Session Number: 9

Remote Real-time Display and Analysis of Substation Data

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Abstract

Substations are often equipped with a number of diverse measurement and monitoring systems which provide information on the performance of protection, switching and power distribution equipment. The usefulness of this data improves with its visibility to users in real-time. This paper will discuss practical cases where real-time substation data from a number of different sites is collected into a database and analysed according to user requirements. Automated alarms, alerts and daily reports are generated which can be used to better manage substation equipment performance and reduce downtime. This paper will be of interest to power distribution and maintenance engineers as well as consultants.

Introduction

Substations exist to provide electrical power to various loads. A number of these loads can be considered critical and the interruption of power will result in equipment downtime and loss of revenue. Due to limited capital budgets only a small percentage of substations are monitored. In spite of the drive for energy efficiency there is an ever increasing demand for electrical power which results in more critical loads being powered from utility substations.

Unavailability of capital also results in substation equipment is being operated for longer periods before refurbishment. Substations are also increasingly operated at higher levels which affects equipment life and reliability. Increased failure of aging systems is likely, as equipment which has traditionally been “idling”, is suddenly expected to operate close to 100% capacity [1].

A number of utilities and large power users have lost knowledge and expertise due to reduced maintenance budgets from downsizing and early retirements. This has resulted in fewer inspections and lack of expertise to critically analyse maintenance data. A number of monitoring options can be used to assist the electrical team improve productivity in order to deal with these issues. The monitoring solutions can be either:

- off-line monitoring using test instruments
- event driven real-time monitoring of devices and sensors
- comprehensive on-line, real-time monitoring of equipment

Where the substation has an existing automation system, a Remote Terminal Unit (RTU) is used to provide the most cost effective real-time solution. Data monitored from various Intelligent Electronic Devices (IEDs) can be integrated into an existing common platform using standard protocols and networks.

However the vast majority of substations do not have automation systems deployed.

This paper will examine a number of cases where event based real-time remote monitoring of substations has been used to cost effectively identify equipment performance issues and operational data.

Substation Equipment Monitoring

Most substations have several generations of monitoring and control equipment. The earliest devices monitored contact closures to indicate status such as breaker open or closed. Monitoring then evolved to measuring analog values such as currents, voltages and temperatures. The interfaces to these monitoring systems were often based on serial protocols and used RS422 or RS232.

In an effort to aggregate these multiple signal types, RTUs are deployed in some installations. RTUs have the ability to communicate with different generations of equipment and data protocols, and provide a standard way of communicating status and control to central sites.

The substation measurements can include the following:

- Energy measurement. Real-time measurement of equipment energy consumption and analysis to determine the effectiveness of efficiency interventions.
- Protection alarms. Real-time display of key equipment protection state.
- Power quality alarms. Analysis and real-time display of key power quality parameters.
- Equipment status alarms. Status monitoring of ancillary equipment such as backup power supplies.

Substation Communication

The IEC 61850 standard describes the communication of devices in substations. However there is a need to continue using IEDs that do not directly support the new communications functions described within the standards. There is a huge installed base of existing IEDs that still have value and can be used to communicate equipment status.

IEDs purchased for automated systems today may not be compliant to new substation communication standards. Therefore, many new and retrofit substations could consist of existing non-compliant products and new compliant products. Integration can still be accomplished through the use of gateway devices that support proprietary communications to previously installed non-compliant IEDs and then translate these communications onto a compliant network connection. This is a practical method to include devices that cannot accommodate the complexity, additional cost, and processor burden required to become compliant with the communications standards.

There are two communication layers that need to be considered when connecting monitoring equipment to a remote control room. These are the internal substation communications and the communications between the various substations and the central site. This is illustrated in figure 1.

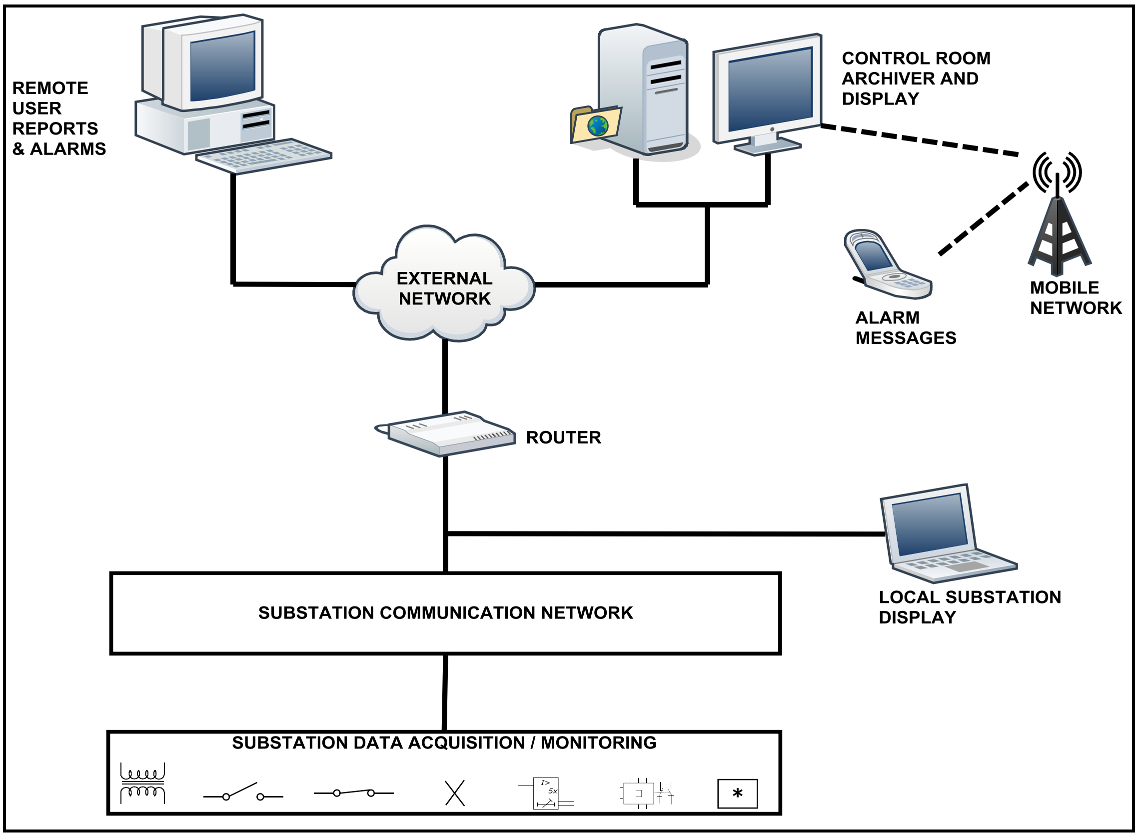


Figure 1: Substation Communications Network

The following needs to be considered in the communications system selection:

