INTELLIGENCE FOR SMART GRIDS LAST MILE

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ABSTRACT

Power Distribution Networks have been operated in an easy and simple unidirectional way by now. Therefore no automatism even remote control technology was applied to Ring Main Units or Sectionalizer close to the last mile of the distribution network. Rising overall consumption, e-mobility, growing share of renewables, installed very close to the customers location, combined with market liberalization effects are changing the operational needs. A more comprehensive approach is necessary to operate Distribution Networks in an efficient and economic way. Smart Grid applies to the whole Power Supply chain and requires Grid Intelligence in the so far neither monitored nor automated Distribution Networks last mile.

INTRODUCTION

A huge share of the installed Power Distribution Networks are under threat either due to increasing rougher weather conditions which are destroying overhead lines or due to age 50+ infrastructures. With the widely spreading acceptance and demand for renewable power generation (DER - Decentralized Energy Resources) like Photovoltaic, wind power and biomass will feed into distribution and sub distribution networks directly. Former Consumers are evolving to become Pro-sumers and the Distribution Network is changing into a Multidirectional Network which requires new automatisms to balance production and load or even prevent overload situations and outages. Due to the very high quantity of Ring Main Units or Pole Top Switches the last mile(s) have been not monitored by now.

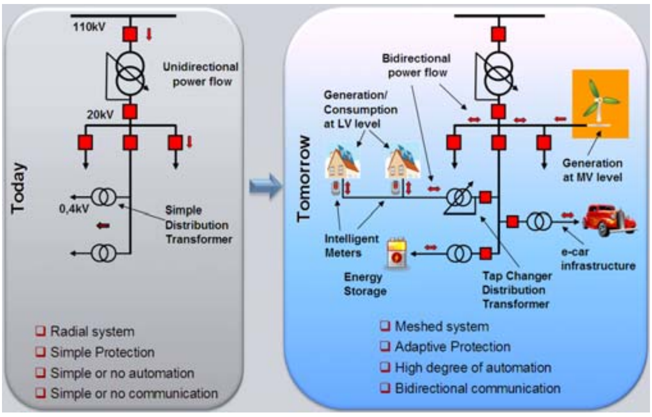

Figure 1: Network transition taking place today

VARIOUS DISTRIBUTION AUTOMATION APPLICATIONS

For sure the focus on the Distribution automation is and will be not the same in every country. Even between the utilities in one county the situation may be different depending e.g. on rural or urban area, but at the end of the day one will face similar challenges to be solved.

These topics are

- Prevention of outages to avoid losses of earnings and/or penalties
- Reduction of power losses both technical and non technical
- Maximized utilization of MV equipment (capacity utilization / life span)
- Low voltage stabilization to stay within tolerances e.g. EN50160
- Demand response or better modulation according to power production
- Asset management

Therefore an approach on Distribution Automation shall not target only one of the challenges, even this will be the reason to begin with, but stay open to cover the major aspects of all other applications.

REDUCTION OF OUTAGES

The reduction of outages is currently a topic in many countries. Two main aspects are in focus: first prevention of outages and second reduction of outage duration.
The real prevention is difficult if weather conditions like flooding or cyclones are the reason. But very often outages are caused by the electrical infrastructure itself. Invest cycles and strategies in the past have resulted in a situation which can be characterized as "infrastructure 50+", sometimes 70+.
Outage prevention in that case is very closely related to Asset Management and will be discussed there. For the reduction of the outage duration RTUs or Smart IED will help. In most of the networks there is no automation up to date. Therefore the workforce has to drive along the overhead lines or Ring Main Units to find the short circuit or earth fault. With installed fault passage indicators it's easier to see where the fault is, but it is still very time consuming. An often used improvement is the use of RTUs

to communicate the status of the fault passage indicators to a control centre. Now the maintenance group can go directly to the faulty section and isolate it. Typically for European Urban areas, this course of action reduces the outage duration by nearly 50% as an average. Next level automation using RTU and spring loaded or motor driven load breakers can bring the outage duration down to minutes.

