Sensors and IEDs Required by Smart Distribution Applications

Smart Grid and Distribution Automation

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Abstract*—In order to meet the electric energy needs at the beginning of this new millennium, utilities need to provide high quality power over a reliable grid, to satisfy customer's growing service quality expectations and to support, as well, a wide array of additional new services. One of the solutions is a successful power grid management activity such as "Smart Distribution" (SD) or Distribution Automation (DA), which hinges on the information collected from the grid itself using an integrated monitoring system that enables real-time monitoring of grid conditions for distribution system operators. It allows automatic reconfiguration of the grid to optimize the power delivery efficiency and/or reduce the impact and duration of outages. The foundation of the monitoring system infrastructure is based on transducers, sensors and Intelligent Electronic Devices (IEDs) collecting information throughout the distribution system. Hydro-Québec (HQ) is showing leadership in this field, conducting several projects related to Smart Distribution such as Volt&VAR Control (VVC), Fault Location (FL), Power Quality Monitoring (PQM) and evaluation of the metering potential of major distribution equipment controls, which collect raw data from the grid, treat it locally and transfer it to system control centers or elsewhere. There, the information is used for real time treatment or non real time post treatment. This paper discusses the structure and the accuracy of an integrated monitoring system based on sensors and IEDs and reports on some of the results and conclusions of Hydro-Québec's projects related to Smart Grid applications and technologies.

Keywords-Smart Grid; DA (Distribution Automation); VVC (Volt & VAR Control); FL (Fault Location); PQ (Power Quality); monitoring; intelligent meters, control; accuracy;

I. INTRODUCTION

Electric utilities needs are becoming increasingly difficult to meet in the face of an emerging "digital society", with its highly automated and complex industry, computerized commercial business processes, changing nature of residential loads and a regulatory environment. All of that requires more reliable communication facilities and is becoming increasingly sensitive to reliability and quality of electrical supply. Momentary supply interruptions or severe voltage sags of prolonged duration can cause disruptions with significant economic consequences.

These requirements and constraints have caused the utilities to rethink their distribution system in terms of distribution automation, sensors, intelligent equipment and smart power system functions, in order to achieve its goals.

With the introduction of new IEDs/controls, classical disciplines in distribution like protection, control, metering, power quality evaluation and additional automation functionalities will come under one responsibility [1].

Some intelligent elements already exist in most distribution grids and this is the reason that the actual distribution system infrastructure (especially sensors, transducers and IEDs/controls) should be used to gather as much information as possible related to network, equipment and product (i.e., power quality) to improve the distribution system overall performance.

Nowadays, several manufacturers offer performing sensors and IEDs or intelligent controls to improve network performance.

II. SMART GRID AND SMART DISTRIBUTION

Growing service quality expectations make SD processes increasingly imperative for the power utilities and trigger the next major step in the evolution of distribution systems towards a Smart Grid.

At the beginning, the foundation of the Smart Grid concept was based only on applications with smart meters affecting the customer side. Then gradually, several DA applications, involving new technologies, have been implemented through the years and now Smart Grid is what its name really means.

In the past DA consisted mainly in automatic operations, conducted by autonomous IEDs/controls, such as fault location, isolation and service restoration and voltage regulation. Today, advances and falling prices of the communication and control technologies, which can be embedded in the distribution grid and used for monitoring and remote control of various major distribution equipment, such as switches, capacitors banks, reclosers and voltage regulators, bring along a list of new automated SD applications.

According to the IEEE PES Smart Distribution Working Group (SDWG) the following applications can generally be identified to SD [2]:

- Remote controlling of feeder reclosers and switches,

- Automatic feeder reconfiguration based on remote control of reclosers and switches (includes fault detection),
- Fault detection (distribution feeder devices),
- Fault location (accurate) based on waveform analysis,
- Capacitor bank control,
- Volt & VAR control using sensors on the feeder,
- Power Quality measurements (harmonic content),
- Distribution overhead grid monitoring (power measurements),
- Distribution underground grid monitoring and control.