- Wired vs. Wireless. Wireless networks are easy to deploy and little installation. However they are vulnerable to electrical interference and have a limited range. Wired networks are preferred as they are
- Protocol. There are a number of standard industrial networking protocols that can be used to transfer data between various substation devices and the control room. As an example these include EtherCAT, Ethernet/IP, Modbus/TCP and Profibus.
- Security. Monitoring applications can operate with require less strict security than where switching or control is required. If a wired connection is used inside the substation there is little risk of security breaches. However the external connection to the control room may be routed through public networks. There are numerous methods to set up a secure Virtual Private Network (VPN) using standard protocols such as PPTP, IPSec or L2TP.

- Availability and Cost. The communications equipment should be readily available, locally supported and cost effective. In addition to the capital cost there are usually monthly running costs. Public networks such as GSM have a charge for the data used. The volume of data should be calculated to determine this cost.

Example: Centralised Monitoring of Three On-Site Substations

The communications network for the monitoring system is shown in figure 2.

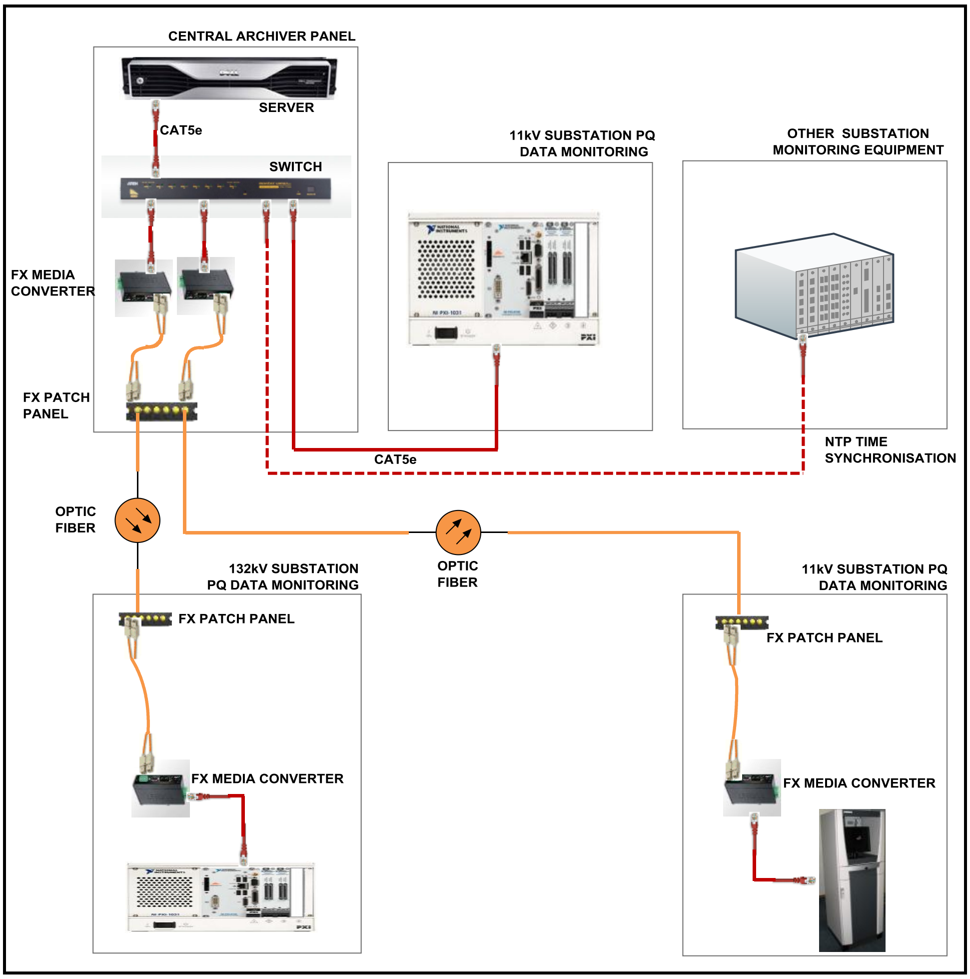


Figure 2: Three Substation Network Diagram

The system consists of a 132kV main substation and two 11KV plant substations. A centralized archiver for storing and viewing real-time data is located in one of the 11kV plant substations. Communication between the central archiver and the local monitoring systems in the substation makes use of copper Ethernet cable. Fiber optic data cable is used to connect between the archiver and the two remote substations. This ensures that the data signals are totally isolated from the electrical grounds at each site. A fiber media converter is used to convert the optic signals to electric and vice versa. The network operates at 1gigabit per second. There is a latency of about 6mS on the network.

This network is used to provide for the following:

- Remote setup and real-time viewing of the monitoring systems. Any of the sites can be configured remotely from the archiver. The measured values and contact statuses can be viewed in real time.
- Automatic transfer of daily data from the monitoring systems to the archiver.
- Group triggering of all the data acquisition systems in response to a high speed disturbance being measured at any of the sites. This ensures that data from all the sites is recorded even if the disturbance was not significant at a particular site.
- Diagnostics and alarms in the event of a failure of the communication system or any of the site monitoring systems. The systems will operate independently and continue to collect data when there is a communications network failure. When the network is restored the site data will be automatically updated on the archiver.

