UNIVERSAL IED FOR DISTRIBUTION SMART GRIDS

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ABSTRACT

To satisfy customer's growing service quality expectations and to support, as well, a wide array of additional new services, utilities need to provide high quality power over a complex and interactive grid with greater reliability, efficiency and security. To achieve this complex task, they need to implement new technologies in their power systems, including accommodating distributed generation (DG) and integrating the latest information technologies (IT) including acquisition and communication. This paper presents a new concept of feeder level universal Intelligent Electronic Devices (IED), based on a modular structure, compatible with all major distribution equipments and complying with international standards. Characteristics like interoperability and plug-and-play offered by this IED as default standardized features will allow improvement in the efficiency of existing Smart Distribution applications and will open the gate for the development of new ones. The results of IREQ's project related to the concept and design of such IEDs and their implications are discussed in support of this vision.

INTRODUCTION

By definition, a Smart Grid is supposed to satisfy customer's growing service quality expectations and to support, as well, a wide array of additional new services. Utilities need to provide high quality power over a complex and interactive grid with greater reliability, efficiency and security. To achieve these complex tasks, they need to implement new technologies in their power systems, including distributed generation, renewable energy resources and the latest information acquisition and communication technologies. The information collected from the grid itself requires hardware, such as sensors and IEDs, distributed along the overhead and underground feeders. Within a Distribution Management System (DMS), they enable real-time monitoring of grid conditions for distribution system operators, improving grid reliability and efficiency. These multifunctional devices are also capable of monitoring the major distribution equipment they are associated with, including substation circuit breakers, feeder reclosers, voltage regulators, switches and capacitor banks for the sake of remote maintenance.
Existing and new transducers integrated into the major distribution equipment and connected to IEDs/controllers will help improving equipment maintenance, especially just in time maintenance (JTM).
Besides customer's growing service quality expectations, present and future Smart Distribution Applications (SDAs) require continuous, real-time monitoring of power quality (PQ), and that not only at low voltage (LV) but also at medium voltage (MV). While at the LV level, the PQ monitoring can be easily done using sophisticated 3-phase intelligent meters installed at customer's service entrance or point of common coupling (PCC), at the MV level, the monitoring is more complex, demanding MV sensors or instrument transformers and remote terminal units (RTUs), making it implicitly more costly.
Mostly because of budgetary constraints, utilities showing leadership in implementing SDAs such as "Volt & VAR Optimization" (VVO), "Fault Location" (FL), "Feeder Reconfiguration" (FR) and "Real-Time Power Quality Monitoring" (RTPQM), will try to leverage the measurement potential of major distribution equipment controllers, whose main functionality requires the collection of raw data from the grid, local treatment and the transfer to power system control centers or elsewhere, where the information, depending on the application, ether is processed in real time or is post-processed. The role of these IEDs/controllers is becoming more and more crucial and in the near future, these devices will play in Smart Grids and SDAs the role the Achilles' tendon plays for the human being.
Surveys performed on commercial products show the availability of a wide variety of controllers for different types of distribution equipments. The problem is that there are too many varieties and the lack of standardization is problematic for the personnel responsible for operating the distribution network, and for asset management in general.
This paper presents a new concept of feeder level universal IED/controller, based on a modular structure, compatible with all major distribution equipments and complying with international standards. Characteristics like interoperability and plug-and-play offered by this IED/controller as default standardized features will allow improvements in the efficiency of existing Smart Distribution Applications and will open the gate for the development of new ones. The results of IREQ's project related to the concept and design of such IED/controller and their implications are discussed in support of this vision.

MONITORING THE GRID

The Smart Grid conditions are monitored for different reasons, including:

- Providing information required by Smart Distribution Applications including:
    - Volt & VAR Optimization,
    - Fault Location,

- Feeder Reconfiguration, etc.
- Providing information required by Dynamic State Estimator (DSE) for the power grid,
- Integrating Distributed Generation (DG) including Renewable Energy Resources (RER), energy storage, demand response, Plug-in Hybrid Electric Vehicles (PHEV) and Electric Vehicles (EV).

By properly coordinating these functions, their cumulative effect significantly contributes to improving grid reliability and efficiency.

Smart Distribution Applications

Today, more and more utilities are taking the path that those showing leadership in implementing SDAs have taken several years ago. It is their turn to implement SDAs, which have proven successful so far, namely VVO, FL and a few others. These applications require voltage and current measurements at low or medium voltage level with either high or acceptable accuracy.

The VVO applications needs a very accurate medium voltage acquisition at the end of the feeder, possibly complying with a class A device accuracy [4], in order to achieve a ±2-4 % voltage level adjustment in substation through the load tap changer (LTC) supplying the feeder. The MV instrument transformers or sensors associated with the acquisition device should also have at least an accuracy of 0.15 % not to degrade the quality of the measurement.

The fault location methods, based on different techniques require either voltage or voltage and current measurements at the substation, along the feeder and at the end of the feeder, locations where in most cases there is an IED/controller by default.

