NETCBM - CONDITION BASED MONITORING OF POWER DISTRIBUTION NETWORKS

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ABSTRACT

In order to smarten the electric power grid, we need to get more data on the current state of the network infrastructure - the more up-to-date the data the better and we need the data to be integrated at system level for effective management of the distribution network. Presently, CBM (Condition Based Monitoring) is used for major power system equipment in the network – Generators, Transformers, HV Breakers etc. CBM has not been extended to other key components of the network like lines, cables, etc. due to lack of economically feasible and proven measuring technologies that can be deployed across the network. Wider monitoring requires deployment of sensors outside the substation premises and therefore more vulnerable to external influences. Even in cases where CBM is implemented, the measurements have seldom been integrated in the context of system level monitoring.

This paper proposes an enhanced / enabled approach of Network Condition Based Monitoring (NetCBM). NetCBM would require widespread deployment of novel sensors, collection of monitored data through Wireless (Sensor) Networks, integration of sensor data into the utility information infrastructure, and life assessment of assets based on the integrated measured data. This paper addresses the architectural considerations for NetCBM based on parameters such as sensor node density, distribution, type of sensors, periodicity of monitoring, data volume generated, power source, geography of the deployment, security requirements, social factors, utility information infrastructure, etc. Based on these requirements the design options such as wireless standards, protocols, network topology, device features, etc are discussed. The integrated quality and quantity of data also enables the application of Analytics to device optimal operation strategies for efficiency and effectiveness – such an approach to analytics is also discussed.

INTRODUCTION

Advanced sensing and measurement technologies are one of the main enablers of the Smart Grid. Power systems today use more of conventional measuring equipment and sensors to monitor various parameters in the system. Even though some of these sensing devices have communication features, they cover limited measurable parameters. Wireless connectivity enables untethered deployment of sensors that makes it easy for deployment and management. Use of wireless sensor networks for monitoring phenomena and events from physical world are increasingly finding popularity in many fields. The advantage of easy deployment of modular sensor devices supported with a self organizing and self managing wireless network is a great enabler for IT systems requiring real-time information for decision making. Wireless Sensor Network (WSN) applications improve the efficiency and reliability of power system network through automated condition monitoring.

THE OBJECTIVES OF NETCBM

NetCBM extends condition monitoring concept to the Power System Network by

- Proliferating the use of wireless sensors throughout the power network and integrating the measured data – Enterprise level CBM
- Integrating equipment level CBM's distributed across the network
- Appropriate analytics based on Enterprise CBM data

The system level approach leverages power of IT applications to process the data measured over the geographically distributed network. The benefits of this approach are:

Prevention of failures: Disruptions occur due to failure of HV equipment. Use of condition monitoring gives advanced warning to initiate remedial action to prevent such failures.

Reduced maintenance cost: Traditionally maintenance of network assets are performed at set time intervals. The intervals are set based on the experience of the manufacturer and user, so that maintenance is performed before an unacceptable reduction in performance occurs. By monitoring parameters that give an indication of the condition of the equipment, cost of maintenance and costs due to outages are considerably reduced.

Optimal utilization of Assets: Monitored data along with design and capability parameters of the network elements, service history and failure history of similar equipment helps in assessment of dynamic capability and estimating remaining life of the assets.

NETCBM APPLICATIONS

The system proposed in this paper will cover use of Wireless sensors for condition monitoring applications such as

- Circuit Breaker status monitoring
- Power transformers, Distribution transformers – hotspot detection
- Distribution feeders
- Monitoring Distribution poles and towers at locations vulnerable for disruption
- Underground cables and assets monitoring

Major aspects of condition monitoring applications are discussed in the next section

NETCBM IN SMART GRID

This implementation will directly contribute to the Reliability, Security and Efficiency of the system which are the key success factors of a Smart Grid. Operationally this deployment will improve the Restoration time, Capacity utilization, CAIDI (Customer Average Interruption Duration Index) and reduce the Blackout probability. Real time monitoring, enabling dynamic control and utilization of the power network is an important aspect of Smart Grid. The measurements aggregated at a system level serve as the core information based on which operational decisions to effectively utilize the network can be taken. The analysis of the data repository built from the measured data also helps in studying the vulnerability of the network components. Analysis and Visualization tools such as Dashboards will support the utility management to collate metrics of grid performance useful for analysis and reporting.

Figure 1 shows the architecture of NetCBM. A set of sensor nodes measuring various parameters in the power system form a multi-hop network. The data from these sensor nodes is uploaded through a Gateway to a suitable backhaul network. The backhaul network can be optical fiber or other wireless options such as GPRS, 3G.