At present there is only local access to the data and network access from the central archiver. It is planned to add external access to the archiver via the plant fiber optic network. This will allow automated reporting and analysis of the data much simpler.

Example: Energy Monitoring in a Commercial BuildingSubstation

The increasing cost of electricity and current shortage of generation capacity has prompted many commercial building owners to monitor energy consumption in detail. This is to determine baseline energy use, identify waste and monitor energy efficiency interventions. In this example no building monitoring system (BMS) was installed and the requirement was to install energy metering and sub-metering in the building substation and the various distribution boards in the buildings. A total of 12 energy monitoring systems were installed each monitoring 4, three phase loads. The loads consisted of the building heating, ventilation and air conditioning system, hot water geysers, lighting and plug loads and temperature of the conditioned spaces. The monitoring systems had to be retrofitted into the substation equipment to measure the busbar voltage and breaker load currents.

Data is stored locally and then sent to a remote server using a GSM APN private network. The remote server processes the data and generates an energy consumption report for each of the monitored loads. Each unit generates a “heartbeat” to advise the server that the equipment is still functioning. A block diagram of the communications network is shown in figure 3.

The energy monitoring equipment can be accessed locally within the building using a WiFi network. This provides access for equipment configuration

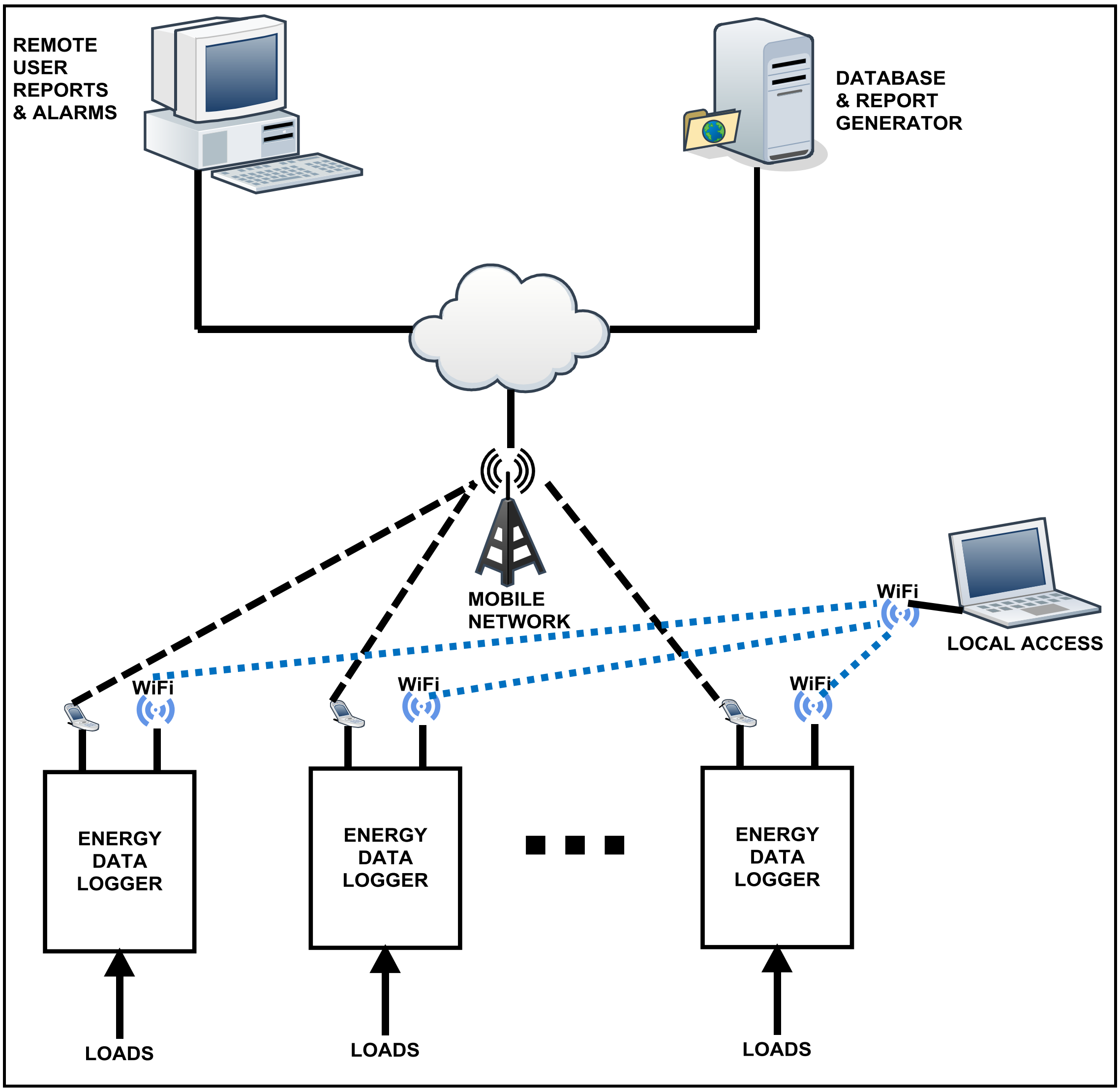


Figure 3: Energy Monitoring Network Diagram

Equipment Time Synchronisation

For analysis of high speed events it is important that all the substation monitoring systems are synchronised to the same time-base. The accuracy of the synchronisation time depends on the highest sampling frequency for the monitoring system. For example if the monitoring systems samples at 80µS, the time reference will need a better than 80µS. Systems that are monitoring for sequence-of-events or disturbances will require time synchronisation. While it is always recommended to time synchronise all remote sites, the time precision is less critical with measurements from energy metering or mean value equipment.

There are a number of options available to synchronise remote sites.

