UNDERGROUND AND OVERHEAD MONITORING SYSTEMS FOR MV DISTRIBUTION NETWORKS

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ABSTRACT

The focus on enhancing the reliability and efficiency of the power grid has led to the implementation of the Smart Grid concept. This concept is based on the deployment of automation, namely Advanced Distribution Automation (ADA) applications, and control technologies relying on the availability of parameters such as voltage, current, temperature, etc., acquired from certain nodes of the grid. For a long period of time, the monitoring of the overhead distribution network has known a continuous evolution and the line type standalone intelligent sensors, commercially available at this time, are the proof of that. While monitoring such parameters may be typically available in overhead distribution locations, it is not the same in underground distribution locations. Measuring in utility vaults or pad mounted cabinets is not as critical as in cable chambers/manholes, due to the accessibility provided by equipment such as transformers, switches etc. Recently, new developments in sensor, IED and communication technologies opened the door to attractive alternatives for monitoring the underground distribution network in general and in cable chambers/manholes in particular. An example of a such monitoring system is presented in this paper.

INTRODUCTION

When comparing the smart grid to the traditional grid, two main aspects emphasize the difference: the presence of distributed energy resources (DER) including the renewables (RE) and the integration of a significant number of advanced distribution automation applications. The grid automation process, based on these applications, is benefitting from the information provided by the real time monitoring of the grid at an increased number of overhead and underground distribution nodes.

Thus, a more dynamic smart grid offers higher reliability, efficiency and greater remote control flexibility through automated devices (reclosers, voltage regulators, load switches and capacitor banks), equipped with intelligent electronic devices (IED), such as controllers and relays, and sensors, representing a new generation of more accurate/better performing transducers.

The deployment of automation and control technologies that rely on the availability of various parameters such as voltage, current, temperature, etc. in certain nodes of the grid has led to the improvement of the power grid behaviour.

The analysis of the structure of the power system has shown that the level of automation and advanced applications integration associated with each structural component (traditional/classic generation, DER, transmission and distribution) has various implementation stages throughout the power system. Since utilities have started implementing the smart grid concept, the process of distribution automation and integration of associated technologies, which was lagging behind generation and transmission, is trying to catch up. Identified reasons that contributed to technology implementation delays are the large number of distribution components, their low cost and the lack of affordable wide spread telecommunication infrastructure.

The Smart Grid is also characterized by a large deployment off smart meters and their telecommunication network. The novel Advanced Metering Infrastructure (AMI) has made possible the acquisition, from the grid itself, and the transfer of a huge quantity of additional data defined as Big Data. Thanks to new analytic platforms, data is stored in relational databases, post-treated by complex algorithms and the results are made available to ADA applications.

An exhaustive list of ADA applications includes:

- Service restoration,
- Distribution underground system monitoring and control,
- Controlled island operation,
- Voltage-VAR Optimization (VVO),
- Fault location,
- Demand response,
- Power-quality monitoring,
- Optimal network reconfiguration,
- Load balancing,
- Predictive maintenance,
- Advanced Protection,
- Power theft,
- State estimation.

At any monitoring node there is a measurement chain, which normally includes sensors, IEDs and communication links [1]. Typically, any monitoring node could or should support and be capable to provide remotely, partially or totally, the following list of system parameters classified in several categories:

- Power measurements (Volts, Amps, MW, MVAr, MVA and power factor),
- Power Quality measurements (sags and swells, voltage and current harmonics, % THD (Total Harmonic Distortion) and TDD (Total Demand Distortion)),
- Environmental measurements (temperature,

humidity, water level, gas presence and concentration).

The following sections discuss overhead and underground monitoring systems that were developed to serve smart grids. The systems selected do not include well-known traditional monitoring systems based on instrument transformers, copper wired communication with modems, etc.

OVERHEAD MONITORING

A brief analysis of the status of distribution monitoring will conclude that overhead monitoring is in a more advanced stage of deployment and operation for reasons such as: larger area covered with overhead distribution supply, more flexible overhead grid operation mode, and better communication accessibility.

A few examples of post type sensors for Smart Grid are shown in Figure 1.

Figure 1. Post type sensors for Smart Grid

The instrument transformers are characterized by:

- Large size; the combined ones (V+I) are even larger,
- Heavy (40 + pounds),
- Well established installation procedure,
- Saturation issues due to ferrite core,
- Limited accuracy at higher frequency.

Compared to instrument transformers, the post type sensors characteristics are:

- Small size,
- Lite (a few pounds),
- Installation procedure more or less established,
- Saturation not a problem anymore,
- Electronic interface required.