The existing DA deployments and the AMI penetration are complimentary technologies, and they will ensure the achievement of Smart Grid initiatives taken by utilities showing leadership.

The Figure 1 illustrates the flow of information in a fully integrated distribution system.

A better knowledge of what is happening in the power system is needed for an improved management of distribution grid. New technologies (sensors, IEDs, software, telecommunication) can provide data required by smart applications to improve the system efficiency through utility's business needs. It is a necessary feedback loop to improve the distribution system performance. The choice of applications and technologies could differ from a utility to another, depending on each one's priorities (power reliability, PQ, customer satisfaction, environment, etc.) and business drivers should decide what applications, what type of data and finally what technologies are needed.

Regardless the path each utility may take to reach the intelligent or smart level of distribution system, reducing the overall cost is an important utility target and achieving it depends a lot on distribution equipment features like interoperability or interchangeability.

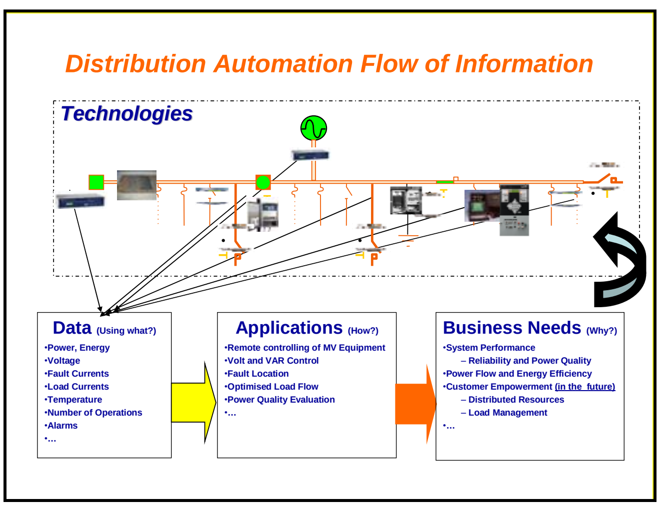

Figure 1. Distribution Automation: Flow of information

A successful implementation of SD applications requires three sets of standards, one for substations, a second one for feeders and the third one for customers. Then, is a need for coordination between these different standards.

The new way of thinking and operating the Smart Grid created the premises for an integrated distribution monitoring system, based on sensors and IEDs capable of providing the data required by latest smart distribution applications formely known as Advanced Distribution Automation (ADA) applications. Some of these devices are already in place in substations and along the feeders.

III. SENSORS AND IEDS

In the early microprocessor based IEDs, metering features such as voltage and current rms-values, power values, were just simple additional features. Today's IEDs have features, which go far beyond these basic functions including frequency, voltage and current harmonic content, symmetrical sequences, waveform capture, etc.

For Smart Grid and SD medium voltage applications, manufacturers propose new "Smart Sensors", which can work either autonomously, when equipped with a communication interface, or in combination with IEDs. Optical current and voltage sensors offer a number of major advantages, but because of a price yet high, it will take a while before a large number will be integrated to the grid. Until then, sensors present at this time on the grid, can be used successfully for monitoring purposes in combination with major distribution equipment controls (see Figure 2) [3].

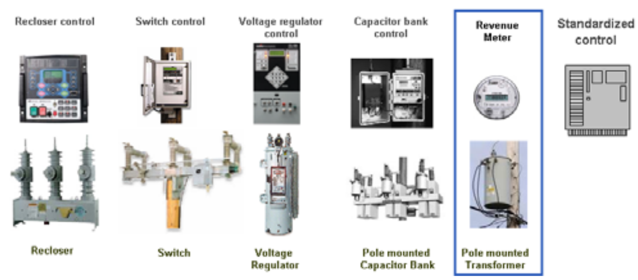

Figure 2. Exemples of major distribution equipments and their controls

IV. HYDRO-QUÉBEC AND SMART DISTRIBUTION APPLICATIONS

Hydro-Québec is showing leadership in this field with its proposed road map towards a smart grid, which should include (see Figure 3):

- Grid monitoring (to improve reliability).
- Equipment monitoring (to improve maintenance).
- Product monitoring (to improve PQ).

