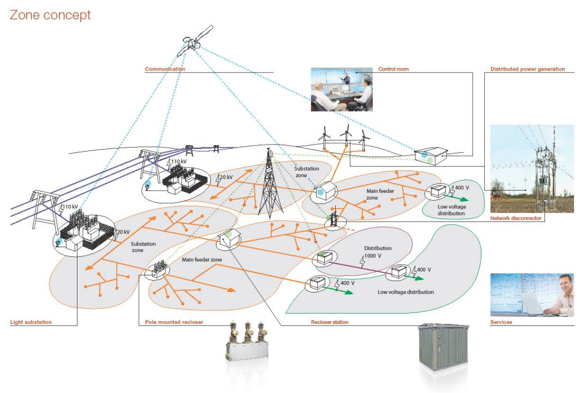

Figure 1. Main principle of the Zone Concept

ZONE CONCEPT AND AUTOMATION LEVELS

The Zone Concept in the distribution network automation is to divide the network into smaller zones. The required automation level in a zone is defined by the differences in fault vulnerability between the current zone and another zones and priority of the loads in that zone. Each zone should be equipped with communication for transfer of status indications, measurements, control commands etc. as required by the secondary distribution application [1].

In general, automation of the Secondary Substations can be classified into four different levels that reflect the needed functional requirements of the different zones. The four levels are: Situational Awareness, Fault Isolation, Power Flow Management and Protection Selectivity. Each level is an incremental step from the preceding one.

Level 1: Situational Awareness

In the first level of automation in the Smart Secondary Substation, connections to fault location information and position indication signals of the load break switch are established. The level can also include low accuracy MV measurements and connections to the low voltage metering and measurement devices. The level provides vertical communication from the lower network levels to the upper levels, e.g. Substation Automation Systems (SAS) in primary substations or SCADA systems in District or Regional Control Centers. This level is considered to be minimum level of the Zone Concept.

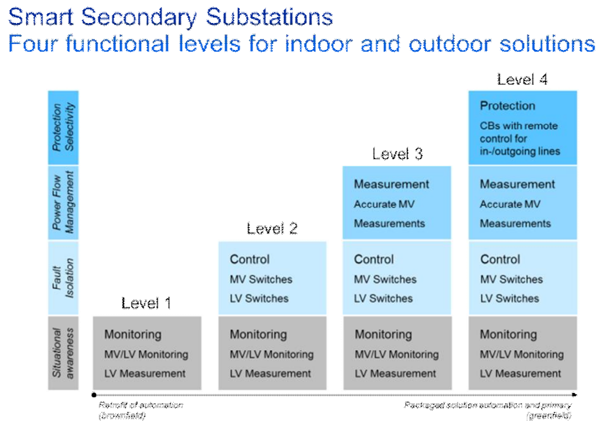

Figure 2. Four levels of the automation of the Smart Secondary Substations

Level 2 : Fault Isolation

The Fault Isolation level provides remote control of the primary equipment in the secondary substation. Automation provided in the upstream SAS or Network Control Centre (NCC) SCADA together with local intelligence in the secondary station enables isolation of the fault in a short duration of time and thereby not allowing the faults to persist and affect more zones. The isolation is partly based on the information provided in the Situational Awareness level. This level of functionality is needed for the creation of the control zone in the Zone Concept.

Level 3 : Power Flow Management

This level adds accurate energy measurements to the existing secondary substation. The high-accuracy energy measurements enable a detailed power flow analysis of the distribution network in the higher level automation systems. Traditionally, data for power details have been based on calculations and predefined models that have not reflected the exact status of the power network in every situation. When entering into the Power flow management level smart secondary substations become a real part of the distribution network by presenting of the accurate details that particular MV network in every operation situation.

Level 4 : Protection Selectivity

The Protection Selectivity level adds full protection functionality to the Smart Secondary Substation. A pre-requisite for enabling level 4 in a secondary substation is the presence of circuit breakers. In most cases, this would necessitate replacement of the switchgear or installation of the pole mounted breakers. In the Zone Concept, a level 4 enabled zones is called protection zone. Protection selectivity enables fast autonomous operations directly in distribution network without external control operations.

FAULT DETECTION IN DISTRIBUTION NETWORK

Elenia Oy(Elenia), the second biggest electricity distribution company in Finland, has piloted different solutions for fault indication aiming to find a solution that answers to the challenges of the long rural feeders with both centralized and distributed earth fault compensation units. Aggressive cabling of the old overhead lines has created network topology where there are lots of distributed compensation. Benefits of the fault location in the rural networks comes mainly from shortened fault times due to regulation in Finland.

In Finnish regulation model there is a quality incentive that calculates regulatory outage costs, i.e. the disadvantage caused by outages, based on the number and duration of outages, as well as the unit prices of outages. Finnish electricity market act also states that in case of interruption of over 12 hours network company have to pay standard compensations for the customers.

Requirements for the fault indication for used compensated cable network are that the fault indication device must be able to detect short circuit faults, earth faults up to 10kOhms and intermittent earth faults typical.

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 (Distribution Management System) systems makes it possible to send better fault information to the service personnel in the field. For example what type of overhead line extensions are needed. 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].

Fault information with type and direction is available and visualized in used SCADA system. Figure 3 shows a remotely controlled CSS with and without fault indication. Red color indicates interruption in the network and the arrow shows the direction of the fault. Color of the arrow indicates the type of fault. Red arrow indicates short circuit fault and yellow arrow earth fault.