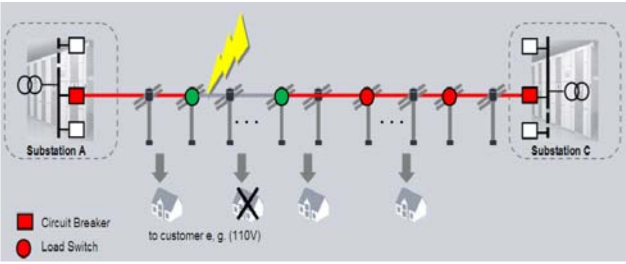

Figure 2: Principle of Fault Isolation Service Restoration

Loop automation using sectionalizer and recloser is a very common solution e.g. in the USA today. This is useful but stresses the equipment by determining the faulty section switching on and off with the short circuit load several times.
It is anticipated using Smart IEDs with combined Protection and RTU functionality will be next level automation. Using network communication on Broadband power line or WiMAX, IEC61850 will help to bring down outage times to a minimum.

With a line protection functionality the fault can be located once it occurs and hence can be tripped in milliseconds. Based on the IEC61850 communication standard every Smart IED knows the overall situation in the loop and can act to reconfigure automatically. Based on load situation and available back-up strategies the Smart IEDs can isolate the fault and close a loop or restore services by using an alternative feeder depending on the distribution network's configuration.

Fully automated and in a minimum of time fault is isolated without any effect on the consumers before the faulty medium voltage section and with the quickest restoration of services on the other side of the faulty section. The typical time to trip is shorter than half a second and restoration should be possible within a minute depending on the primary equipment e.g. type of recloser.

In every case, the outage time to be reported to the authorities or network regulator must not be reached for any consumer which is not directly connected to the faulty section. This will guarantee a minimum of losses in earnings and reduce penalties as much as possible.

NEED OF "NEW" PROTECTION SCHEMES

In a radial network the load situation is normally very clear. The line infeed by a substation supplies the electrical power to consumers down stream. Therefore the load situation is distinguishable and easy to differentiate from a fault situation. With the installation of distributed power generation like wind generators, solar panels or bio mass the load supplied by the substation is reduced and a short circuit or earth fault can be powered by distributed renewables as well.
Today's used fault passage indicators are not able to handle such situations well and traditional over-current protection relays can't clearly operate.
One solution to handle the bidirectional power flow is to use directional over-current protection functionality with adaptive coordinated parameter settings. But trails show that the definition of suitable parameters can not be derived on existing ones or done automatically. The load situation caused by the power producers has to be measured and taken into account by the algorithm. Up to now the handling seems to be very complex.
The use of a line protection relay simplifies the fault detection by concentrating on the cable or overhead lines condition, itself. A very high selectivity and thereby a precise fault location is the result and helps to reduce the fault clearance time after service restoration. One has to keep in mind that typically more than 80% of the outages are caused by the medium voltage distribution network. So focusing on the MV-Distribution network and using communication to verify infeed and output of Distribution networks sections a very selective protection system can be applied. For the communication a networking ability is required so that the Smart IED is able to send information to both neighbour stations in minimum. Using the data of the next stations each Smart IED is able to calculate the losses on the power line between them. This enables the Smart IED to detect earth faults and short circuits on the monitored section. But the use of network based communication and the IEC 61850 can do more. Every Smart IED in the network has all necessary information of the network switch position. With preconfigured algorithms the Smart IED will automatically reconfigure the network in case of a fault. By that, a service restoration is carried out within seconds.
The real restoration time is manly depending on the switches used in the secondary stations. With circuit breakers the reconfiguration can be done directly. Using load switches an interims step is necessary to open and close the line feeder in the primary station while reconfiguration. In any case, the tolerances given by the authorities will be undercut. Therefore a Smart IED with line protection functionality using IEC61850 helps to reduce outage effects by a determined and fast fault location and isolation and services restoration.

REDUCTION OF LOSSES AND MAXIMIZED UTILIZATION OF EQUIPMENT

Long overhead lines and cable network have technical losses due to asymmetric load mainly. Smart IEDs can help to optimize the cos φ as a cap bank controller directly and can record load curves for future planning in addition. New consumer or distributed power generation can be connected to the network to optimize the load situation and the utilization of the existing equipment.

The know-how of low and high demand times of the daily or monthly reports helps to recognize the load and especially overload situations. Transformers are able to be used in overload situations but depending on temperature and duration this can effect live time or end directly in an outage. Smart IEDs with its integrated automatic transformer monitoring and protection will prevent transformers form being damaged by overloads, supply data for controlled overload situations and give the asset management a clear report of exceptional usage.