GPS Time Synchronisation

This option uses a global positioning system (GPS) receiver to provide a time reference. The system is stand-alone and can be used at any site. The only limitation is that the GPS receiver antenna must be mounted outside the substation to have an unobstructed path to the orbiting satellites. GPS time references are typically accurate to 10nS. An application similar to that shown in figure 4 will be required to provide the monitoring system with a reference clock.

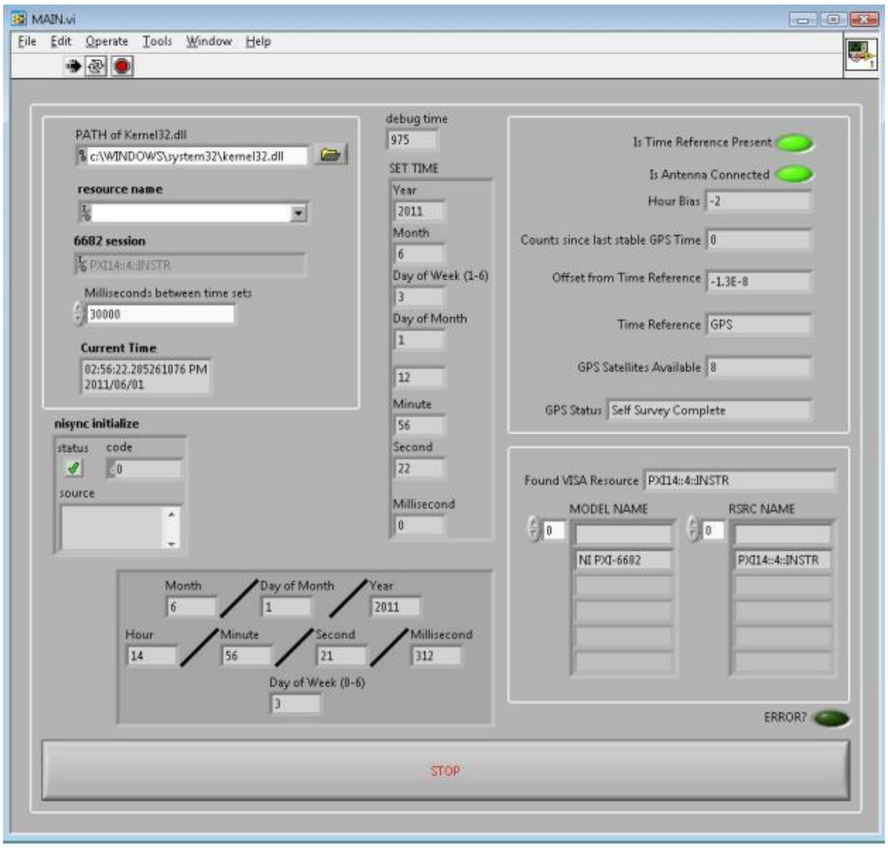


Figure 4: GPS Time Synchronisation Application Example

The three substations referred to in Case 1 above were all fitted with GPS time receivers to ensure the high speed acquired data was time synchronised.

Network Time Synchronisation

Where the remote monitoring systems are interconnected via a private or public network a network time server can be used to provide a time reference. The network time protocol (NTP) client application updates the system time from an NTP server which is located on the network. Any of the network stations can act as an NTP server and there can be multiple NTP servers on the network. NTP time is accurate to around 1mS on local networks to 10mS on public networks. This is ideal for equipment for energy measurement.

An example of an NTP Server application is shown in figure 5.

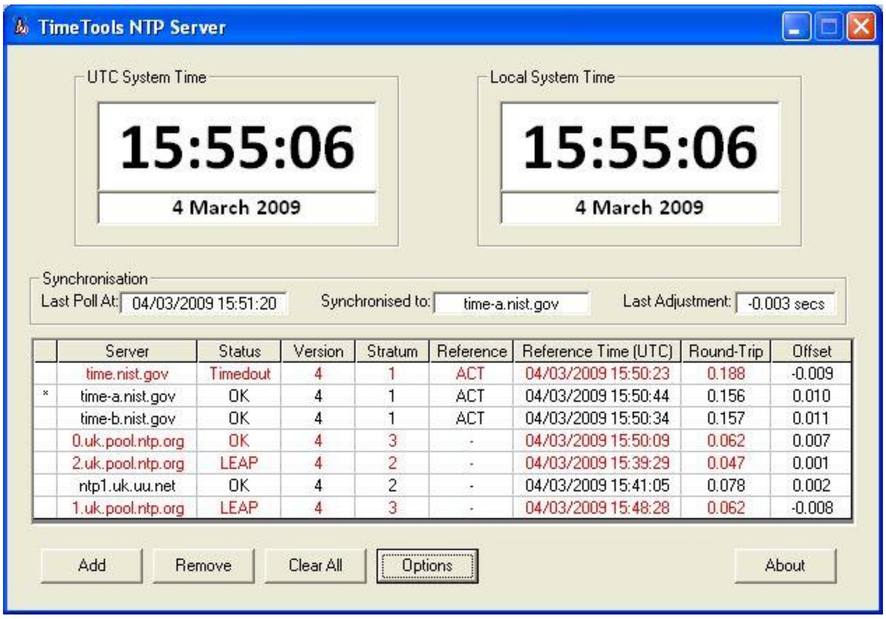


Figure 5: Network Time Synchronisation Application Example

Data Analysis and Conversion

The IEC61850 standard specifies a System Configuration Description Language (SCL) for the configuration of electrical substation devices. This includes representation of modeled data and communication services specified by the standard. Data monitored from various non-compliant substation IED's will invariably use differing formats that need to be converted. There are a number of standard formats for integrating and viewing engineering data. For example there are two useful formats for the analysing and viewing of power quality data between different vendors. The first is the IEEE Recommended Practise for the Transfer of Power Quality Data (PQDIF) and the second is IEEE Standard Common Format for Transient Data exchange for Power Systems (COMTRADE) [2].

On the central system data is often viewed in real-time using the vendor application as there may not be sufficient time to do the conversion in real time. When data from various vendor systems need to be compared the data is then converted to a vendor independent format such as COMTRADE.

