

Technology that is Shaping Smart Grid in Distribution Networks

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Abstract - This paper discusses the recent developments in the field of medium voltage distribution equipment and their implementation of new technologies that are driving Smart Grid applications. The utility industry today is challenged to improve power quality, availability, reliability and economics in order to avoid costly interruptions of service to all levels of customers and these technologies are critical to their success.

Recloser technology has evolved beyond the typical substation circuit breaker and its protection system. It is a multifunctional all-in-one fault clearing system with expanded interrupting capabilities and complex protection and control logic. It is integrated with SCADA and digital communications with a reduced footprint and cost compared to traditional substation installations.

Index Terms— Smart grid, recloser, testing, reliability, distribution, IEC 61850.

I. INTRODUCTION

It has been recognized in every country that economic growth is heavily dependent upon the reliable delivery of electricity to the customer, whether that is a bulk industrial, commercial, or residential customer. Further, efficiently using every source of generation including "green" sources has become a mandate of many countries.

The utility industry today is challenged to improve power quality, availability, reliability and economics in order to avoid costly interruptions of service to all levels of customers. In the USA this started in the 1960's shortly after the electric grid infrastructure build out came to the point of interconnecting most of the power delivery systems. It was realized that reliability would be increased if an operations center were monitoring and controlling the distribution network, the term Distribution Automation was coined to describe that goal.

Many utilities installed SCADA systems so their operations center could evaluate the status of the distribution substation and attempt restoration of the faulted circuits. However it was quickly realized that more detailed monitoring was needed and increased abilities to sectionalize circuit faults were required. Sectionalizers and Reclosers with control and communications were developed for this task but they too were limited by the technology available at that time. (Duquesne Light implemented a 23kV DA system starting in 1974 consisting of 300 sectionalizers & reclosers.) The scope and scale of these systems were cost justified but not easy to implement and doubts remained as to their reliability.

Around this time the energy crisis of 1973 and 1979 refocused the industry to Demand Side Management

(DSM) which looked to control the end customer by focusing on how and when they used electricity. DSM systems (meters with communications and some controls) were installed in order to give localized control centers the ability to monitor and issue control over certain customer equipment to bring supply and demand into balance. This would save investing in new generation and economic incentives were provided to the customer to allow this to happen when needed. The 1980's saw an explosion of activity to install these systems as they became better understood and marketed. However, this technology didn't address the original problem of fault isolation and system reconfiguration. Hence, reliability still suffered.

The 1990's brought a focus on power quality concerns, mainly voltage sags, swells or unbalanced conditions that occurred when there was a short circuit fault in the distribution system or unwanted harmonics from your neighbor. Again, the ability to monitor and detect such conditions drove many of the design and operational considerations in the distribution network. The idea was to identify the power quality issues and correct them increasing customer satisfaction and reliability. To a large extent this resulted in the realization that again the ability to quickly and properly isolate the faulted portion of the distribution system would do the most good. Identifying harmonic sources like poor grounding or improperly isolated industrial machinery only went so far with a customer without power. If the distribution circuit was switched off, there was not much power quality to argue about.

In 2005 the term "Smart Grid" was coined to describe the effort to "intelligently operate the transmission and distribution network and integrate the growing sector of Distributed Energy Resources (DER) to the power grid". It was envisioned that all of the past concepts could be brought together to create this automated intelligent power grid. However, again the fundamental operational problems remained. Fortunately, there had been a convergence of sorts taking place before this "Smart Grid" was conceived; a growing renaissance to solve the issues of the distribution system operations in an economic way that would actually define many of the Smart Grid applications.

The realization now is that we do not have to conform to the "that's the way we have always done it" mentality and we can actually make vast improvements to the design and flexible operation of a power system.

The technologies that are leading this renaissance are seen in use everyday – the primary one being the evolution of the microprocessor. But there are many

industries that have contributed: communications, materials science, physics, power electronics, etc.

- Digital communications have revolutionized our internet, cell phones, and TV.
- Modern digital multifunction protection and control relays are widely accepted in utilities.
- Development of new materials and interrupting technology reduces apparatus size.
- New sensor technology is smaller and more accurate.
- New industry standards allow for integrating data and devices as systems at all levels.
- Distributed generation being deployed can be an advantage for reliability.

One problem the 100+ year old utility industry has suffered from was the traditional view of how the grid is designed to operate instead of how it could operate.