To achieve its ambitious programs on energy efficiency and outage duration reduction, Hydro-Québec has focused on three targets:

- Capacitor banks installation.
- Volt control.
- Accurate fault location.

Pilot projects have proven the efficiency and economic feasibility of two SD systems, VVC and FL.

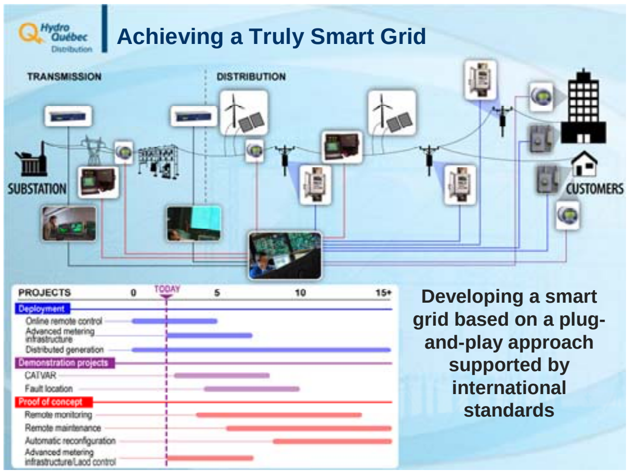

Figure 3. Hydro-Québec roadmap to achieve a truly Smart Grid

Another research program targeted the non-revenue metering potential of distribution medium voltage sensors and IEDs/controls and data integration from these devices. Features such as voltage and current measurement accuracy, linearity, remote control, communication, data transfer, etc., have been evaluated using IREQ's test facilities. Some results and conclusions from previous tests were presented in [4]. Results from latest tests are presented further down.

V. IREQ'S TEST FACILITIES

Besides a large number of laboratories, IREQ has an overhead distribution test line allowing research and development activities for distribution system, namely validation and certification of different distribution equipments (see Figure 4). It includes two feeders and different models of sensors, instrument transformers and pole-mounted major distribution equipments, which can be remotely controlled using available phone, Internet and WiMax communication links. The main switchboard for network and telecommunications is located in the control room.

The line is mainly used to facilitate tests related to SD applications, namely to verify new equipment functionality, metering and communications capabilities, remote control and command.

Figure 4. IREQ's test facilities (control room and feeders)

VI. TEST RESULTS

The research project conducted in 2010 included voltage and current measurement accuracy tests on medium voltage sensors/transducers along with different controls (recloser, switch, voltage regulator) present on Hydro-Québec's distribution grid to evaluate the error deadband. The evaluation tests were performed on the chain composed by two devices, the sensor and the control, and not separately on each of them.

Some tests were performed in laboratory using a system composed of one FLUKE 6100A master unit and two 6101A slave units. The calibrator provided 60 Hz current sine wave to feed standalone sensors (CVMI Lindsey 9660) and recloser external current transducers belonging to reclosers from different manufacturers (Cooper-VWVE, Cooper-Nova, Joslyn-TryMod 300).

Two setups were constructed; one to measure the accuracy of the chain ABB-OVR integral current transducers and PCD2000 control and a second one for voltage measurement accuracy with power distribution transformers (ABB 3 kVA and 10 kVA) and different IEDs/controls.

The last test evaluated the potential of a voltage regulator control (Cooper CL-6A) to measure voltage and current using reversible voltage regulator's integrated PTs and CT.