An example of a voltage disturbance from a remote substation which was converted and plotted with a COMTRADE viewer is shown in figure 6.

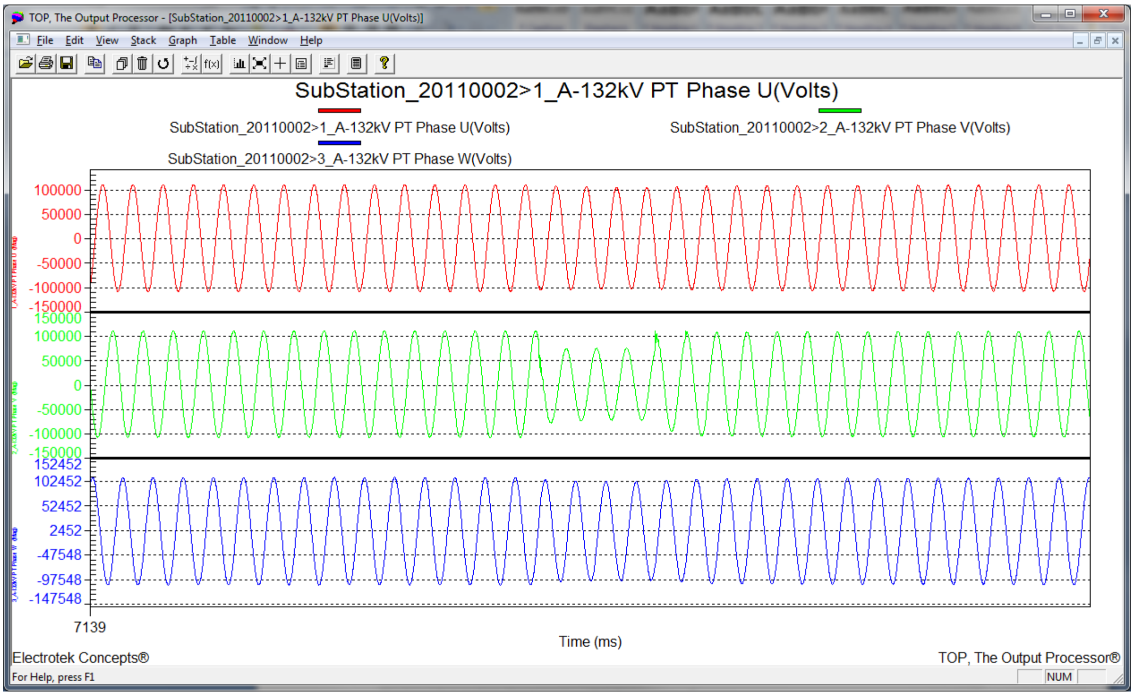


Figure 6: Substation Data Shown in COMTRADE Viewer

Various mathematical operations and analyses can be performed on the remote data. An example of a Fourier transform performed on the data from channel 1is shown below in figure 7.

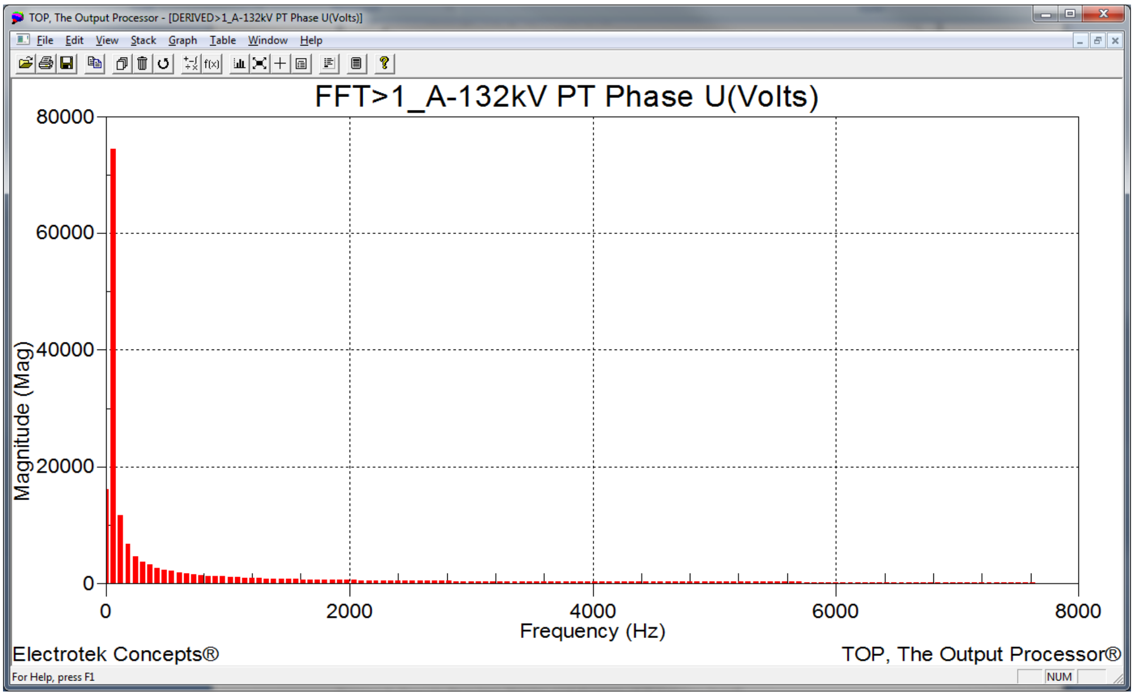
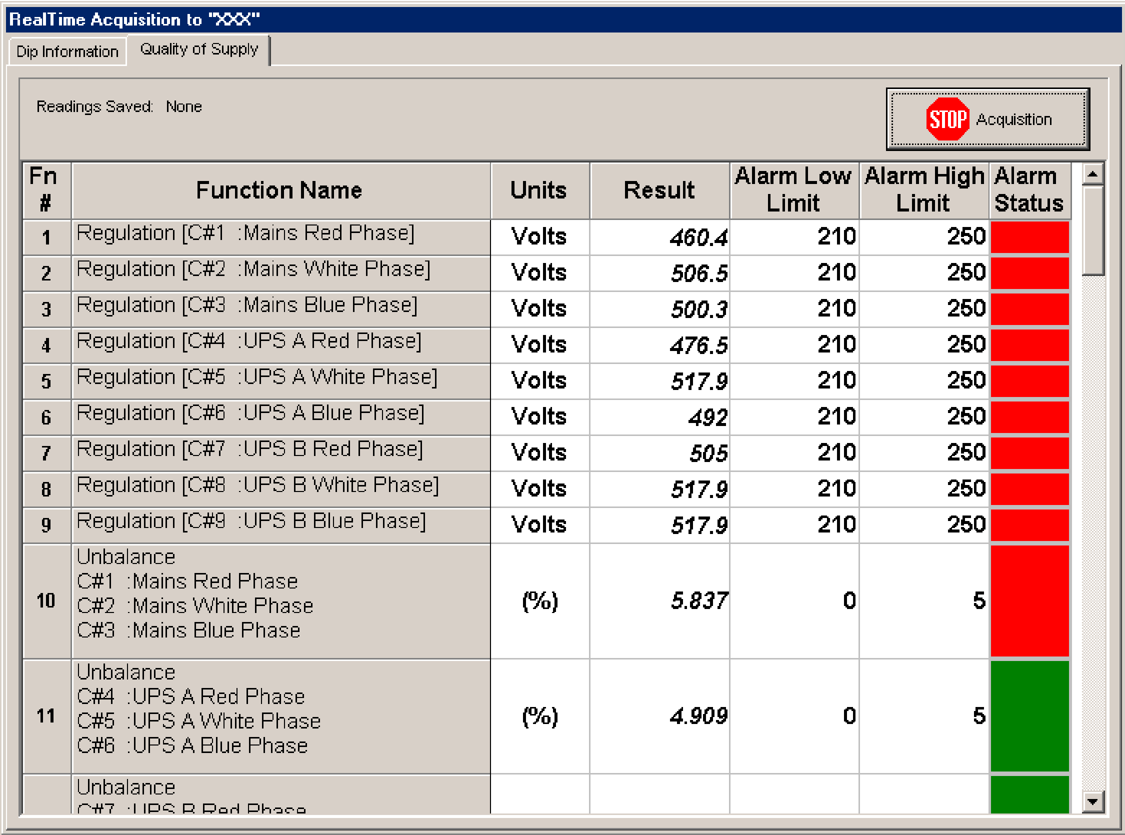


