Combining existing and modern equipment towards a new generation of Self-healing Network

Niklas SIGFRIDSSON
Vattenfall Operations Nordic – Sweden
niklas.sigfridsson@vattenfall.com

Elisabeth MAN
Sweco – Sweden
elisabeth.man@sweco.se

Florin STELEA
Pöyry – Sweden
florin.stelea@poyry.com

ABSTRACT

This study aims to combine new equipment with advanced information exchange in an existing rural grid, to improve reliability and availability of power supply. The new equipment installed is new recloser at crucial points with breaking capacity and Intelligent Electronic Device (IED), modern communication equipment, to be integrated with existing switchgear in the network. This is to be monitored and controlled as an entity with a modern Distribution Management System (DMS) with advanced fault localization and restoration function.

The benefits identified within this study is that new equipment gives better supervision and control of the grid, faster fault finding faster restoration of healthy parts of the grid. Thus fewer customers are affected by fault. Other benefits identified are possibility to handle the network in reverse power direction and rerouting of Distributed Energy Resources (DER).

The study is ongoing and is carried out in the island of Gotland at the Smart Grid Gotland site. The identified challenges within this study lies in the information exchange between the DMS and IED.

As the demand of advanced DMS in the MV-network will increase with higher demand of reliable power supply, this study will be input to projects when forming intelligent MV networks.

This study has a cost-awareness where installation cost will be evaluated for future investments in existing distribution network.

INTRODUCTION

Within power distribution, plenty solutions of "self-healing network" is to be found which are based on conventional power technology such as voltage measuring units and auto reclosers. Often, local logic is implemented, at a local feeder level, with limited control.

Advanced DMS-functionality with accurate fault location, load flow analysis and short circuit calculations has historically been benefitted the transmission network. The increased demand of reliable power supply from consumers and the economic benefits related to the Swedish market regulation of electricity distribution [1] increases demand of control and monitoring of the MV network.

Most distribution companies are facing the same reality: ageing distribution network with ageing equipment, high demand of improved availability and reliability of electrical power from customers and authorities, and at the same time limited budget to do reinvestments [2]. This is also the case with the distribution network in the island of Gotland, where the project Smart Grid Gotland (SGG) takes place. This paper describes the aim to install a pilot towards self-healing network where the challenge lies in the information exchange between IEDs and DMS. A zone concept is installed with new reclosers with sufficient breaking capacity in crucial net points and Intelligent Electronic Device (IED) [3]. Modern communication equipment needs to be integrated with existing switchgear in the network, to work as an entity with a modern DMS-system.

TOWARDS SELF-HEALING NETWORK

On the island of Gotland, Sweden, a smart grid installation in the MV rural grid is currently under development, within the project Smart Grid Gotland (SGG). Vattenfall is partner in the SGG project, where a pilot installation of a new generation towards self-healing network with advanced DMS functionality will be carried out. The installations within SGG differ from many other Smart Grid demonstration project by means of installations carried out in an existing rural grid with existing equipment. Cost awareness is also regarded within the project and will be evaluated for further investments in existing distribution network.

The pilot area for the installations is a predefined 10kV grid with existing switchgear, feeding industry facilities and private consumers. The pilot network area also includes Distributed Energy Resources (DER) connected to it, consisting of wind farms and photo voltaic installations.

There is fault location and restoration logic installed in the pilot area today which is from the seventies. It utilizes a dedicated system for fault localization and semiautomatic network restoration, based on local voltage measurements. This logic identifies in a blunt manner if a fault is upstream or downstream to a certain disconnector. In the same blunt manner, a restoration takes place up to that specific disconnector.

There are several disadvantages with the existing fault finding and restoration system. It is slow compared to centralized computerized systems and gives only a hint of the fault area. The existing system requires that the customers experience two power losses before the fault is isolated and unfaulty network restored. This automatic fault location and restoration system only operates when feeding in "forward" direction. On the other hand, the system still limits fault impact and gives a hint of the faulted area.

Zone Concept

New reclosers with sufficient breaking capacity in crucial net points combined with IED are to be distributed in the network. These new reclosers are installed within the ABB zone concept, where the idea is to divide the existing rural grid with overhead lines into zones for more efficient and faster fault clearance, restoration as well as monitoring and control abilities. Figure 1 shows the 10kV pilot network for the SGG rural grid installation, where the two 10kV stations A and B have radial feeders with possible interconnections through the northern and southern links. Proposed installations of zone reclosers and colored protection zones are visualized in the zone map.

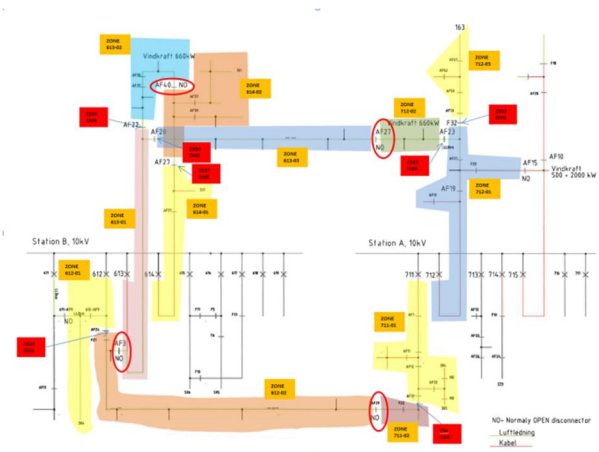

Figure 1: Zone map with arrangement of zones and proposed place for reclosers in the 10kV pilot network.