A. *Current Measurement*

The sensor-IED/control chains submitted to current measurement tests are illustrated in Table I.

The evaluation process was based on average rms-values over 5 or 15 minutes, depending on the type of control. SEL-651R and PCD2000 measured average rms-values over 5 minutes and S&C M series did it over 15 minutes.

TABLE I EXAMPLES OF SENSOR – IED/CONTROL CHAINS SUBMITTED TO TESTS

Chain sensor/transducer - control		
Type of measurement	***Distribution Device and Transducer/Sensor***	***Control***
Current	CVMI Lindsey-9660	SEL-651R
	CVMI Lindsey-9660	S&C M series
	ABB-OVR	PCD2000
	Cooper-VWVE	SEL-651R
	Cooper-Nova	SEL-651R
	Joslyn-TryMod 300	SEL-651R
Voltage	ABB MicroPole 3 kVA	SEL-651R
	ABB ONAN 10 kVA	S&C M series
Voltage and current	McGraw Edison/VR-32 50A	CL-6A

1) *Recloser with standalone current sensors*

The statistical results for the chain CVMI Lindsey-9660-SEL-651R are graphically presented in Figure 5.

This control is provided with an adjustable calibration factor (same for all three phases) for current and voltage and uses float values for doing calculations.

The current measurement error, for a load current superior to 120 A, meets the value (0.3 %) given in the sensor's data sheet.

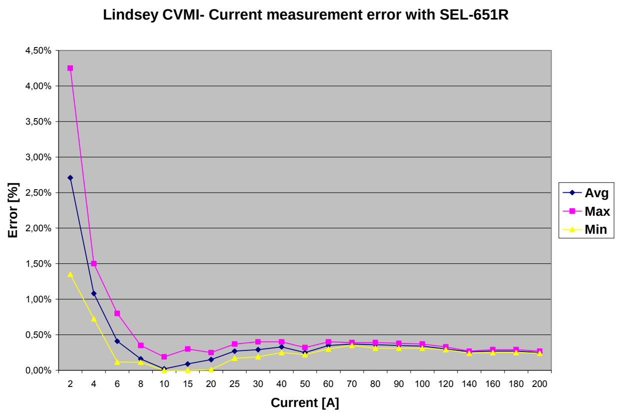

Figure 5. Current measurement error with CVMI Lindsey current sensors and SEL-651R control.

2) Recloser with integral current transducers

For this category, the test was performed on the chain composed by integral current transducers of an ABB-OVR recloser and its control PCD2000.

The three-phase recloser poles were connected in series and the current transducers were supposed to read the same current magnitude.

The level of current reading error of this chain, for a load range from 75 A to 400 A, was inferior to 1 %, which corresponds to the current measurement error value provided by the manufacturer. The error-load chart for three-phase recloser transducers and for currents from 10 A to 400 A is illustrated in Figure 6.

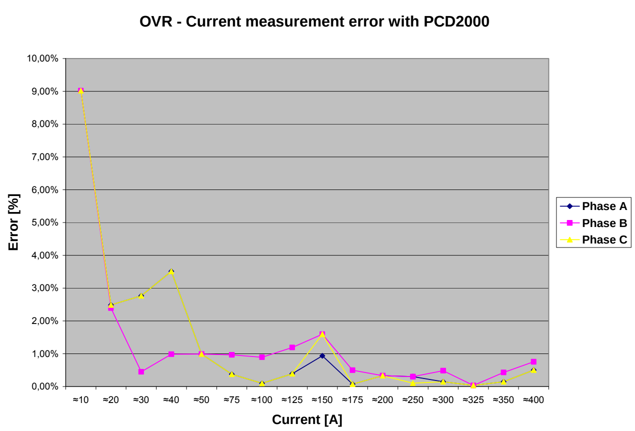

Figure 6: Current measurement error with OVR integrated current transducers and PCD2000 control.