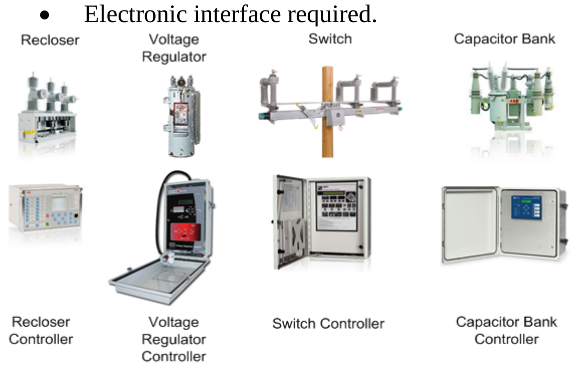

Figure 2. Major distribution equipments and their controllers.

In recent years, utilities started exploring possibilities to leverage the monitoring potential (data acquisition (voltage, current, etc.), analysis, storage and transfer to the power system control centre) of IEDs already connected to the grid such as:

- RTUs,
- Controllers,
- Relays,
- Meters/AMI.

All these IEDs are capable to measure:

- Line currents,
- Line to ground voltages,
- Capacitor current,
- Neutral current.

For a long period of time, the monitoring of the overhead distribution network has known a continuous evolution and the line type standalone intelligent sensors commercially available (see Figure 3) at this time are the proof of that. They are a combination of sensor, IED and communication interface (wireless) in the same body, which can be installed easily on the medium voltage distribution conductors with a hot stick [2].Their installation can be permanent or temporary; they can be removed with the same hot stick and installed again at a different location where the utility needs to monitor the grid. Equipped with radio frequency (RF) or cellular communication capabilities, these line monitors can connect to existing communication networks at almost any new location.

These devices are one-phase monitors that basically measure the phase load current. Some of them measure also the electric field and a few the phase voltage.

Before integrating more advanced technology solutions for overhead grid monitoring, some utilities may decide to temporarily install stand-alone line type sensors, for a transition period.

Figure 3. Line type sensors for Smart Grid

The new concept of universal controller introduced in [3][4], defines a device that is capable to replace successfully the first three types of IEDs mentioned above, and which will simplify and improve network operation control and maintenance.

A universal controller should be capable to operate and control any type of major distribution equipment and measure voltage and current magnitude and phase angle with standardized accuracy, also detect and record (waveform capture) power quality disturbances affecting the grid.

Scientific and technological communities are actively exploring possibilities to develop guides and standards to govern the development of such IED/controller designs.

UNDERGROUND MONITORING

In the past, non-economical communications technologies, limited the integration of underground smart applications. A limited number of utilities decided to deploy high quality reliable fiber optic based communication networks. Such solutions are extremely costly to install, maintain and repair.

Typical underground environments include cable chambers/manholes, vaults and pad mounted cabinets.

Figure 4a shows medium voltage cables entering a cable chamber, while Figure 4b shows the sensing and communicating system, discussed in this paper, installed on a cable chamber wall.

Figure 4. a) Cable chamber/manhole environment; b) Installed sensing and communicating system

The version with the same monitoring system, attached to a pad mounted cabinet is presented in Figure 5.

Figure 5. Pad mounted cabinet with sensing and communicating system

A typical utility cable chamber environment can be quite challenging in terms of options for power supply for the measurement equipment. This challenge is compounded by a real need to provide a system solution that can measure electrical and environmental parameters in real time and with high enough accuracy for power quality measurements and network diagnostic applications while minimizing the supply power requirements.

From the different systems that were explored, the one that emerged as a viable solution is under evaluation and testing at IREQ/HQ's research facility.

<u>Underground Sensing and Communicating System</u>

The architecture of the proposed underground sensing and communicating system (see Fig 6) consists of the following hardware modules:

- Power Harvester module (PHM) w/battery storage option including:
  - Magnetic Core Assembly (MCA),
  - Power Regulator module (PRM).
- Rogowski coils (with concentric sensor holder mechanism),
- Current Sensing Module (CSM),
- Voltage Sensing Module (VSM) (under development),
- Environmental Sensing module (ESM),
- Sensor Analytics Unit (SAU),
- Wireless Communication Gateway (WCG).

The system also includes a software module that facilitates user access to the monitored and recorded data, and permits remote system configuration, visualization of recorded data, etc.

This underground sensing and communicating system has been deployed with Research Institute of Hydro Quebec (IREQ) in the late fall of 2015 in two cable chambers. Measured currents and environmental data (temperature, salinity, humidity, water level, carbon monoxide, hydrogen sulphide, and methane) have been monitored on an ongoing basis.