Placing breakers/reclosers further out in the network to break and isolate faults further out is neither unique nor novel for a distribution network. The novelty of the zone concept within SGG rural grid project is that the existence of each zone breaker can be motivated with economic benefits in terms of payback time of each installed switching device and how much each switching point contributes to fewer customers affected by fault in terms of changes in reliability indices. The calculations are executed in a specific zone calculation tool developed by ABB Center of Excellence in Vasa, Finland.

Another novelty of the zone concept is that the calculation takes into account specific feeder data related to its physical environment such as how many percentage of the feeder length is surrounded by forest, farming land etc. among many other parameters to point out the most optimal location of the recloser.
The results of the calculation tool are presented by feeder. An example of how the tool presents and visualizes the results are shown in Figure 2 to Figure 5. The figures below show the results for feeder 612 in the network.

Optimal location

Optimal location of Line Recloser 2 (LR2) is shown by "traffic light table" with distance from substation. It is shown that the optimal location is at 6,0km from substation.

Feeder 612-01

	km	arg max
	1,0	4029
	2,0	7415
	3,0	10157
	4,0	12256
	5,0	13711
LR2	6,0	14522
	6,8	13232
	7,6	11936
	8,4	10635
	9,2	9329
	9,9	8017

Figure 2: Optimal location of Line Recloser (LR2) is indicated by "traffic light table" in distance to substation.

Change of reliability indices

The theoretical change of reliability indices through installing the recloser in the 612 feeder is shown in Figure 3.

Zone 612-01

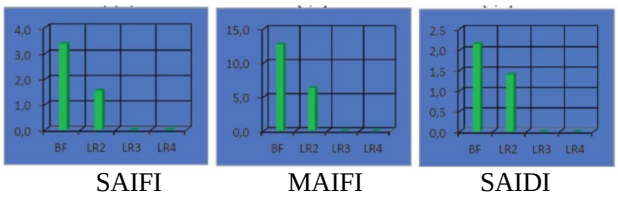

Figure 3: Theoretical change of reliability indices SAIFI, MAIFI, SAIDI when installing a Line Recloser (LR2)

By installing a recloser in feeder 612, two zones are created: Zone 612-01 and zone 612-02, see Figure 1. Zone 612-01 reaches from the Basic Feeder (BF) to the recloser ZS24, which in the calculations is called LR2. Zone 612-02 reaches from ZS24 further out in the radial until a normally open disconnector.

The original feeder where no reclosers are installed is called the Basic Feeder (BF). It is protected by the substation breaker/recloser against short-circuit and earth faults.

The left graph in Figure 3 describes the theoretical change of System Average Interruption Frequency Index (SAIFI) for zone 612-01, when installing LR2. SAIFI is the average number of interruptions a customer experience over a time period, typically a year. The graphs show a comparison of the reliability indices between BF and LR2. The left graph shows that an installation of LR2 decreases SAIFI substantially for the first zone.

The middle graph in Figure 3 describes the theoretical change of Momentary Average Interruption Frequency Index (MAIFI) in zone 612-01, when installing LR2. MAIFI describes the average number of momentary interruptions a customer experience over a time period, typically a year. In this case, it can be interpreted as most of the momentary interruptions occur beyond LR2.

The right graph in Figure 3 describes the theoretical change of System Average Interruption Duration Index (SAIDI) in zone 612-01, when installing LR2. SAIDI describes the total duration of interruption for the average customer, experienced over a time period, typically a year. The right graph shows that SAIDI will decrease theoretically for zone 612-01 when installing LR2.

Cost savings

If the quality of electricity distribution is raised, the network tariffs of electricity distribution can be raised, according to the regulations of the Energy Markets Inspectorate. The cost saving diagram shows the quality parameter for unplanned interruptions per year.

Feeder 612

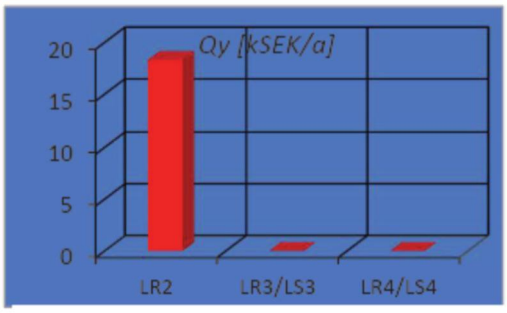

Figure 4: Cost saving diagram showing quality parameter change for unplanned interruptions per year in kSEK introducing recloser in feeder 612.