Figure 7: FFT Analysis for Substation Data

Once the data from the substation monitoring system has been converted to a vendor independent format, there are a number of applications that can be used to analyse and display the site data.

Data Presentation

The presentation of data from the remote substation equipment can be displayed in real-time for specific details. The results presented below are from cases similar to that described above. For example the screen in figure 8 is an example of a display that summarises the supply and UPS voltages for a data centre substation.


RealTime Acquisition to "XXX"

Dip Information | Quality of Supply

Readings Saved: None

STOP Acquisition

Fn #	Function Name	Units	Result	Alarm Low Limit	Alarm High Limit	Alarm Status
1	Regulation [C#1 :Mains Red Phase]	Volts	460.4	210	250	
2	Regulation [C#2 :Mains White Phase]	Volts	506.5	210	250	
3	Regulation [C#3 :Mains Blue Phase]	Volts	500.3	210	250	
4	Regulation [C#4 :UPS A Red Phase]	Volts	476.5	210	250	
5	Regulation [C#5 :UPS A White Phase]	Volts	517.9	210	250	
6	Regulation [C#6 :UPS A Blue Phase]	Volts	492	210	250	
7	Regulation [C#7 :UPS B Red Phase]	Volts	505	210	250	
8	Regulation [C#8 :UPS B White Phase]	Volts	517.9	210	250	
9	Regulation [C#9 :UPS B Blue Phase]	Volts	517.9	210	250	
10	Unbalance C#1 :Mains Red Phase C#2 :Mains White Phase C#3 :Mains Blue Phase	(%)	5.837	0	5	
11	Unbalance C#4 :UPS A Red Phase C#5 :UPS A White Phase C#6 :UPS A Blue Phase	(%)	4.909	0	5	
	Unbalance C#7 :UPS B Red Phase					

Figure 8: Real-Time Display of Substation Data

The screen in figure 9 is an example of a substation supply disturbances. The graph was the last captured value with the date/time and channel.

In figure 10 waveforms of the supply voltage feeding the substation are displayed.