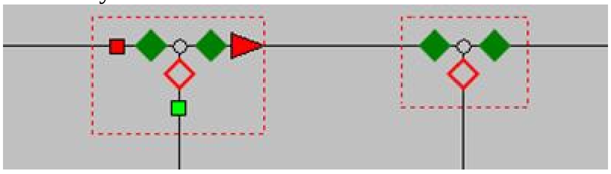

Figure 3. Remotely controlled CSS with and without fault indication in SCADA system

DMS visualizes remotely controlled CSS fault indication as in Figure 4.

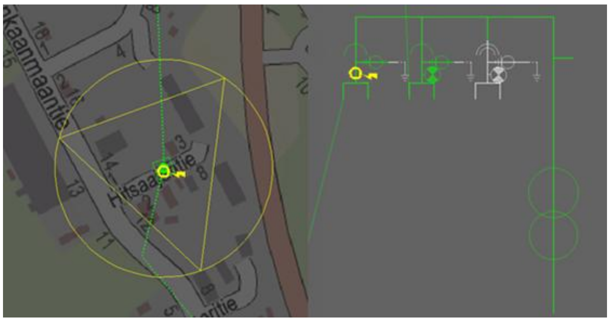

Figure 4. Remotely controlled CSS with fault indication in DMS system

When the network area is large and has long distances between assets there is a clear need for good versatile remote control system for the automation devices. Possibility to update the devices firmware and to change the settings remotely is essential to minimize the required efforts of device management. In the modern automation systems fleet management it is not enough to only monitor automation equipment remotely but also there is need to have the automation hardware to internally self-monitor itself and flag it upwards if there are any problems to report.

Today widely available (in Finland over 90% of users) public 4G/LTE networks are cost efficient and practical solution for utility communication especially for secondary distribution. High transfer rate of data and sufficient bandwidth of 4G/LTE enables system wide fleet management on highly practical level.

Obvious reason to install new automation into the network is to lower the operation costs. Need to lower the operation costs shouldn't overrun the need to have also a cost efficient solution. That in mind it is important to think about installation costs of the automation systems. The most cost-efficient way to install automation into a CSS is to have it done in factory site where processes are streamlined to their peak and room for error is smaller than in the field.

FPI IN COMPENSATED NETWORK

This paper describes a usage in fault passage indicators the usage of novel algorithm for earth fault indication in compensated MV-networks. The algorithm combines optimal transient and steady-state performance into one function. The operation of the algorithm is based on multi-frequency 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 the fault resistance value and the 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 engineer [3].

Field tests in pilot with ABB RIO600 fault passage indicator has shown that this type of FPI device suits well to compensated networks being able to indicate different fault types in it. With used algorithm correct operation up to 10kOhm faults has been shown. Such high fault resistances require also accurate measurements which are enabled by sensors utilizing non-conventional principles such as Rogowski coil or voltage dividers. Only with this type of non-conventional sensors it is possible to arrange current and voltage measurements in modern space efficient secondary GIS.

Figure 5. RIO600 as fault passage indicator with remote control.

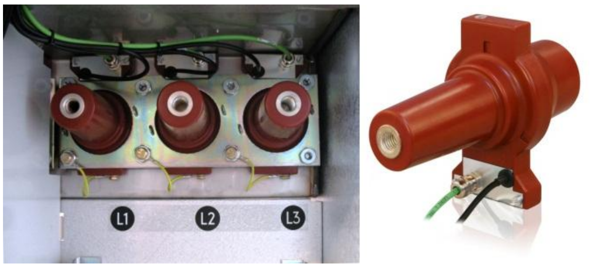

Figure 6. Factory installed combined voltage and current sensor replacing the bushings.

AUTOMATED POWER RESTORATION

Elenia has increased the amount of automation devices since 2006 dramatically. The amount of new primary substation has been increased causing a lot of new medium voltage feeding points. Number of remote-controlled disconnectors has almost tripled between years 2006-2015. During massive automation installation Elenia executed the total reconstruction of field communication between SCADA system and automation devices. Since year 2010 field communication has based on very reliable and secured public mobile network with the annual availability level 99.7%. The base of automated power restoration system was in order.

Elenia has taken FLIR (Fault Location, Isolation and power Restoration) in fully automatic use in December 2011. The system based on co-operation of two systems, SCADA and DMS. The basic idea is that after new permanent fault SCADA send the information package of fault to DMS. Then DMS calculates the location and creates the optimal switching sequence to SCADA for isolation and restoration. SCADA verifies possible hindrances and finally executes the sequence. Elenia has excellent experiences from FLIR when decreasing the customer effects. Still, there are possibilities to improve FLIR functionality with fault indicators.

Implementation of fault indicators to existing FLIR is technically straight-forward and the benefits can be remarkable. Using FLIR and fault indicators it is possible 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 [4].

CONCLUSIONS

Pilot tests and usage has shown advanced and accurate fault indication covering the demanded requirements of detection up to 10kOhm 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/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's 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 where device configuration, settings, health and communication status can be monitored and managed at all time. For these purposes the public 4G/LTE communication operator was selected due its sufficient bandwidth and high data transfer rate.

With advanced and accurate fault indication and automation with full FLIR it is possible to further minimize the outage times in different distribution network levels. Regulation outage costs are minimized when fault isolation time is reduced using accurate fault location information. Additionally this information speeds up the fault repairing actions in the field. Customers benefit from the precise outage time information.

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