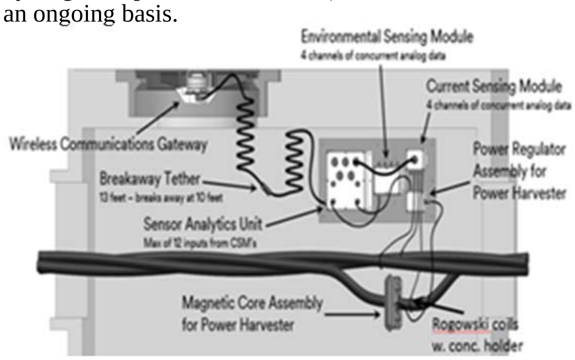

Figure 6. Schematics of sensing and communicating system

Main system components and their functions are as follows:

Power Harvester Module

The function of the PHM is to harvest power from a medium voltage power distribution cable. It includes two main assemblies, the Magnetic Core Assembly and the Power Regulating Module. The MCA (see Figure 7a) uses a single or dual inductive coupling mechanism, depending on line load to supply power to the electronic system. The MCA construction, allows it to be installed around a medium voltage cable.in utility cable chambers, vaults or pad mount cabinets etc.

The PRM (see Figure 7b) features built in protection against extremee line fault currents consisting of a voltage limiting discharge device across the power feed and a local fuse to protect the power discharge device. This module is the front end that regulates and modularizes the power intake from straight 120/240V line voltage to providing 12/24V input from the PHU.

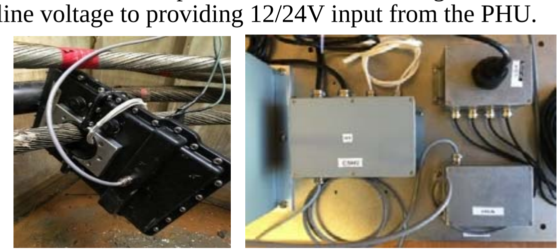

Figure 7. a) Magnetic core assembly; b) Power regulator, current sensing and environmental sensing modules

Current Sensing Module

This module (see Figure 7b) is equipped with 4 channels of concurrent analog data (3-phase and neutral). The function of the CSM is to monitor data from the sensors. The data is aggregated, filtered, time-synchronized, time stamped, GPS located, analyzed, encrypted and communicated from the SAU to the WCG. Higher accuracy readings from the medium voltage cables are obtained via Rogowski coils installed on adjustable concentric holders.

Environmental Sensing Module

The ESM (see Figure 7b) is designed to assess the local environment. If needed, additional units can be added. It is sampling data from various environmental type sensors with different measuring functions such as: temperature, humidity, water level, salinity, gases, etc.

System Analytics Unit

The SAU (see Figure 8) is a powerful universal controller [2] that allows for monitoring various electrical and environmental parameters in real time. The current SAU prototype is designed to accommodate 12 analogue channels from the CSM and VSM and 8 digital channels from the ESM. A protected breakaway tether ensures data communication between the SAU and WCG. Local analytics (reporting by exception) is performed in the SAU with signals from the CSM and ESM.

Only 7.5W are required for this sensing and communication system to operate in transmission mode (worst case scenario).

Currently, for the purpose of technology validation and testing at IREQ/HQ facility, highly precise time stamped/GPS data is collected live via a website, but in the future, this system can be interfaced with the utility network system (using DNP3 or IEC 61850 communication protocols). This monitoring system allows real time configuration of utility selected parameters and is flexible to permit future expansion. A front view of the SAU mounted on the assembly plate is shown in Figure 8.

Figure 8. System analytics unit (SAU)

Wireless Communication Gateway

The WCG is embedded (flush mounted) in the centre of the cable chamber cover (see Figure 9a, b, c). Its main elements include a Global Positioning System (GPS) receiver and a wireless cellular radio. A dual band antenna is also integrated into the moulded housing of the WCG. The WCG has been designed and built using thermoplastic materials/coatings capable to withstand harsh mechanical and environmental conditions.

Figure 9. a) Modified cable chamber cover; b) Cover with embedded WCG; c) View of bottom WCG

Graphic user interface

A user friendly web interface has been developed to allow users to remotely monitor recorded data with customized options such as frequency of measurements intervals, severity of events colour coding, equipment status, etc.

The graph in Figure 10 is obtained via this user interface website and shows an example of currents measured on a 3-phase plus neutral basis during a test performed at IREQ's laboratory.