Cost efficiency

A calculation of investment efficiency of the suggested recloser is shown in Figure 5. Inverting the cost efficiency gives the pay-back time in years. For feeder 612, an estimated pay-back time of the installation is approximately 7 years.

Feeder 612

Figure 5: Cost efficiency diagram showing pay-back time for the investment

DMS for distribution network

New Distribution Management System (DMS) with Outage Management System (OMS) to monitor and control the network in real-time is being installed. The DMS system for SGG project with extensive functions for accurate fault location, advanced logic for fast isolation and optimal restoration is frequently used in the transmission network.

The DMS for SGG project consists of a restoration switching function based on short circuit calculations and load flow analysis. This function will significantly change the fault handling on the rural grid. The restoration switching function identifies possible switching options and rerouting in real-time for the operator. Further isolation can thus be made and the system can optimize the possibility to restore power to as many customers as possible and still be in control of voltage and frequency level. The aim of centralized and computerized real-time restoration switching function is rerouting in a fast and controlled way without creating overloads, voltage or frequency violations and at the same time optimize the restoration area.

Advantages of utilizing DMS in the zone concept

The novelty of including load flow analysis and short circuit calculations in the daily operation is given by the possibility to determine the best operation status of the system on daily basis, with updated and accurate information about power generation and load situation. This is especially interesting when the power generation fluctuates, which wind farms and photo voltaic do. Thru installation of the distributed IEDs in the existing rural grid, opportunities are given to monitor and control further out in the network.

If this information can be utilized with the DMS-system provided, this can be the foundation towards an efficient, correct and intelligent self-healing network.

The study intend to use load flow analysis at fault situation to be able to further isolate the faulted area and

create new routes and network configurations for the unfaulty areas. This is at certain extend performed today, but manually by the operator.
With centralized logic, parameters can be prioritized within the restoration switching logic. This is a substantial advantage for the operator, which today needs to be updated manually. The logic can then through calculations prioritize customers with critical need of power or prioritize so fewer customers are affected by the fault, or prioritize minimal load affected by the fault, among other parameters.
It is within the scope of SGG Rural Grid project to investigate in the possibility to show how reliability indices changes further when combining DMS with the zone concept, and to find an aggregated reliability indices change for the whole pilot area.

Fault location

A fundamental condition for faster fault handling in the DMS-system is the accuracy of fault localization.
For transient faults, a normal auto-reclose function restores the temporary faulted section. It is identified that the benefit of the restoration switching is at persistent fault. When fault location is identified, restoration switching suggests alternative route independent of power direction. An accurate fault location connected to the Geographical Information System (GIS) contributes to faster fault location for the field crew in the rural grid as well.

System information exchange between DMS and IED

The DMS system and the zone concept IEDs within this project are not developed in cooperation. This gives the SGG project the opportunity to study and identify requirements and gaps between information required and information available as well as the format of information exchange.
This study has identified that the fault locator in DMS requires fault magnitude of current, the faulted phases and type of fault. The IEDs within the SGG project are typically MV IEDs, where the internal disturbance recorder measures the fault magnitude of current as well as the faulted phases but not type of fault. Since the fault location is essential for the restoration switching, further study is ongoing within the SGG rural grid project.

Earth fault location

Another challenge within fault localization is in case of earth fault. Swedish distribution networks are normally earthed with Petersen coil system, which makes the fault difficult to localize. This is also an ongoing challenge within the project.

Rerouting possibilities with DER

Another advantage identified within the project is the benefits of rerouting in a network with a large amount of DER. With a large amount of DER, reversed power flow needs to be handled, as well as power quality distortion generated by DER. This is investigated in a separate study and can be read in paper no. 0391 “Benefits of using DMS-system for distribution network to optimize DER” in this conference.
As the demand of reliable power supply is increasing as well as the economic benefits related to the Swedish market regulation of electricity, it is foreseen that DMS-systems with advanced control and monitoring will increase its presence in the MV-network. Hence, the study about information exchange between a fault measuring system and fault localizing system as well as possible solutions of the information exchange will be input to projects when forming intelligent MV networks.

CONCLUSIONS

A combination of old and new equipment with advanced information exchange contributes to improve reliability and availability of power supply. In this study, challenges are identified for system information exchange of fundamental information to form for the self-healing network.

Computerized fault location of earth fault in Petersen-coil earthed networks are recognized as difficult, which is identified within this study. The local disconnector logic utilized in the Gotland’s network today does somewhat point out fault, no matter if it is earth fault or phase fault, though in a very blunt way. Since the demand of reliable power supply is increasing as well as the economic benefits related to the Swedish market regulation of electricity, studying and identifying the requirements and gaps between information required and information available as well as the format of information exchange between a fault measuring system and fault localizing will be input to projects when forming intelligent MV networks.
It is identified within this study, that there are benefits of operating the MV network with centralized logic, mainly in the area of fault handling and restoration possibilities.
The work is ongoing within the SGG project to solve system integration issues in order to form the desired self-healing network, where existing and modern equipment cooperates in a harmonious and feasible manner.

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