II. HOW TO IMPROVE POWER QUALITY

The prolonged effect of short circuit faults on sensitive equipment supplied by distribution feeders can lead to their failure and significant losses. This is pushing the requirements for the performance of distribution protection systems and making them similar to transmission protection systems requirements.

The improvement of power quality during short circuit faults can be achieved in several different ways. Like any other problem that has to be solved, we need first to understand the nature of the problem and its effect on sensitive users. The most common short circuit faults in the system – single-phase to ground faults – are characterized by the fact that they introduce a voltage sag in the faulted phase, and at the same time they result in a voltage swell in the two healthy phases. This is clearly seen in Figure 1 that shows the recorded waveform and the voltage phasor diagram for a single-phase to ground fault.

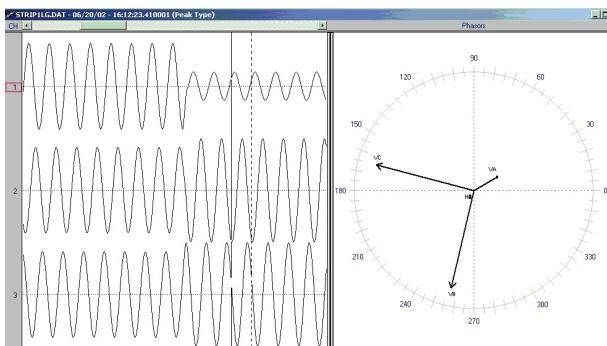


Fig. 1 Phase voltages for a single-phase-to-ground fault (Phase A)

The case of two or three-phase faults is quite different. For three-phase faults all phases experience a voltage sag, while for a two-phase fault - the two faulted phases will have lower voltages, with the healthy phase without a significant change compared to the pre-fault levels.

Fig. 2 shows a plot of depth vs. duration of actual cases from a high-volume manufacturing plant, with some of them resulting in process shutdown due to variable speed drives and vacuum pumps failures.

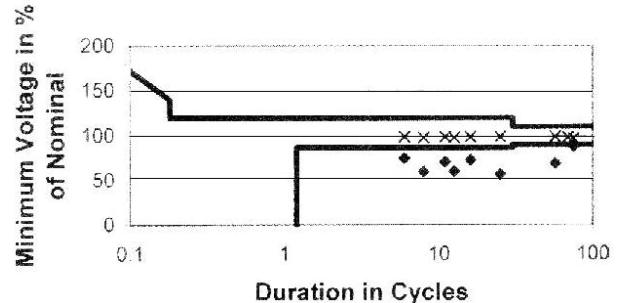


Fig. 2 ITI (CBEMA) curve from a manufacturing plant

There are several factors that determine the voltage level during a short circuit fault on the transmission or distribution system:

- System configuration
- Fault location
- Fault resistance

The first characteristic of voltage sag – the depth – is something that we can't control, but we have to study in order to be able to predict or estimate the effects of different faults on the sensitive equipment.

The second characteristic of the voltage sag – the duration – is the parameter that we can control by properly applying the advanced features of a state-of-the-art distribution automation system using modern reclosers and sectionalizers with digital protection and communications. Using the industry standard IEC 61850 and especially the use of GOOSE messages in distributed protection schemes can reduce the fault clearing time of these distribution systems.

III. RECLOSERS

Reclosers have evolved into multifunctional fault clearing systems. They contain all of the components of a traditional substation fault clearing system but within an optimized foot print that can be mounted on a single distribution pole. Further, the interrupter of these systems can be operated as independent pole or ganged 3-pole operator depending on the system conditions and configuration requirements. Each reclose operation can be adapted in both protection element and setting applied and even change logic based on evolving fault conditions. One system can even "test" the line segment for a persistent fault by applying a reduced current pulse to the line and measure the response. This enables the recloser to limit the damage to connected equipment and system apparatus and only reclose when the fault has been removed.

They contain state of the art digital protection and control relays coupled with flexible communication options for SCADA and distributed protection

functions. Recent advances have increased their system ratings to match and even exceed traditional circuit breakers installed in a substation, up to 38kV and 20kAIC. In fact, most easily exceed the duty cycle of traditional CB's and do not require maintenance until accumulating upwards of 20,000 C-O operations. These recloser systems are also a fraction of the installed cost of their traditional equivalents. This is the reason they are now being provided in all form factors for use in overhead, pad mount, vault, and traditional substation applications.

These technological advances and all-in-one packaging allows for easier design and engineering of a distribution network that can be operated in a highly efficient and flexible way. In fact this technology is key to making the distribution part of a Smart Grid a reality.