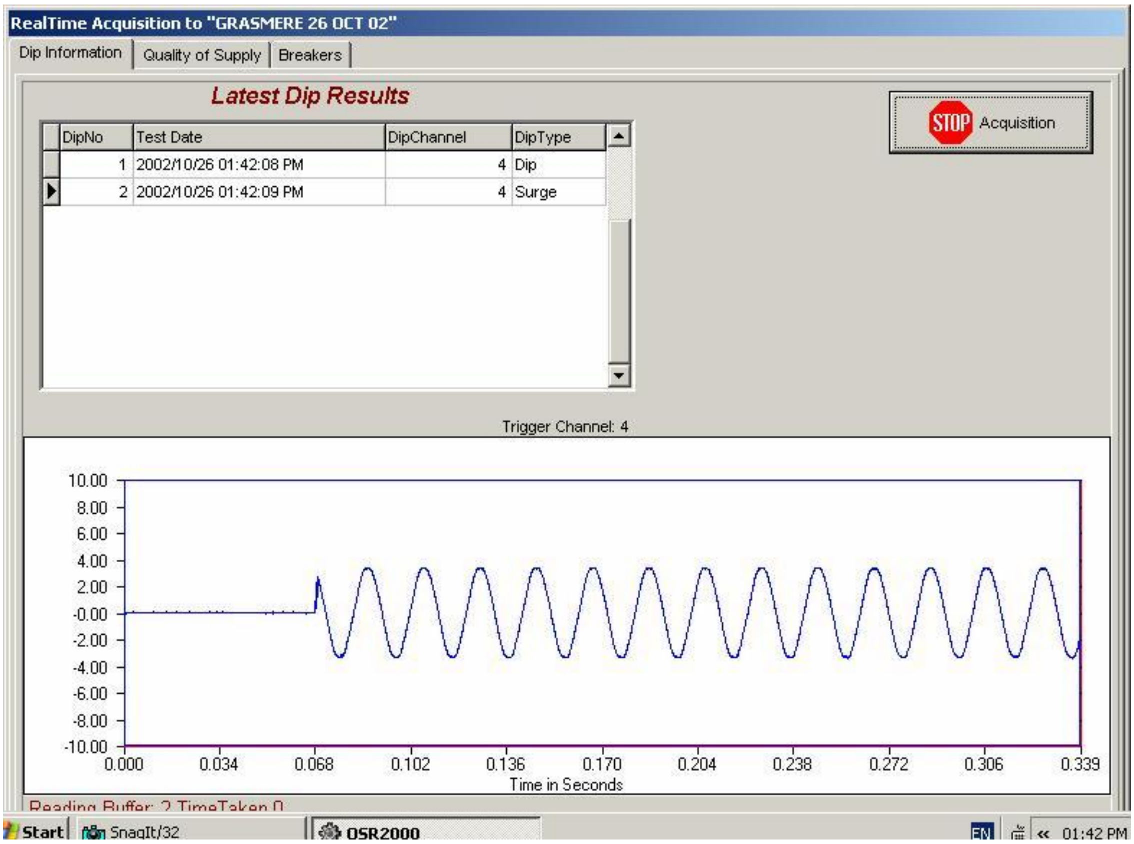


Figure 9: Real-Time Display of Substation Disturbance

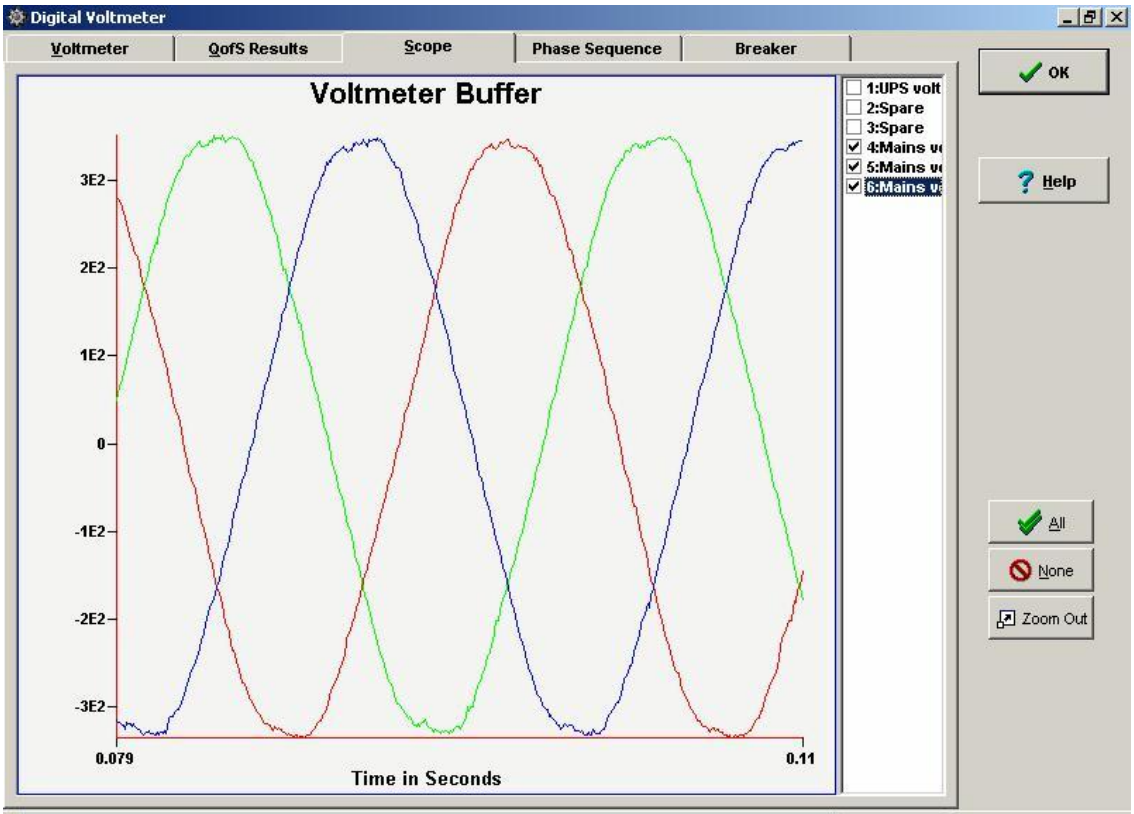


Figure 10: Real-Time Waveform Display

In addition to the remote viewing of real-time data as shown above the data from several substations can be shown together on a status screen as shown in figure 11.

