A COMPREHENSIVE SECONDARY SUBSTATION MONITORING SYSTEM

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ABSTRACT
This paper introduces a comprehensive monitoring system for urban MV/LV substations. The system has been specified by Helen Electricity Network Ltd, a subsidiary of Helsinki Energy. The pilot system has been developed by a group of companies specialized in SCADA, power system protection, and power quality issues. The system includes e.g. power quality measurements & database, disturbance recordings, fault location, transformer monitoring, and remote control of the MV switches at the substation. The paper reports the experience of the pilot project consisting of five secondary substations.

INTRODUCTION
The development of the first generation secondary substation monitoring system started at Vamp Ltd in 2002. This system measured all electrical quantities on the LV side of the transformer, calculated the loading of the transformer and registered the abnormalities in power quality. SMS technology was used for communication.

The second generation system was developed during 2007 according to customer feedback. The new monitoring unit was based on the technology used in protection relays manufactured by Vamp Ltd. This technology had been used in all relays developed after year 2000. One of the most important customer requirements was the indication of MV earth faults and short circuit faults. Another important issue was the development of the communication between the monitoring unit and the SCADA and DMS systems in the control room. The SMS technology was replaced by IEC-104 protocol and GPRS.

The invitation to submit tenders of a comprehensive substation monitoring system by Helen Electricity Network Ltd (Helen) included functions that required co-operation of several partners. Co-operation of Netcontrol Oy, PowerQ Oy, and Vamp Ltd was created to fulfil the requirements of the specified pilot system. The delivery of the pilot system was started in June 2008 and it was completed by October.

THE MAIN FEATURES OF THE MONITORING SYSTEM

The system consists of four functional areas:
- Secondary substation level functions
- Communication between secondary substations and the control centre
- SCADA interface to critical functions
- Power quality database and reporting

Figure 1 presents the system diagram of the developed system.

In addition to technical issues, the most important feature of the system is cost effectiveness, including investment costs and annual operation and maintenance costs. This requirement is essential due to the low fault frequency level characteristic of urban cable networks and the large number of the secondary substations, in Helen’s case 2.400. This is a very high number compared to the number of primary substations, only 20. Although the pilot project consists of only five secondary substations, the technical requirements have been specified so that the system can be expanded to cover hundreds of substations. Part of the substations will be equipped with remote control.
THE FUNCTIONS AT SECONDARY SUBSTATIONS

In the pilot system there are two types of secondary substations: remote monitored and remote controlled. Four of the substations are remote monitored and one is remote controlled and equipped with two transformers.

The main instrumentation of the system in a remote monitored secondary substation with one transformer is simple, consisting of two units: measurement and control unit WIMO 6CP10 and communication unit Netcon GW325. Figure 2 presents an example of the monitoring equipment at a secondary substation.

Figure 2. The main instrumentation of a remote monitored secondary substation.

One of the pilot secondary substations was equipped with remote control, because in the future Helen will apply this technology in a part of its substations. The chosen substation includes two transformers, both of which are monitored. The monitoring and control of this kind of substation is possible using the equipment illustrated in Figure 3.

Figure 3. Monitoring and communication devices of a remote controlled secondary substation.

The measurements and associated control and alarm functions are carried out by measurement and monitoring unit WIMO 6CP10. The device can be characterized as a simplified protection relay, including only one trip relay. On the other hand, the measuring properties of the unit are versatile and it can be equipped with several types of sensors. This is illustrated in Figure 4.

Figure 4. Connection diagram of WIMO6CP10.

SENSORS

Normally secondary substations are equipped with current transformers on the LV side in each of the three phases. The nominal current is typically 5A. The phase voltages can be directly connected to the measurement and monitoring unit. The power is supplied by one phase voltage.

In addition to traditional phase current and voltage measurements WIMO unit measures the temperature of the transformer using a Pt100 sensor.

Short-circuit fault indicators on the MV side can be connected to the digital inputs of the measurement and monitoring unit. To be able to indicate earth faults, WIMO unit measures the earth-fault current on the MV side using a zero sequence current sensor.

Figure 5. Examples of short-circuit and earth-fault sensors that can be connected to WIMO measurement and monitoring unit.

THE FUNCTIONS OF THE MEASUREMENT AND MONITORING UNIT

The measurement and monitoring unit records the measurements and state indications with time stamps. Most of the measurement data is used for customer power quality monitoring. The following quantities can be measured and calculated:
- Disturbance recording files
- Voltages, 10 min average
  - voltage sags, depth, duration and time stamp
  - voltage spikes, height, duration and time stamp
  - voltage 10 min average alarm level (max, min) monitoring and alarm
- Hourly averages of active power
- Hourly averages of reactive power
- Phase currents, 10 min averages
- THD (2..15 harmonic) in each phase

The quantities are recorded in permanent memory during the last month. However, the normal procedure is to remote read the recorded data once a day and store it in the measurement data base in the control centre.