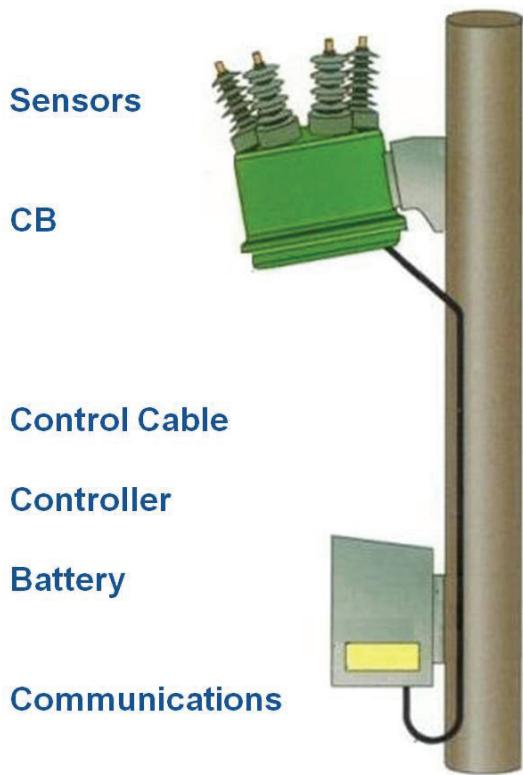


Fig.3 Recloser System

IV. DISTRIBUTED PROTECTION APPLICATIONS

Peer-to-peer communications are used to perform protection, control, monitoring and recording functions. Any function can be divided into sub-functions and functional elements. The functional elements are the smallest parts of a function that can exchange data. These functional elements in IEC 61850 are called Logical Nodes. When a function is executed based on the exchange of messages between two or more devices, it is called a “distributed function”.

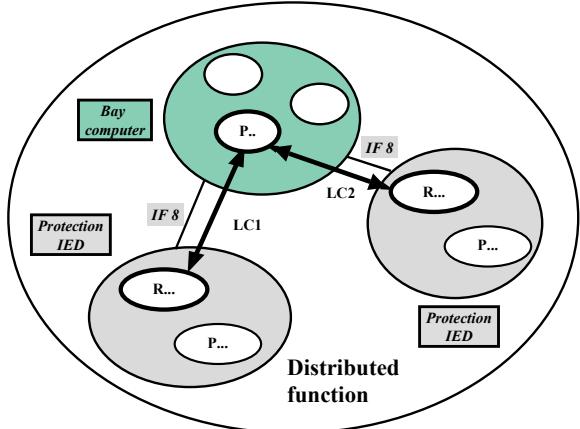


Fig. 4 Distributed Function definition in IEC 61850

The exchange of data is not only between functional elements, but also between different levels of the substation functional hierarchy. It should be kept in mind that functions at different levels of the functional hierarchy can be located in the same physical device, and at the same time different physical devices can be exchanging data at the same functional level. (Figure 5)

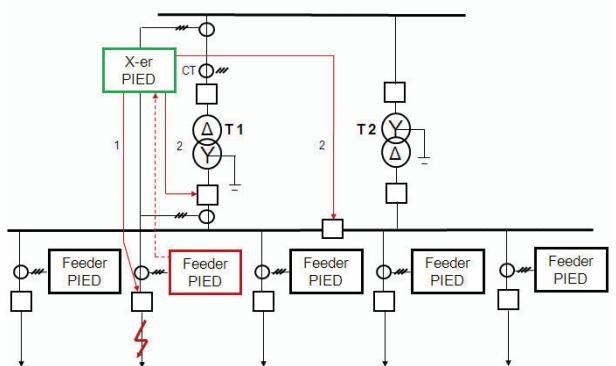


Fig. 5 Selective backup protection demonstrating distributed protection

Figure 4 shows Logical Connections (LC) - the communication links between functional elements - in this case logical nodes of the P and R groups. IEC 61850 also defines interfaces that may use dedicated or shared physical connections - the communication links between physical devices. IEC 61850 is being extended for Wide Area Network (WAN) applications to facilitate GOOSE data and interlocking messages for transmission protection systems and wide area protection schemes. At the same time, it is being applied to distributed generation applications of wind, solar, and hydro generation. It is only natural that it would also extend into the distribution automation network applications.