Dynamic State Estimator

In order that the Smart Grid can reliably deliver energy to consumers under a dynamically changing power flow, grid operators need real-time information obtained from grid measurements and from computationally efficient tools. Direct measurement of grid state variables is susceptible to inevitably errors due to varying magnitudes. A DSE is an essential tool for grid monitoring because it processes a redundant set of measurements to obtain the best complete estimate of the current grid state, including topology and loading condition. State estimators, integrated into DMS, provide estimates of unmeasured parameters by processing data collected at substations and along the feeders to determine the steady-state voltage phasors (magnitude and angle) at strategic points in the grid. These estimated phasors are then used to calculate other quantities needed by the grid operator, such as branch currents, branch power flows, etc. [2].

Integration of DG

Distribution system operation becomes much more complex in the presence of DG, many in the form of RER. As the number and type of DG multiply, intelligence at the producer's site becomes a necessity, to monitor its production, ensure proper protection coordination and to effect control.

It is foreseeable that for high penetrations, RER be required to participate in power flow control (peak shaving or other) and voltage regulation (CVR or VVO). While part of this will depend on the nature of the resource itself, at the very least, monitoring will be required in order that control points be adjusted with an accurate representation of the system in mind. Looking further, microgrid operation, including planned islanding will require advanced control functions at the production site and the ability to coordinate with the microgrid controller and the DMS.

MONITORING THE EQUIPMENT

Comparing to substation equipment, major distribution equipment (see Figure 1) is much cheaper, and for this reason, the just in time maintenance in distribution grids was never applied. Today, the late evolution in transducer technology allows new temperature, acceleration, distance or proximity sensors for maintenance purposes to be integrated into major distribution equipment at affordable prices. So, the IED/controller has to accommodate a new package of signals coming from all these sensors, in addition to those eventually provided by voltage and current instrument transformers. Also, existing maintenance related functionalities should be updated to accept and take into consideration newly available information or new ones should be developed in support of JIT maintenance.

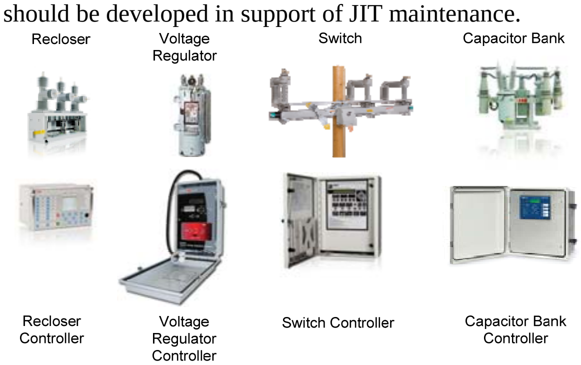

Figure 1. Major distribution equipments and their controllers

MONITORING THE PRODUCT

Using IED/controllers and sensors integrated in the MV equipment instead of PQ dedicated RTUs and MV instrument transformers is the best cost efficient way to succeed in performing voltage and current monitoring at the MV level. The sensor accuracy is a problem of great interest and concern at the same time, and the tests performed for sensors accuracy evaluation, including optical models, show that the average accuracy of these devices varies from ±1 % to 2 % while for the best performing the accuracy is lower than ±0.5 % [1]. However, it was noticed during the tests that the sensor response at either voltage or current fundamental frequency is far more accurate than the frequency response, and that requires separate calibration factors for magnitude and phase angle at each frequency to be configured in the IED/controller firmware.

SMART FEEDER

A typical North American medium voltage feeder as a distribution engineer sees it today is shown in Figure 2.

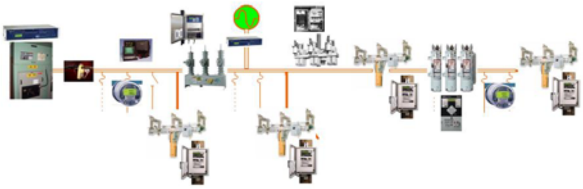

Figure 2. Classic Feeder

In a Smart Grid, an automated distribution feeder equipped with information technologies becomes a Smart Feeder and its topology is illustrated in Figure 3.

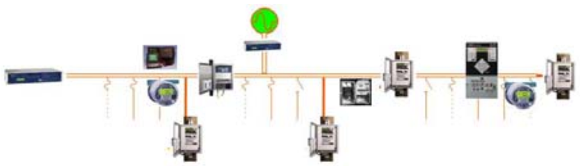

Figure 3. Smart Feeder

The integrated voltage and current monitoring systems include:

- Intelligent revenue meters partially or fully complying with international standards (IEC 61000-4-30) and capable of detecting and recording PQ disturbances and waveform capture.
- Controllers and relays capable of measuring voltage and current, detecting and recording PQ disturbances and waveform capture but not yet complying with the international standards

Considering the vision of the smart feeder of Figure 3, there are a number of benefits that can be achieved by rendering these devices multifunctional; to the extent that one device could ultimately be configured to serve the function of any of the individual controllers. This would simplify standardization, training, interfacing, and firmware updates. Indirectly, this would help foster the development of the Smart Grid, as engineers and researchers could then focus on the development and deployment of applications, rather than the details associated with coordination and testing of different controller philosophies.