Other functions, not related to power quality, are the following:
- Measurement of the earth-fault current (MV side) and earth-fault indication
- Indication of MV short circuit by s-c indicators
- Measurement of the temperature of the transformer using Pt100 sensor

Three general purpose digital inputs can be used for e.g. various state indications or contact alarms.

Monitoring of transformer load and temperature is expected to decrease the probability of transformer fires, which can be very hazardous especially in urban networks. Especially because the increase of cooling load in Helsinki has transferred the transformer peak load in many cases from winter to summer time, temperature monitoring is a useful feature.

At the control room level the critical data, such as earth fault and short-circuit fault indications, transformer temperature alarms, and alarms of nonconformities in power quality data are directed to SCADA system. The less critical data related to power quality, and disturbance recordings, is stored in the power quality data base.

LOCATION OF EARTH FAULTS AND SHORT CIRCUIT FAULTS

The location of faults in the MV network can be based on the indication of short circuit and earth fault at secondary substations. In short-circuit faults, the short circuit indicators activate and send alarm signal if the fault current has passed the secondary substation. Indication of earth fault is based on the measurement and analysis of the earth-fault current. In earth isolated network, selective indication is easily achieved.

Depending on the fault location, several secondary substations can send the indication simultaneously. The indication is immediately transferred to the control centre where it can be shown graphically by SCADA or DMS system. Figure 6 illustrates the principle of the fault location.

![Figure 6. The principle of the fault location.](image1)

COMMUNICATION

Normally there is no wired communication to secondary substations. Thus it is reasonable to apply wireless communication, already existing for other purposes, and completely covering the distribution networks in urban areas. The public wireless GSM/GPRS telephone network satisfies the needs of secondary substation monitoring system. The speed of data transfer is adequate and the costs are low since the size of the transferred data is limited.

Every secondary substation is equipped with GPRS gateway, and a data concentrator is installed in the control room. Virtual Private Network (VPN) connections are established between the control room and the secondary substations. Figure 7 illustrates the communication system.

![Figure 7. Overview of the communication of the secondary substation monitoring system.](image2)

Inside the secondary substations, Netcontrol Oy’s GPRS gateway is used, and the communication between WIMO units and Netcon units is polling and IEC-101 based. The communication between secondary substations and the control centre is arranged using IEC-104 protocol, and it is tunneled over the GPRS using VPN.
In the control centre the data concentrator links the information between the secondary substations and the SCADA system, and it also links the requests of the power quality management system to the secondary substations. In the communication between the PowerQ Oy’s power quality database and WIMO units GETSET protocol by Vamp Ltd is used. The use of two different protocols is possible, because each protocol has its own serial port in the WIMO.

To avoid overloading of the SCADA system, the data concentrator groups 50 secondary substations into one virtual substation. This enables the monitoring of hundreds of secondary substations in the future.

The status of the communication equipment is monitored by the data concentrator in real time. In case of communication failure the concentrator rebuilds the connection or gives an alarm, if the fault is permanent. In the future it is possible to expand the communication capabilities of the system with other wireless solutions.

NOT JUST POWER QUALITY

Power quality information system is delivered as Application Service Provisioning (ASP) by PowerQ Oy. This means that implementation is easier and utility’s own resources are not needed in system management.

The necessary measurement information is regularly or on demand transferred to the database of the PQNet system. PQNet has various advanced reports and automatic monitoring of user set limits. System provides easy and sophisticated tools for crushing data and making conclusions needed by different utility processes. Examples of monitoring reports are given in Figures 8, 9 and 10.

Measurement information can be processed to serve following utility processes:
- Fault details and fault effect to power quality
- Reporting for customer complaints for quality of supply
- Transformer condition monitoring using load and temperature analysis
- Optimizing network assets according to actual load
- Recording and detecting any exceptions in electricity supply close to the end customer
- Determining reason and responsible for these exceptions

EXPERIENCE OF THE PILOT SYSTEM

The technical efficiency of the pilot system has met all expectations. The reliability of the communication has proven to be high compared with corresponding systems in other countries.

The primary goal of the system is to shorten outage times. This emphasizes the importance of fault location. During the pilot phase the system has demonstrated its effectiveness. Two earth faults have occurred, and in both cases the indication has been correct, which verifies the usefulness of the method at least in earth isolated network. In the future, earth-fault location for compensated networks will be tested as well.

CONCLUSIONS

A unique secondary substation monitoring system has been introduced. A successful pilot project has been carried out. The technical performance has fulfilled the expectations regarding e.g. communication, fault location, and power quality monitoring, and the costs are reasonable.

The utilization of public wireless networks and standard IEC communication, allowing flexible connection of distributed RTUs to the utility SCADA system, assure easy system expansion and future technology development of the separate components of the distribution network monitoring and control system.

By implementing secondary substation monitoring as described, the distribution network operator will achieve improvements in supply performance and asset management with good cost efficiency.