The allocation of functions between different physical devices defines the requirements for the physical interfaces, and these can be extended into the distribution feeder network to reclosers and sectionalizers using fiber, digital radio, carrier, or microwave. (It would even be possible to use dedicated

WiFi or GSM spectrum in some areas.) All of the communication technologies easily support TCP/IP and can function as either dedicated or shared resources. The shared interlocking and even data exchange using GOOSE can provide fast fault isolation and reduce service interruptions. Advanced logic and algorithms for restoration schemes can be easily implemented when secure and fast communications between these devices are implemented.

V. COORDINATED SCADA AND PROTECTION

The protection and control in substations is distributed in nature by the fact that each protective relay is designed in general to provide primary protection of individual substation equipment such as distribution lines, transformers, capacitor banks, etc. Extending this distributed protection to the distribution feeder network was limited in the past because of restrictions in secure communications.

Today the wide spread deployment of digital communications technology has allowed a once crowded frequency spectrum to be re-allocated and provide expanded access to more licensed "digital spectrum" for critical infrastructure applications. Utilities can now take advantage of this and provide secure data and control links from the substation to the distribution network.

The ability to provide both monitoring data and control interlocking in both directions opens the door for integrating SCADA and Protection requirements within the network. Now, the ability to both know where problems occur and optimize the network reconfiguration in near real time, a utility can provide the level of reliability and availability demanded by the customer.

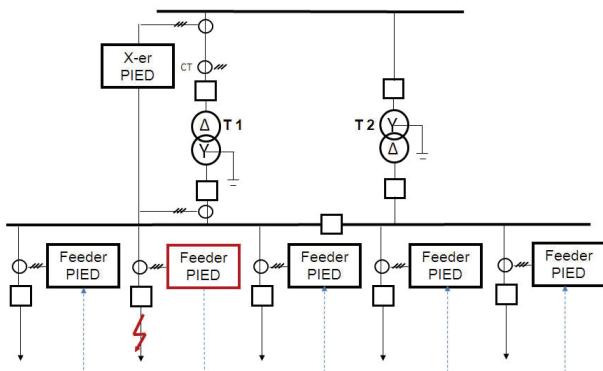


Fig. 6 Traditional sympathetic trip protection

Where broad fall back schemes were implemented at the substation level to preserve the network during certain system events (like a sympathetic trip logic scheme) a more defined response can be applied. Instead of blocking, delaying, or adjusting the protection's sensitivity on adjacent feeders, the networked SCADA and Protection system can know precisely the load condition, fault type and network configuration, and use a scheme to isolate the faulted segment with minimum impact to the overall network.

This could include single phase tripping, active VAR control, and network reconfiguration to minimize any inrush condition. But this can also be applied to restoration schemes and not just fault scenarios.

VI. STRATEGIC RECLOSER DEPLOYMENT

In the past, a dedicated control point was required for a Demand Side Management system for each piece of equipment that the local Operations Center wanted to control. This limited the total number of devices that could be part of the system and as distribution systems grew, keeping up with the rebalancing was difficult. However with the Smart Grid technologies this can become a distributed control function. Using the modern Recloser as both a circuit sectionalizer and a remote SCADA control – the DSM function could be better served locally and with more intelligence. Given a scenario of a willing commercial or industrial customer, a dedicated recloser could monitor and control the demand usage of the customer keeping the integrity of the source network a priority.

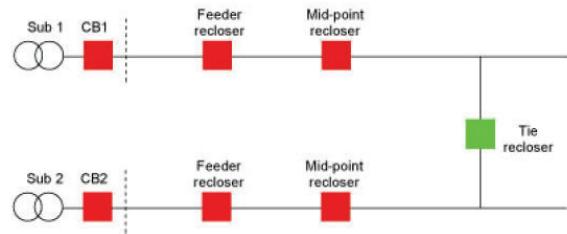


Fig. 7 Recloser Deployment in Loop Scheme

This could be reversed and viewed from the point of a distributed generation source which ties into the distribution network - where security and uptime should be maximized. The ability to have key operational status from other network reclosers and the local substation / operations center in near real time provides both utility and distributed generation customer the most flexible options. In the past, having a distributed generation source support an islanded distribution network would be a dangerous proposition. But with proper two way communications these scenarios would be operationally possible. Modern reclosers are utilizing improved sensor technology that allows bi-directional operation and protection. Accurate synch check is a normal function and even active synchronizing is a real possibility and even critical for a self-healing system.

