SMART DISTRIBUTION THROUGH LAYERED INTELLIGENCE FOR NEXT GENERATION SELF-HEALING DISTRIBUTION NETWORKS

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ABSTRACT

This paper describes the benefits of layered intelligence between an Integrated Distribution Management System (IDMS) platform and Distribution Automation (DA) range of automated feeder switches and fault interrupting devices. The IDMS is capable of aggregating all local and central intelligence, whilst DA devices are able to actively manage and correct for faults in the field. The integrated solution combines rapid, real-time response to system conditions using distributed intelligence, small-area optimization using regional area controls, and overall system level view and wide-area optimization from enterprise-level applications. This represents a significant step forward for the industry, because it is a truly integrated solution - not just an interoperable solution - enhancing operator usability and situational awareness. By providing an integrated solution, utilities are now able to deploy smart grid technologies with confidence that the true value of these technologies is being capitalized to enhance end use customer satisfaction from improved grid reliability.

INTRODUCTION

The introduction of Smart Grid has led electric distribution utilities to steadily increase the deployment of smart field devices on distribution feeders to improve service reliability and to optimize the distribution grid for efficiency. Some of these deployments are still in early pilot stages, whilst others are in full roll-out after thorough justification of the electric distribution utility business. As the individual capabilities of these DA devices expand, there is a corresponding increase in data flow and two-way communications exchange between devices and the central control system (IDMS). While there is potential for the control room operators to be overwhelmed by this data storm, this also presents an opportunity to enhance situational awareness by presenting only useful and actionable information. In parallel, utilities are also deploying advanced grid optimization and management solutions in their control rooms to better manage their distribution assets in real-time, for both typical "blue-sky" days and also during major storms with significant outages.

To manage the complexity from the introduction of these new technologies, active collaboration is underway between suppliers and electric distribution utilities to offer an integrated system of layered intelligence. This collaboration has led to the development of new management strategies, operational practices, and software technologies.

The growth in Distributed Energy Resources (DER), including distributed generation (solar photo-voltaic, et al.), community energy storage (batteries), electric vehicle charging, and demand response has also accelerated the challenge facing electric distribution utilities, leading to the need for providing enhanced distribution response to dynamic field conditions as well as improved visibility for the control room operators.

A reasonable approach to dealing with an increasingly dynamic distribution system is to employ local logic in individual devices to sense and react to the grid at their location, a regional area of control that takes a larger system view of the local area, such as a substation or group of substations or feeders, and also have a large central control system that has a view of the entire distribution system for wide-area optimization and control. Then, tie these layers of intelligence together so that a command or policy issued at any higher level will properly filter down to the end field devices, which ultimately take action. There is more granularity of control with each step closer to the field devices.

Essentially, it's using the right solution for the right job, by putting the appropriate level of intelligence and decision-making capability at different levels in the distribution system. The following sections of this paper will describe the different intelligence layers being deployed in the Smart Distribution grid, and the proposed integration of these layers to create a layered intelligence approach for grid self-healing, and there has been some effort in implementing this intelligence from a hardware/devices perspective using IEC standards [1].

LOCAL INTELLIGENCE

A starting point is the local intelligence at the individual device level. A local control is fully autonomous and performs switching or other functions without relying on communication to other devices or a master station. The local control is fully dedicated to the task at hand and is directly connected to all necessary sensors and switching devices.

One good example is a fault-interrupting overcurrent protection device. Overcurrent protection in modern devices is a function of local sensing of voltages and currents, processing and decision-making by the local control, and action taken by the switching device. This is a time-critical function to remove short-circuits from the distribution lines to prevent damage to the power system equipment. It requires immediate response to local conditions, with elapsed time from initiation of the fault event to the opening of interrupter contacts frequently in the range of a fraction of a second. Local logic is the only sensible way to react to an overcurrent condition, due to the immediate reaction required. No relay or protection engineer would agree to taking this local logic for overcurrent protection and putting it in a remote location, regardless of the expected speed and reliability of the communication system.

The value of local intelligence should not be minimized. These intelligent devices out on the distribution feeders are the enablers of other intelligent systems and are the devices that ultimately perform the actions requested by other systems. When communication links are lost, or a larger system is not available for any reason, it is the local intelligence in the field devices that keep the system running. As previously stated, fault interrupters rely on current and voltage sensing to perform their primary function of interrupting faults. Modern devices use advanced sensor technologies to integrate metering class accuracy sensors into the switch hardware, yielding accuracies in the range of ±0.5% current and voltage measurements. High accuracy enables more precise control at the local device level. This measurement data is also reported over SCADA for use in IDMS load flow and state estimation calculations, and can also feed into higher level central or regional-based control systems such as a Volt/VAR optimization system. Oscillographic data and event logs are recorded in local memory for later viewing and help the utility understand what happened and how the system responded to an event.