UNIVERSAL IED/CONTROLLER

At IREQ, one such initiative aims at achieving this universal controller [3]. The project includes two stages:

- Development of a generic specification for a universal controller that meets the needs of all of the applications outlined previously.
- Initiation of a process that will allow the development of an international standard for a universal controller based on a modular concept.

The specification consists of four different areas: pole-mounted cabinet construction, hardware components, software, and battery for back-up power supply. It outlines a modular hardware design, based on a standard rack, which accepts standard electronic cards. This rack can be housed either in a pole-mounted cabinet or directly into the body of distribution equipment. The following subsections provide greater detail on each component.

Cabinet construction

Part of the specification is aimed at the pole-mounted mechanical enclosure of the controller. A standard sized cabinet is defined, sized in order to accommodate the universal controller. In addition to defining dimensions, considerations also include aesthetics (as part of meeting environmental requirements, related to work done in recent years on improving public acceptance of utility equipment) and ease of operation.

Hardware components

There are a number of plug and play hardware components that combine to provide the functionality of the IED. Each would be mounted on nineteen inch standard rack mount system used by leading manufacturers. The required hardware includes:

User Interface

The standard front panel is replaced by a touch screen electronic tablet (see Fig. 4), which allows configuring locally the controller, operating the equipment and downloading the information from controller.

Figure 4. Example of touch screen electronic tablet

This handheld device communicates in short distances with the controller either with a wired connection or an encryption wireless communication channel. This feature significantly reduces problems associated with security and tampering. In addition, a user interface manages all user accounts in agreement with the control center for different authorization levels with remote intrusion detection.

Main board (including CPU)

This card is the heart of the IED. It contains many major integrated circuits such as:

- Main central processing unit (CPU) for manipulating data and executing software instructions. It communicates with the others cards through a standardized high speed bus;
- Non-volatile memory for firmware and critical data storage;
- Programmable logic devices (FPGA, CPLD, DSP, etc.) to accelerate data processing;
- Time synchronization device to support required time-stamping accuracy.

Communication interface

This card, equipped with its own CPU, manages in real time securely encrypted communication between the IED/controller and the grid control center by different types of communication media, including both wired and wireless technologies. The card exchanges remote operational data (control and acquisition data) and remote non-operational data (oscillographic event reports, event summaries, etc.). Standard protocols (Modbus, PG&E 2179), including IEC 61850 should be supported, as well as DNP3.

Voltage and current inputs

This multi-input card makes an analog to digital conversion of signals coming from voltage and current instrument transformers. Optionally, up to six voltage inputs (3 on source side and 3 on load side) and four current inputs (3 phases and neutral) should be available.

Sensor electronic interface

This multi-channel card conditions/amplifies signals coming from different types of sensors including optical, Hall effect, Rogovsky coil, capacitive or resistive dividers, etc. The card should be able to supply at an appropriate voltage level and to calibrate each type of sensor (voltage, current, temperature, pressure, humidity, etc.) according to the required accuracy.

N/O and N/C contact blocs

The card provides an appropriate number of input and output contacts, controlled by the firmware. Input contacts, non-isolated and isolated, are generally used to integrate equipment status or other verifications. Output contacts are of two types, those for generally usage and power outputs. As power outputs are interfaced with specific apparatus, the inclusion of three pin contacts (NO + NC) is of great importance to ensure general compatibility.

Power supply

The card controls and manages the power needs of the controller and in certain cases of the equipment itself and is equipped with a dedicated CPU which provides visibility of the health and status of the main and backup power supply. It has many internal protections to quickly diagnose a power problem. When battery powered, it optimizes energy consumption by disabling optional features (sleep mode). This smart system also acts as a universal battery charger-analyzer being able to adapt its charging cycles and its maintenance charge to the type of battery and environmental conditions. In addition, it drives a temperature controller, with its heating element or cooling device.

Software

The intent of the generic specification is not to influence the manner in which firmware is developed but rather to impose a philosophy under which the code is developed. There are two main components to this: enabling the use of firmware that is multiplatform and requiring that standard protocols are supported.

Multi-platform firmware

The controller should allow loading of the appropriate firmware that is required for the main function of the equipment being controlled and for the advanced SD functions to which it is associated such as:

- Main function (protection, voltage regulation, VAR control, feeder reconfiguration, etc.,
- Remote measurement,
- PQ evaluation,
- JIT maintenance,
- Cyber security.

Standard communication protocols

The multi-platform firmware should be able to support standard protocols being used by the power industry, namely local utility, in order to enable interoperability and interchangeability. These include: IEC 61850 version for distribution feeders [5]; IEC 870 [1]; DNP 3 [7].

Battery for the backup power supply

The capacity and battery technology will be chosen so that the battery lasts a minimum of 10 years, taking into account the load and the climate conditions.

CONCLUSIONS

The universal controller proposed in this paper has the potential to streamline deployment of advanced distribution applications, improve workforce efficiency, reduce costs, and improve reliability. With this in mind, the universal IED is arguable as important to the realization of the Smart Grid vision as smart meters, DER, ICT and DMS. Leveraging international standardization initiatives will be one of the keys in the success of this initiative.

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