Maintenance strategies and condition monitoring help to replace transformers before they cause long time outage. In addition they form the base to use MV distribution networks in controlled overload situations.

LOW VOLTAGE STABILIZATION AND POWER QUALITY

The availability of cost efficient Photo Voltaic (PV) solar panels and government programs, to roll out this technology for green power production, boosts decentralized power generation. Some countries are facing a similar situation with wind power generation in wind parks and up-coming micro wind turbines on poles or directly mounted on house roofs.

The volatile production brings some problems into the LV distribution network and at the same time the Power Quality norms have narrowed the tolerances e.g. EN50160 in Europe.

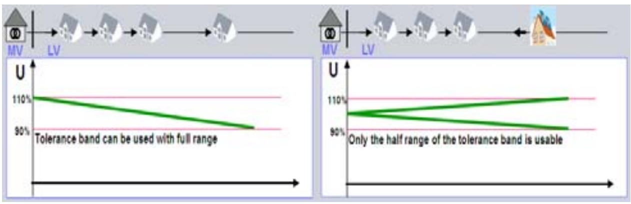

Figure 3: Tolerance band use alteration by renewables

Currently two strategies apply to handle the situation:

① The use of distribution transformers with tap changer
② The use of controllable photo voltaic inverters.

Depending on the individual type of power producers both techniques help to optimize the network infeed by keeping network effects under control.

Up to day distribution transformer are simplified cost driven but unable to support the new situation with decentralized power production. New types of distribution transformers offer electronically supported tap changer for uninterrupted tap changer control. Today's concepts are using 93%, 100% and 107% of nominal voltage as taps. A special tap changer controller is smoothing the effects, so consumers will not notice tap changing by flicker and end users' electronic equipment will not be affected.

For a Smart IED knows the current network and load situation well, it can operate tap changer control and transformer monitoring as an integrated solution. Additionally the Smart IED can support the second strategy to control PV-inverters as a LV network master at the same time.

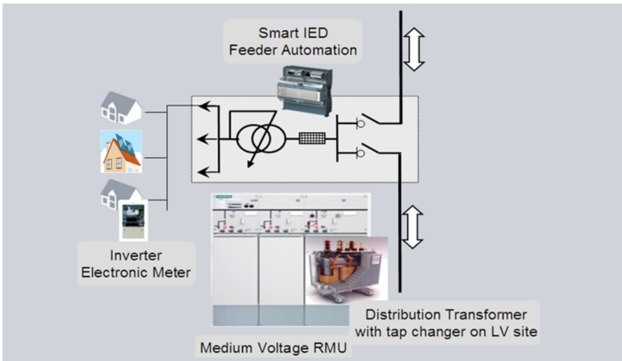

Figure 4: Components to optimize Power Quality even Low Voltage and Medium Voltage

The advantage of using PV-inverters to stabilize the LV network is the ability to control active and reactive power since they do not need to operate at unity power factor. This applies also to for medium voltage distribution with large PV generation to take over some of the voltage regulating tasks from capacitor banks.

Both applications allow in typical cases to handle 25% more load on the primary equipment. In this way new invest in cable or overhead lines can be avoided or prolonged and save money thereby. It goes without saying that over voltage and under voltage effects will be controlled at the same time. The PV inverters main advantage is to solve the problem directly at the source. PV converters measure their infeed and can control it. For a whole LV network simply a master is needed to coordinate all connected inverters.

A Smart IED with its existing capabilities is predestined to be used. All necessary measured values of the network can be sampled by using IEC61850 protocol from distributed sensors or even better directly from inverters or electronic meters.

COMMUNICATION INTERFACES

As a world wide standard in utilities communication the IEC61850 shall be used.
The use in the medium voltage distribution for protection relays and for Smart IEDs is by now well-established. It is anticipated that an extended use into low voltage based on the same data type framework is applicable.
Currently, the members of the IEC working group 17 are framing out application scenarios for feeder automation, taking into consideration applications for low-voltage integration in the automation schemes. The goal is, to verify the feasibility of existing logical notes and define logical nodes, when necessary, in a certain time.

For the communication network a narrowband power line carrier can be used as appropriate for today's automatic meter reading. Alternatively wireless communication systems can be used. Very common today are MAS Radio systems (UMTS; GPRS) and utility owned cell towers. An upcoming chance for new communication strategies will be WiMAX and broadband power line to interconnect areas with low voltage and medium voltage distribution. WiMAX is currently in a more experimental stadium while broadband power line carrier (BPLC) can be transferred easily from techniques used in power transmission. Easier coupling systems and amplifier with lower transmitting power allow low-cost, real-time connections across the distribution system for medium and low voltage.