DISTRIBUTED INTELLIGENCE

When two or more intelligent field devices are linked together by communications, it creates a more powerful "system" that increases the functionality and benefits of the system. Distributed control is achieved with peer devices that work together to meet a common performance objective, while also accommodating the objectives of the local control. Each device is fully equipped with local intelligence such as sensing capabilities and perhaps overcurrent protection, and an additional software application based on a distributed intelligence architecture is loaded on the controls to add more capabilities.

For example, two switching or fault-interrupting devices can communicate directly with each other to create an automatic source-transfer system. This "system" will use one feeder as the normal source of power for customers served between the switches, and then quickly switch to the alternate feeder if the primary source is lost. Even this most basic restoration system is an example of how distributed intelligence can create teams of devices that work together in a coordinated fashion to solve problems in a defined geographic area.

Distributed intelligence for automatic restoration systems can be scaled to cover a much larger area, with any number of sources, mid-line switching points, and normally-open tie points between adjacent feeders in a single contiguous deployment. The switching controls sense local conditions and communicate to other devices nearby, preferably through direct peer-to-peer communications. This allows for very fast reaction to events on the system.

As mentioned in the introductory section, the great variety of complexities that are emerging in the distribution system will highlight the benefits of having distributed intelligence that can process local information, remedy the problem as much as possible, and report the new conditions to the dispatchers in the central office.

REGIONAL INTELLIGENCE

The next layer of intelligence can be called a regional control or regional intelligence. This is a software system that is used for remote monitoring and management of field devices, and depending on the application it may also have grid control capabilities. It is much more than a data concentrator.

A regional controller aggregates the impact of the underlying field devices to satisfy regional objectives while accommodating lower level local objectives. Depending on the application, control preference may be given to either regional or local level objectives. An example would be a software system that monitors a group of hundreds of field devices that perform overcurrent protection and automatic restoration. For enhanced functionality, this field device management system should have direct communication access to each of the field devices under its jurisdiction. This facilitates gathering the usual information such as open/close status, voltages, and currents… but, importantly, it can offer enhanced data acquisition by gathering event logs, waveform captures, and settings files from the field devices that contain a wealth of information. It is not useful to expose everything in a control for SCADA operators, since they are not usually looking at the detailed event files. But, having a system automatically gather and collate the appropriate information for the engineers and technicians that do need to access the details for investigation saves time. It is possible to rely on the regional management system to determine the settings and firmware version installed in a fleet of field devices, saving monotonous engineering and technician time.

There is another category of information that is very useful to the personnel in the control centre that is generally not available today. Dashboards of field device operational performance, both in real-time and historical, can help control centre, engineering, and operational personnel. Examples of useful information would be how many times any individual device has operated over the most recent 24 hours, how many times a device has experienced communication loss in the past week, or how many times an overcurrent protection element has picked up on a device but has not resulted in a trip over the past year. This information helps utilities troubleshoot an immediate event on the system, but can also be used to identify long-term problematic areas.

Finally, a third category of information that can be created at this regional level is performance metrics for the devices and systems employed on the distribution system. Many utilities install advanced protection devices and distribution automation systems, but do not have a method for automatically monitoring their performance. An automatic system that aggregates the number and types of operations of field devices is the first step. Next, converting the switching actions or other behaviour of field devices into economic or operational benefits to the utility and its customers provides an on-going economic justification index for continued investments in the distribution system.

CENTRAL INTELLIGENCE

All of these other layers of intelligent control roll up under a central control system that has a view of the overall distribution system. Central intelligence integrates the other layers of control with enterprise-wide performance objectives. The goals of the central control system are not limited to the operation of physical devices. Decisions are driven by a broad set of information regarding system operation, including real-time financial incentives, weather forecasts, and high-level resource constraints such as capacity limitations or expected generation shortages. Central intelligence does not need to analyse the entire controlled system, but rather relies on underlying regional, distributed, and local controllers to achieve the lower level objectives.

The IDMS often has an interface to other large-scale central systems such as an Energy Management System. The IDMS is scalable to cover the entire distribution service territory, and can provide large-scale optimization functions. The IDMS runs power flows and state estimation to quantify present conditions and estimate future conditions. Outside factors such as weather patterns, real-time energy pricing, and generation capacity or shortages can be part of the decision-making process.

The IDMS is in the ideal position to take in all these outside factors and issue policies to the next level of control systems, which leads us to the concept of integrating these various levels of intelligence into an integrated or layered system.

LAYERED INTELLIGENCE

A Chief Executive Officer of a company can lead the way, but he or she needs to have a group of dependable managers that can carry out the various missions. And in turn, each of the group of managers needs to have capable employees to actually do the daily functions by applying their own creativity and decision-making within the context of the guidance given to them by leadership. This is a simplistic view of an organization, but the concept of layers of intelligence on the distribution system follows a similar structure. The goal is to put the appropriate level of decision-making and action at each level in the organization.