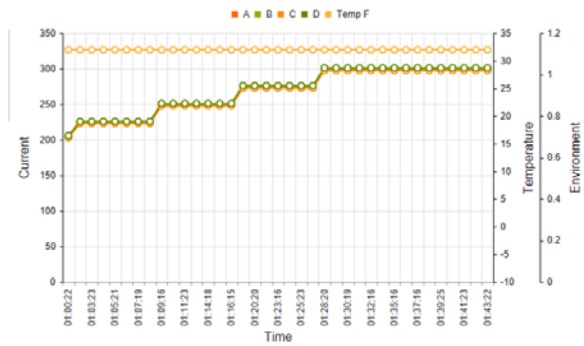

Figure 10. RMS current measurement graph available through the system web interface

Future developments

Most ADA applications require voltage information (MicroGrid Operation, VOLT-VAR Optimization, Fault Location, State Estimation, etc.). Voltage monitoring for an underground grid demands access and connection to live parts which is possible in underground vaults but not in cable chambers or dead front pad mount cabinets, because of the insulation shield construction of medium voltage cables.

The present sensing and communicating prototype only allows for current measurements; a voltage sensing module (VSM) is presently under development and will be integrated in future prototypes. Voltage readings for the VSM can be obtained through sensored accessories such as splices, terminations and deadbreaks benefitting from measurement features such as integrated voltage and current transducers [5].

CONCLUSIONS

The implementation of the Smart Grid concept has been quantified, among others, in the deployment of Advanced Distribution Automation applications. Information provided by monitoring the distribution grid is essential to ADA applications.

The trend is to have as many monitoring nodes as possible with limited cost and to use state estimation for nodes without monitoring.

A continuous technology development process and changes in the monitoring approach foster data acquisition from the grid itself and its treatment using complex algorithms at the analytic platforms level. Today, a more efficient and accurate monitoring is possible due to better performing sensors and IEDs. Distribution overhead monitoring sees the introduction of line type monitors, intelligent devices covering data acquisition, analysis and transfer to the power system centre and implicitly to ADA applications.

The underground monitoring, which was significantly lagging, sees itself reinvigorated with the help of new developments such as the sensing and communicating system presented in this paper, which can be implemented with minimal infrastructure changes to the underground network. Existing manhole covers can be easily modified to accommodate the WCG without expensive structural changes. The system is flexible and expandable; the architecture is modular and thus can be scaled up or down. This system is designed with a high computational/low power chipset and with secure wireless communication allowing real time GPS synchronized data with high bandwidth and low latency to be transmitted above ground.

Initial and future functionalities with technology capability include: faulted circuit indication, fault segment identification, environmental alarms (gases, water level, temperature, humidity, salinity, IR thermal scan camera, acoustic, vibration, etc.), incipient fault detection, fault recording, etc. Utility benefits that enable improved SAIDI, CAIDI, SAIFI, CAIFI, power quality and system design upgrades can be achieved with superior situational awareness, enhanced asset monitoring, more accurate post mortem fault analysis offered by such a system and technology.

This technology addresses present and future key utility challenges such as condition monitoring for electrical and environmental events, distributed energy balancing, grid optimization/efficiency, safety and security.

The system addresses in particular utility cable chamber/manhole safety access by allowing the utility to monitor hazard evolution and identify potential safety risks such as gases or water presence before actually entering the manhole. Gas infiltration trough the underground network of cable chambers and connecting ducts, represent a high risk in inner city densely populated areas. Such risk can be prevented by continuous monitoring of the gas level and type and thus enhances public and utility safety. This system also improves maintenance productivity and efficiency by providing useful real time environmental information that allows the utility to accurately schedule access and next course of action accordingly.

Acknowledgments

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REFERENCES

[1] F. Zavoda, 2011, "Sensors and IEDs required by Smart Distribution Applications (SDA)", *Proceedings ENERGY conference*.

[2] F. Zavoda, M. Bollen, S. Rönnberg, J. Meyer, J. Desmet, 2015, "CIGRE/CIRED/IEEE working group C4.24 – New measurement techniques in the future grid", *Proceedings CIRED conference*.

[3] F. Zavoda, C. Abbey, Y. Brissette, R. Lemire, 2013, "Universal IED for distribution smart grids", *Proceedings CIRED conference*.

[4] F. Zavoda, R. Lemire, C. Abbey, 2014, "Implementing Predictive Distribution Maintenance Using a Universal Controller", *Proceedings IEEE-PES T&D*

[5] 3M- Electrical Markets Division, 2013, “Sensored Cable Accessories Brochure”,