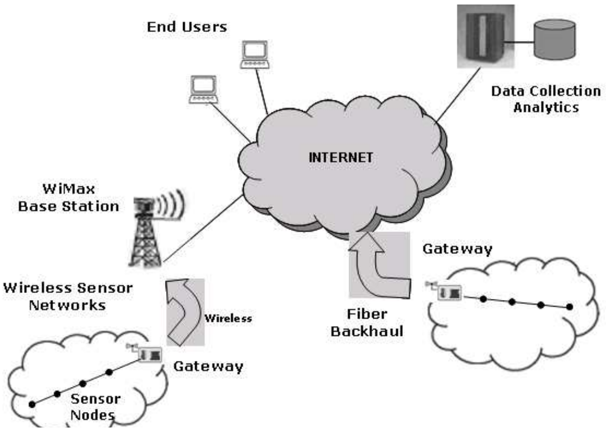

Figure 1: NetCBM Architecture

The data from wireless sensors throughout the power network is aggregated to a central server. Network level analytics applications, with visualization tools are deployed on the aggregated data. End users located at various stations will be able to access the application through the internet / intranet, monitor the network conditions, perform detailed analysis and take control actions.

SAMPLE APPLICATIONS

Overhead lines strung from supporting towers or poles sprawl for kilometers and form the backbone of the distribution network. Even though larger part of the distribution feeders is underground cables, at critical locations where a clearance for underground cable laying is difficult, overhead sections are used. The distribution network carries power from HV (High Voltage) substations, sources to industrial complexes, urban areas and rural communities across the network.

Several distribution system assets such as switching objects and distribution transformers are located in remote areas where security is scant or not available. Surveillance is important for assets located in crowded urban areas also. The distribution grid is vulnerable to terrorist attacks, vandalism, and extreme natural conditions including weather, fire and seismic activity. These conditions can bring lines and poles down and disrupt service to wide areas. Detecting objects, animals and humans in proximity can improve the security of the system. Feasibility of digital surveillance using sensors and webcams has been studied for this application [3].

Fault statistics for Mumbai city, reported by the utilities in the region as part of the Standards of Performance report to the regulator [9], indicate that underground cable faults result in maximum number of outages followed by Distribution Transformers conditions.

Distribution feeders condition monitoring

Cables buried underground face threat of damage when other civic agencies such as Water Supply and Drainage and Telephone companies take up maintenance work of their assets. Very often, the distribution utilities come to know of damage only after it has resulted in disruption of power to the supply area. Monitoring the cables to guard against any damage is an important requirement. Solution based on wireless sensors will be an important step towards increasing the reliability of the distribution network.

The sensor applications suitable for Under Ground cables are

- Partial Discharge (PD) detection in cables, joints and splices: Capacitive coaxial cable sensors and Inductive sensors based on high frequency current transformers, loop antenna
- Cable thermal detection using fiber optic distributed sensors and IR based measurements

OH and UG Distribution - Faults Identification

Several methods such as impedance based methods have been used for distribution system fault location. The impedance based methods can have accuracy of less than 3%. Many HV / MV protection units have built-in fault locators based on impedance based methods. But in case of MV networks, the impedance methods are not successful due to varying electrical characteristics in different parts of the network.

Wireless sensors based approach will be effective in Fault localization, and open circuit detection. By locating a set of current sensing elements at periodic intervals, a central system collecting all the information can arrive at a faulty region by analyzing the measurements at various locations along the feeder. Similar approaches can also be applied to HV feeders. The distance between successive sensors will be based on the resolution required for the solution and the feasibility for physical mounting. A simple example application is shown in Figure 2. In the radial network with the direction of power flow from the HV/MV substation to the receiving station, the fault shown closer to S3 can be identified by the increase in current in S1 and S3 and the reduction in current measured by S2.

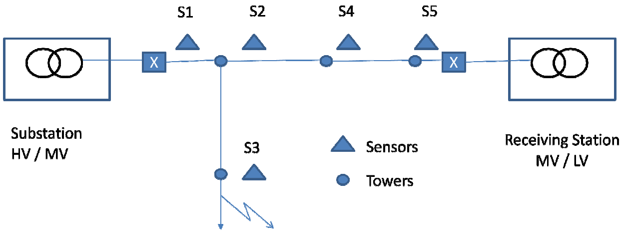

Figure 2: Sensor data based fault localization

The intelligence to detect this can be part of the gateway node that collects the sensor data of the section of the network or it can be part of the analytics deployed on the aggregated sensor data. The identified faulty region can be indicated in Human Machine Interface part of the SCADA / Network Monitoring System. This application can also be extended to detect theft of electrical power through strategic placement of measurement nodes.

The sensors use the current transformer for measurement and powering the wireless sensor with backup power from batteries. The sensor based fault localization algorithm can also use data from protective relays. By optimal location, sensor based measurements can complement the measurements available from digital relays and Fault Circuit Indicators (FCIs)

Few measurable system parameters can affect fault indicator and relay operation such as inrush current, cable discharge, proximity effect, back-feed voltages/currents etc.

The ability to quickly pinpoint from a central location where a fault is located and identifying spurious trippings can significantly shorten the time to restore power after a fault. NetCBM can include analytics on the collected data to establish correct operation of FCIs and relays based on other measured parameters and identify corrective actions.