3) Recloser with external current transducers

This test was carried out on a TriMod 300 recloser external current transducer connected to a SEL-651R control and the test results are presented in Figure 7.

The error chart shows an error level decreasing constantly from 1 % to 0.20 % and then becoming steady for currents higher than 100 A.

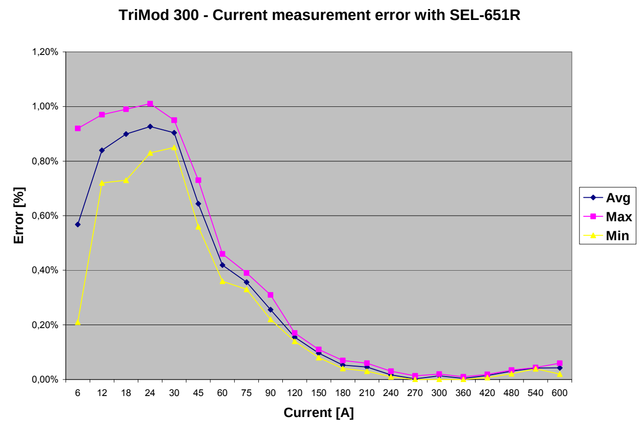

Figure 7. Current measurement error with TriMod external current transducers and SEL-651R control.

4) Switch with standalone current sensors

The test on CVMI Lindsey-9660 was repeated with an S&C M series control doing the current average rms value acquisition.

The chart of the current reading error, using this sensor-control chain, is presented in Figure 8.

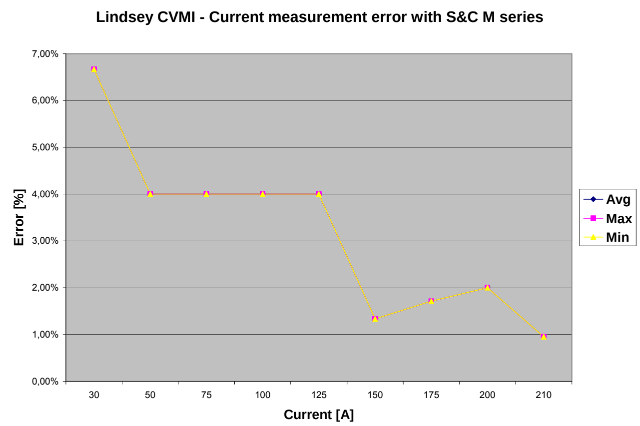

Figure 8. Current measurement error with CVMI Lindsey current sensors and S&C M series control.

The current measurement error is significantly higher comparing to the case 0 because of a pre-set fixed current calibration factor (adjustable factor unavailable) and an rms value calculation algorithm, based on integers instead of float values. Fortunately, most recent controls are provided with an adjustable calibration factor and unfortunately, it is the same for all three phases instead of one for each phase. The sensors are not identical and separate phase calibration factors would allow readings that are more accurate, either for current or for voltage.

B. Voltage Measurement

The tests on voltage measurement error tried to evaluate the level of error introduced by power distribution transformers used along with controls of major distribution equipments for voltage readings at MV (medium voltage) level. The following combinations were used for voltage signal acquisition:

a) *ABB-MicroPole 3 kVA with S&C M series.*
b) *ABB-MicroPole 3 kVA with SEL-651R.*
c) *ABB-ONAN 10 kVA with SEL-651R.*

All the tests corresponding to this category were no-load tests and the voltage range was 12.4 kV to 15.6 kV.

The graphical representation of the measurement error for combinations a) and b) is shown in Figure 9. The average error for both combinations is inferior to the threshold 0.5 % suggested by the standard IEEE Std C57.12.00™-2006 « Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers ».