VII. FUNCTIONAL TESTING OF RECLOSER SYSTEMS

Since the recloser has evolved into a complex fault clearing system it is necessary to approach testing with the same tools being used in substation protection systems. In fact, some recloser operational logic is more complex than a typical substation protection scheme. It is therefore necessary that the test set used be able to provide the correct system simulation waveforms and control signals as found in the control cable interface of the recloser controller. (Figure 8)

By the same token, the ability to test the switch or interrupter requires being able to provide the properly simulated control signals and measuring the operational open / close sequences. Detection of misaligned or slow operations is critical for proper maintenance of the switch/interrupter system.

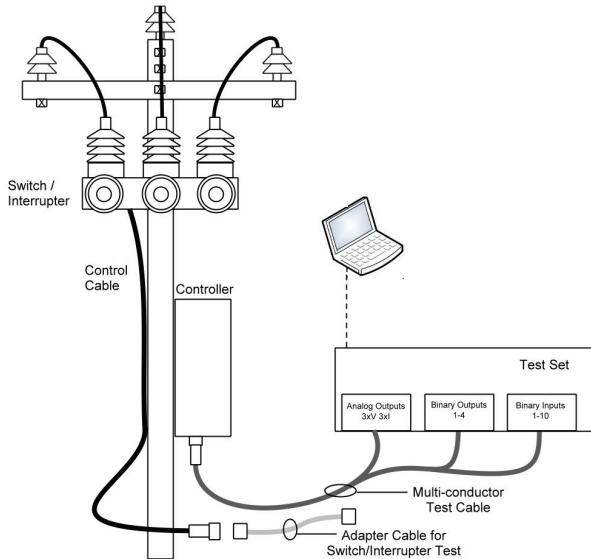


Fig. 8 Typical Recloser Controller Under Test

The ability to perform synchronized testing of multiple reclosers that are part of a loop scheme or automation network is a new but necessary requirement to prove that field installations work as designed and do not suffer from interference, bandwidth issues, or other geographical communication problems when the systems are commissioned.

The testing of distributed protection functions can be facilitated if they are based on IEC 61850 GOOSE. The main difference is that in this case the test set needs to be able to act as IEC 61850 remote device(s), i.e. to be able to publish and subscribe to GOOSE messages in the network. Figure 9 shows a block diagram of typical SW tools for effective test development.

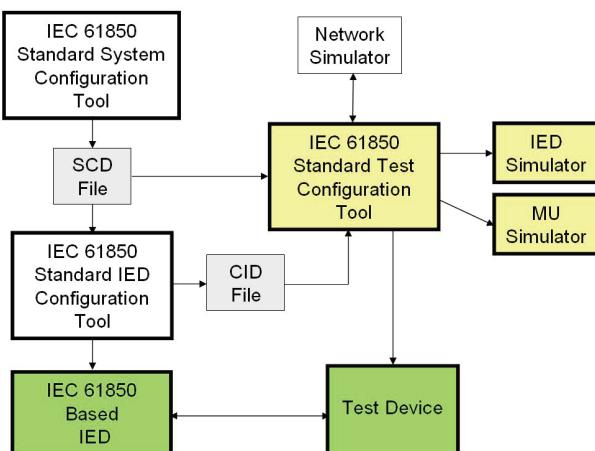


Fig. 9 Test system/configuration tool, simplified block diagram

For all practical considerations the procedures and processes used for testing a communication based transmission protection scheme can be directly extended to the networked distribution automation protection and control scheme. As such, training of test personnel is a critical success factor for implementing Smart Grid applications and testing protocols within a utility.

VIII. CONCLUSIONS

This paper discusses the developments in the field of medium voltage distribution equipment and their implementation of new technologies that are driving Smart Grid applications. The utility industry today is challenged to improve power quality, availability, reliability and economics in order to avoid costly interruptions of service to all levels of customers.

Recloser technology has evolved beyond the typical substation circuit breaker and its protection system. It is a multifunctional all-in-one fault clearing system with expanded interrupting capabilities and complex protection and control logic. It is integrated with SCADA and digital communications with a reduced footprint and cost compared to traditional substation installations.

Reclosers can now be applied in many configurations such as pad mount, vault, overhead, and even substation structures. They are gaining rapid acceptance and are key to making a Smart Grid system work. Testing these systems is as involved as wide area protection schemes or communication based transmission protection. As such they require test sets capable of testing this new technology and require more training than ever before.

IX. REFERENCES

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Benton Vandiver III received his BSEE from the University of Houston in 1979.

He was with Houston Lighting & Power for 15 years and Multilin Corp. for 4 years before joining OMICRON electronics where he is currently Technical Director in

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