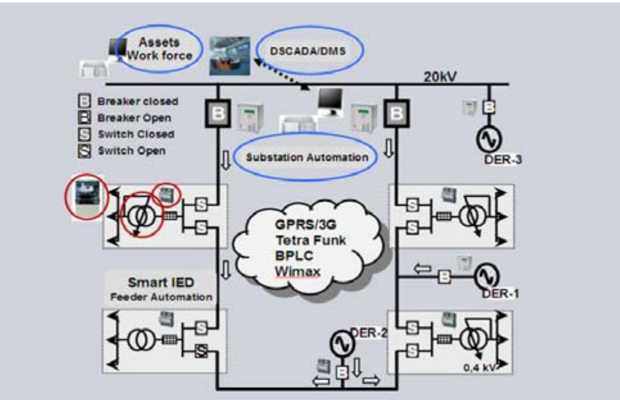

Figure 5: Distribution Network Communication:
Medium Voltage – Low Voltage

DEMAND RESPONSE

Today's Demand Response (DR) is a mechanism to manage customer consumption in response to supply conditions, which means, having customers reduce their consumption at critical times e.g. by load shedding. In Smart grids this paradigm will change into consume energy when available. To use all the energy which solar or wind power can supply, electrical load has to follow generation as much as possible. Smart IEDs in the ring main units can control Consumers e.g. cold storage houses to use available electricity to go further down in temperature to avoid a need of cooling in the next high demand or low generation period.
Based on coevally recorded load profiles the forecast of future demand will improve and allow a really cost-optimized energy purchasing.
With in the future feasible electricity storages in low-voltage networks or installed in ring main units a Smart IED can control them directly, based on actual demand, forecast and energy efficiency algorithms.
Hence e-cars are rolled out, loading schemes can be provided by the Smart IED to prevent overload situations in the low voltage network.
Furthermore, home energy management (HEM) and Building energy management systems (BEM) could get their input, in the future by the Smart IED, as a master of the low voltage network section and part of the medium voltage distribution network. Moreover, Smart IEDs used in such a structure will enable the use of micro grids as well.

ASSET MANAGEMENT

With available communication and the data Smart IEDs are working with, an improvement for the asset management goes along.
Due to the lack of online data up to now, asset management strategies bank on power distribution equipments installation date and vendor's specification even many of the installed equipment has reached or exceeded lifespan.
Additional information is provided by maintenance reports of utilities' own working force describing conditions e.g. of breakers or cables. By the frequency of faults on specific parts one can deduce the condition of other equipment of the same type.
Missing but valuable information for condition monitoring are live values, like trips or overload situations to be considered in refurbishment programs. Based on these additional information provided by a Smart IED and collected in an asset management data ware house, these process data will give the management clear indications refurbishment plans can be based on.
Knowing the precise details of utilities technical assets enables to apply efficient services – and offer the possibility of predictive maintenance the network really do need. This kind of precision comes with an asset management software support for installed-base and management processes that enable one to serialize, identify, and track assets over their complete life cycle.
And a well timed refurbishment keeps maintenance cost at bay and prevents outages.

CONCLUSION

Distribution Automation technologies are commercially available for wide scale utility deployment. Applications which may have greatest potential on the economic scale are operations and efficiency, Management of peak loads, predictive maintenance and system restoration technologies. But Distribution Networks are as manifold as the times and the technology available when they have been erected. This challenges today‘s technology to cope with a variety of existing equipment applying cost efficient solutions for sensors, actuators and especially communication to meet today’s and tomorrows needs. And it changes the traditional Remote Terminal Unit into Smart IEDs with local network management competence.

Smart IEDs are the answer for today’s needs and applicable for tomorrows requirements. With smart sensor interfaces they can integrate nearly every existing medium voltage and low voltage installation. Smart actuators are able to upgrade the majority of medium voltage switches to be operated from remote even they are designed to be operated by a handle. Communication capabilities based on IEC60870-4-104 or IEC61850, peer-to-peer to other Smart IEDs, to remote sensors and PV-controllers or e-car charging stations provides the necessary grid intelligence to manage the LV-Grid or Micro Grid in a professional way.

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