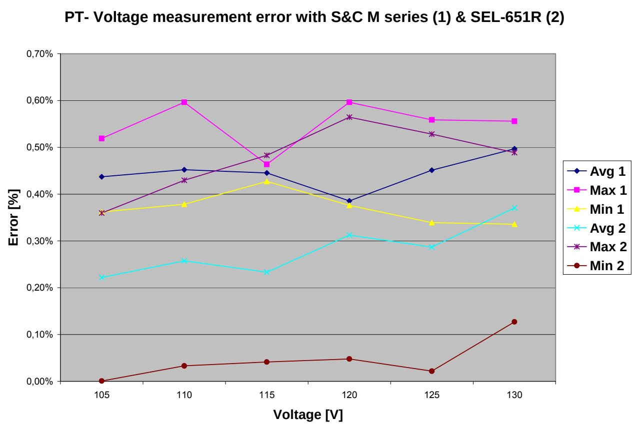

Figure 9. Voltage measurement error with 3 kVA MicroPole distribution transformer and S&C M series and SEL-651R controls:

C. *Voltage and current*

The last test, performed on a reversible voltage regulator PTs and CT and its control, is not yet totally concluded. So far, only the metering and communicating potential of the control (CL-6A) was evaluated. The IED/control was configured to save average current and voltage rms-values over one minute period, which are usually required by a VVC application. The remote data transfer from three CL-6A controls through a SMP4 gateway and over a FO (Fiber Optic) link was successful but the reliability, when using the same gateway and a phone line, was questionable.

D. *Measurement error with the chain sensor-IED*

The voltage and current measurement accuracy of the chain sensor-IED is generally acceptable for statistical grid evaluation, despite the fact that this hardware combination introduces a reading error higher than 0.1 %, value defined by IEC 61000-4-30 for class A devices. However, the continuous evolution of sensor and IED technologies and a better sensor calibration are potential factors contributing to the improvement of the chain accuracy in the next future.

VII. THE IED OF THE FUTURE

Smart distribution applications, based on information from IEDs and smart sensors, improve the efficiency of distribution grid management. Power engineers learnt from experience that operating at the same time an increasing number of different IED models, integrated to the distribution grid, causes stress on network operating personnel for several reasons:

- Different control hardware, firmware and communication software when different manufacturers.
- Data format not always compatible with standard formats.
- IEDs with lack of interoperability or low degree of interoperability.
- Not "plug and play" design yet.

To reduce cost and reach the "plug and play" design (see Figure 10), the development of distribution system technologies, including both aspects hardware and software, must be coordinated trough appropriate standards.

To be proactive, IREQ and its Strategic Platform initiated the project DACCORD, which proposes a new strategy for conception, integration, deployment and utilization of a generic modular IED/control for smart distribution systems, complying with future standards, in three stages:

1) *New concept of IED/control.*

2) *Strategy for device integration, deployment and operation compatible with the Smart Grid architecture (new feature: plug and play (P&P) (interoperability included)).*

3) *New strategy of how to use IEDs/controls advanced complementary functions developed for SD applications.*

The first stage is focused on developing a generic specification for a modular distribution equipment control, which will cover three aspects:

1) *Hardware (modular):*
   a) *Main board with CPU,*
   b) *Front panel (including touch screen),*
   c) *Communication interface,*
   d) *Signal (voltage and current) interface,*
   e) *Electronic interface (required for voltage and current sensors),*
   f) *N/O and N/C contact blocs.*
2) *Software:*
   d) *Firmware multi platform (CIM) including advanced functionalities such as:*
      - *Main function (protection, voltage regulation, VAR control, feeder reconfiguration,…).*
      - *Remote metering.*
      - *Remote-predictive maintenance or JIT (Just In Time) for distribution equipment.*
      - *PQ.*
      - *Security.*
   e) *Communication software and protocols:*
      - *IEC 61850 version for distribution feeders.*
      - *IEC 61870……*
      - *DNP 3.0.*
3) *Backup power supply.*

The data provided by such IEDs will fall into both real-time and non real-time categories. In the real-time category, distributed sensing provides increased power grid monitoring

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for grid state estimators, device status and health, fault detection and location, PQ, safety and security. Advanced functioning will include demand distribution for load balancing; transformer, circuit breaker and tap changer monitoring; detection of energized downed lines, high impedance faults and faults in underground cables.