Transformer condition monitoring

Detection of Partial Discharge (PD), electrical arcs and hot spots help in identifying deteriorating condition of transformers. On line partial discharge detection sensors based on magnetic radio-frequency capacitive coupling antenna allow non-intrusive PD detection. They are used for PD detection in switchgear and transformers. Acoustic sensors can also be used for PD detection. Infrared thermal sensors are used to detect hotspots in critical elements of the transformer. These correlated with other measurements – 3 phase currents, Air temperature, and humidity help in detection of abnormal conditions and used to trigger an alarm in the Network Monitoring Systems. The wireless communication link can also be used to upload image of important transformers and important nodes in the network to detect security infringements.

ENTERPRISE LEVEL CBM

Wide deployment of sensors for condition monitoring could change the way that the distribution grid and equipment are operated and maintained. A variety of advanced sensors help achieve this functionality. To process and interpret all of the data generated by advanced sensors, NetCBM offers a centralized monitoring and control applications with advanced analytics.

The proposed NetCBM approach will significantly influence the distribution system maintenance practices. NetCBM approach offers a cost-effective way to gather much needed data from aging system components. The information that is gathered from wireless sensors would assist in decision making on refurbishment and replacement, as well as increase worker safety through early identification of failing components. Many of these sensors operate in remote locations that cannot otherwise be effectively and continuously monitored.

This helps operators and analysts interpret data and make optimal operation and maintenance decisions on a local and regional basis. Maintenance actions are then executed just in time, deferring unnecessary maintenance, avoiding component failure and making best use of existing assets.

WSN REQUIREMENTS FOR POWER NETWORKS

Collaborative signal and information processing over a WSN is related to fusion of distributed information. Important technical issues include the following aspects

- Processing data from more sensors generally results in better performance but also requires more communication resources.

- To minimize the information lost when raw data is transmitted, more bandwidth is required.

Therefore, one needs to consider the multiple tradeoffs between performance and resource utilization. Examples of recent research results can be found in [2], where localized algorithms and directed diffusion are developed.

As a large geographically distributed system, the distribution grid, with its many sensors, can be viewed as one large sensor network. Some monitoring systems that were developed earlier were more for “remote monitoring of selected assets” than “network condition monitoring”. The sensor network becomes a promising solution for large area monitoring of the power grid and could drastically enhance our situational awareness of its condition, if cost effective and reliable WSNs are developed and deployed.

Because of dynamic environments, along with energy and bandwidth constraints, WSNs pose many technical challenges.

Sensor Nodes

A sensor node is made up of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit. For standard measurements like temperature, all subunits can fit into a small size unit (about the size of a match box).

Some of the requirements of sensors (sensor nodes) for Power System application are

- Sensor nodes should be small in size and cost-effective as the requirement is large in number and for certain applications have to be densely deployed
- Low power consumption – as battery power without effective energy recharging options has to be used e.g. underground applications
- Simple network protocols and algorithms to be used as the performance is limited in power, memory and computational capacity. The NetCBM analytics application will handle the complex analysis requirements on the collected data

Networking and Communication

Main network requirements for WSN applications are

1. Self-organizing capability to handle dynamic positioning of sensor nodes, changing topology.
2. Self-healing capability to handle failures of specific sensor nodes resulting in re-routing
3. Optimized network routing

A WSN is organized in many topologies such as star, cluster tree, mesh etc. depending on the application. Among them, a cluster tree topology is more suited to networks that cover larger physical areas, where no single device is able to directly link with every other device.

The large cluster tree network self-organizes into smaller subnets, each of which has a master node. Data flows from an end device to its master node, through a router node to a higher subnet, and continues upward until reaching a central collection device.

Selection of sensor technologies and communication options for deployment of NetCBM should consider the following aspects:

- WSN may face strong electromagnetic interference from power line disturbances. Radios supporting suitable RF modulation characteristics, antennas, frequency band of operation needs to be selected.
- Powering the sensor nodes also will be an issue as powering from high voltage mains will not be easy. Solar powered rechargeable battery could be an appropriate choice, if the overall power consumption of the node can be managed to that level.
- There will be a need for custom designed communication platform and sensor assembly with suitable packaging to protect from environmental adversities, for a feasible low cost monitoring system.
- The protocols used for networking and management of the nodes need to be selected to enable efficient synchronization, routing, and low power consumption.

ROUND UP AND WAY FORWARD

NetCBM will offer the platform to realize “swarm intelligence” [6], a concept that encompasses advanced sensor and communication technologies for a future awake, responsive, adaptive, self-healing, price-smart, eco-friendly, efficient, real-time, flexible, and interconnected electricity network. When realized, this concept results in:

- Enhanced real-time monitoring and control of power system conditions; increased adaptive intelligence, automation; improved reliability and quality of power at the point of use.
- The ability to continuously monitor the parameters of the critical components across the power system enables a fundamental shift from traditional time-based / usage-based maintenance to condition-based maintenance.
- Availability of real-time data on equipment condition and the potential risk of failure enable better informed system operation.

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