On the distribution system, the benefits of this are speed of action, less reliance on long-distance communications networks, and the ability to pare down the amount of data to be communicated and processed by any single component of the overall system. An example of layered intelligence is the integrated system from the control room all the way through to the end field devices in the context of self-healing.

Automated restoration systems, also known as self-healing systems, are commonly deployed on the distribution system using distributed intelligence. A communications link back to a centralized SCADA system is not necessary for the restoration logic to function, but it is often present for remote control and visibility anyway. All devices in an automatic restoration system need to have some awareness of the normal configuration of the circuits, so that the location of available alternate sources and tie points are readily known during fault events

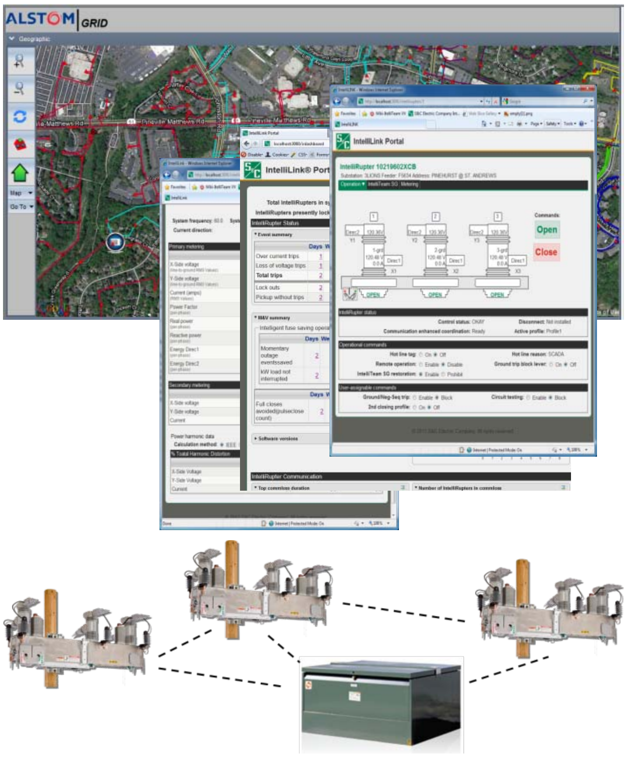

Figure 1. Layered Intelligence - Central Intelligence (IDMS), regional intelligence (performance dashboards and device drilldown), and local /distributed intelligence (protection and switching devices).

A key function of an IDMS [2] is to optimize feeder configurations over a large area to minimize losses, balance loads among substations, and alleviate large-area voltage concerns. In an integrated system, either the operators or the IDMS can operate switches to create a new normal configuration that better optimizes the system. The new locations of normally-open and normally-closed switching devices can be passed to a regional controller, which then in turn updates the distributed intelligence of all affected field devices. In an integrated system, the automatic restoration system can be synchronized to the IDMS-initiated new normal configuration in a matter of minutes, with no truck rolls to the field required.

When faults occur on the distribution system, the first device to act is the local overcurrent protection device. If it is a permanent fault the device will lockout. The next immediate action is for the distributed intelligence system to operate switching devices to fully isolate the faulted section by opening downline switches, and then reroute power to the unfaulted sections, respecting the loading capacity limits of line segments and sources. All of this happens automatically within seconds and without human interaction. The control centre gets indication of the field event via the SCADA system, and field crews are dispatched to the problem area.

As soon as the self-healing event is completed, the regional software system collects waveform captures, event files, and in some cases even builds a playable file that replays the switching events on a one-line diagram. This is useful to the distribution system trouble-shooters and long-term planning engineering, as well as control centre personnel.

Additionally, a well-integrated system can allow control centre personnel or mobile crews to drill down through the IDMS to look inside the end field devices. Having access to complete device operation screens, settings files, and waveform captures brings back useful information and gives operators greater visibility of the system. A dashboard presents a table of information for a visual scan of the status of field devices versus looking at indicators or screens for each individual device.

CONCLUSION

Electric distribution utilities are rapidly embarking on implementing new Smart Grid technologies which include a combination of equipment, software systems, and communications systems to continue providing electric service to all customers in a reliable, efficient, and safe manner.

Most electric utilities already have some elements of central intelligence, such as an IDMS, some regional-based control such as substation automation or self-healing on the distribution feeders, and a mix of local intelligence in standalone power equipment controls such as relays, recloser or pulsecloser controls, capacitor controls, and voltage regulator controls.

This paper introduces the concept of layered intelligence as a foundation for building a smart distribution system by integrating multiple layers of intelligence throughout the system that work together and complement each other. As is often the case in the electric industry, the “people” challenge outweighs the technology challenge, and hence utilities also have had to implement change management processes in tandem with new technology deployments. The authors will discuss this in a future paper.

REFERENCES

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