The bulk data download (waveforms) will be a feasible characteristic of the evolving telecommunication structure.

The lifespan of the backup power supply battery will be increased to 7 to 10 years by using new long life battery technology, remote maintenance and reducing IED energy consumption with efficient IED management.

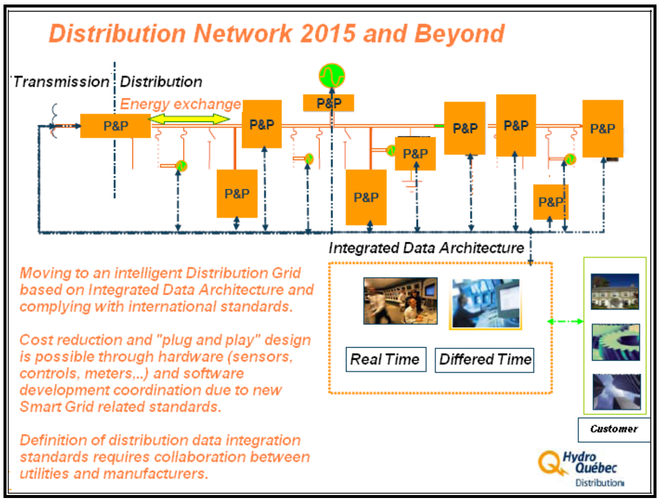

Figure 10, HQ's vision of distribution grid 2015 and beyond with integrated data architecture complaying with international standards

By this project IREQ (Hydro-Québec) tries to:

- Initiate a debate, within Smart Distribution related national and international Working Groups (CEATI, IEEE, CIGRE/CIRED, ...).
- Influence those WGs to start working on definitions for modular hardware and software of standardized IEDs in order to make possible the edition of future related standards.
- Kick off collaborations with other utilities, manufacturers and organizations.
- Influence distribution equipment manufacturers to develop and build standardized models.

VIII. Conclusions

The IEDs with very high functionality will lead to significant cost savings and offer new problem solving capabilities. With these changes, utility personnel will need extensive training on the new practices, and a close partnership between vendors and utility customers will be necessary.

Sensors and communication technology fields are evolving quickly. IED manufacturers are taking advantage of performance of new technologies, upgrading their devices to be compatible with smart sensors. The best example is the new generation of reclosers, with integral voltage and current sensors.

Smart grid integrated monitoring devices rise the potential for implementing DA applications like VVC, FL, PQM and open the gate for new ones. Old and new applications will share the same resources.

Due to extensive implementation of SCADA and AMI systems, the infrastructure required by DA applications mentioned above is often already in place.

HQ's projects resulted in the acquisition of knowledge about present distribution equipment performance and improvements needed in the future (technologies, sensors, IEDs, standards…) in order to integrate data acquisition.

The accuracy of data acquisition process is an important factor, critically affecting the efficiency and reliability of DA systems and furthermore the efficiency and reliability of the power distribution system.

The accuracy of the chain sensor-IED is generally acceptable. However, the controls under testing do not qualify for class A devices, as defined by IEC 61000-4-30.

The frequency response of smart sensors doesn't reach yet the level of accuracy that PQ experts would like. This feature should be improved in the next future to allow the implementation of smart applications based on discrimination of grid polluters.

Using IEDs/controls for grid monitoring is an inspired decision based on following advantages [5]:

- Presence of AMI in Smart Grids.
- Connection of IEDs to the MV side of the grid.
- Continuous evolution of IEDs and sensors.

There is a trend in controls evolution to follow up the path taken by intelligent meters a decade or more ago, and that is very encouraging.

Acknowledgment

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