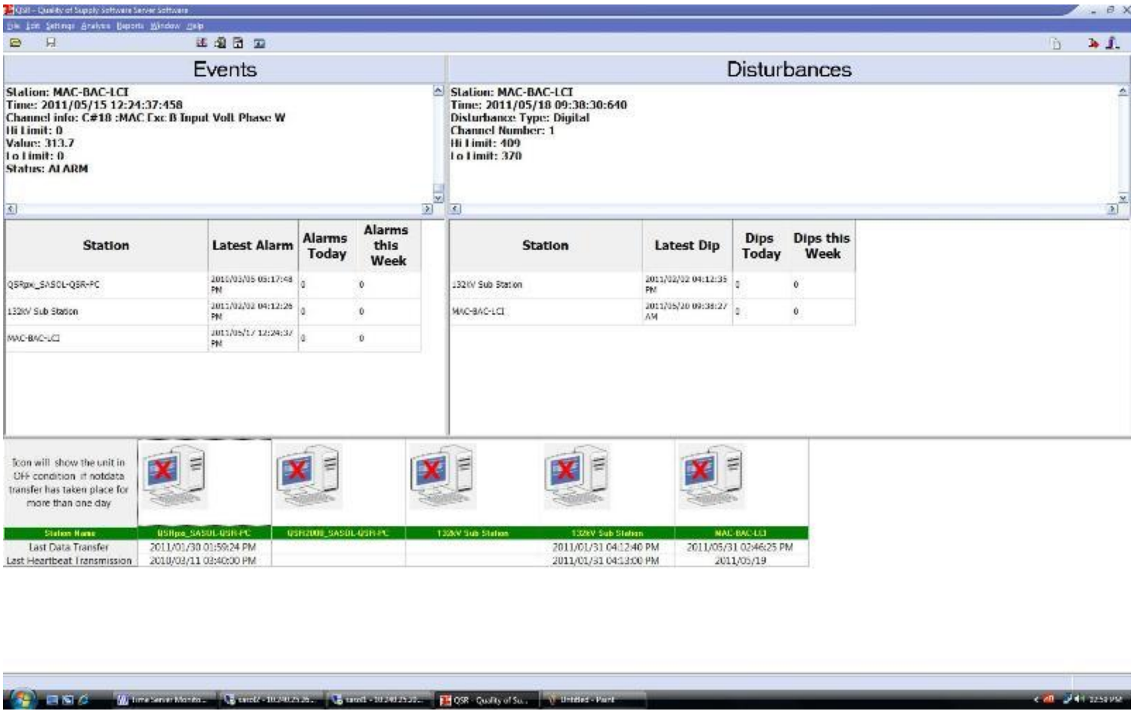


Figure 11: Control Room Display of Remote Substation Sites

In this screen a number of systems are shown with the alarm events and voltage disturbances that have been received. Operators can also view the last “heartbeat” message that has been received so the control room system can alarm if any of the remote substations fail to communicate.

For the examples shown the alarms, events and heartbeats are XML format files which can be processed by a number of software applications and saved to a SQL database.

An example of an alarm message that was sent from the substation to the control room is shown in figure 12.

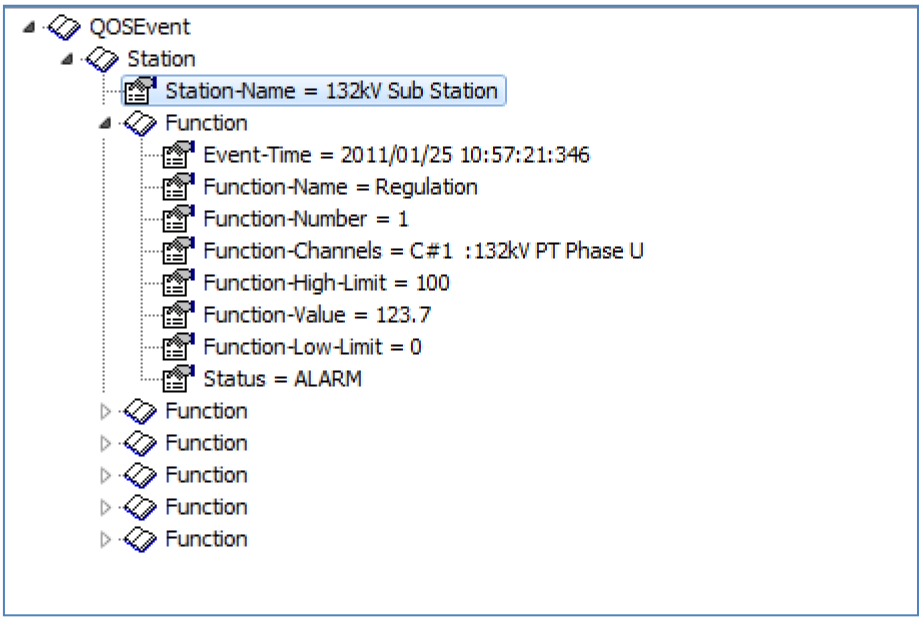


Figure 12: Substation Alarm Message Format

This message encapsulates all the necessary information to allow for processing by a system that is not familiar with the measurement system. Similar formats are used for the voltage disturbance and heartbeat messages which are shown in figures 13 and 14.

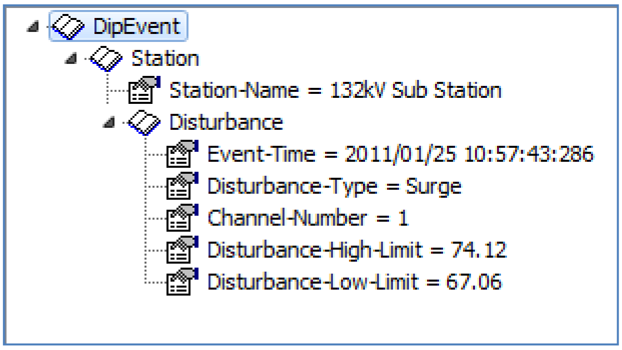


Figure 13: Substation Voltage Disturbance Message Format

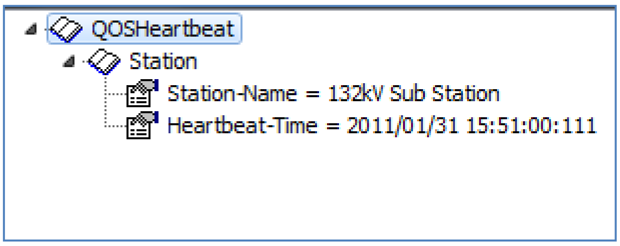


Figure 14: Substation Voltage Disturbance Message Format

As discussed above a summary data file is sent daily at midnight with the mean value data for the past 24 hours. This file contains the raw value information as well as a database table of the measured parameters. An example of the table is shown in Figure 15.

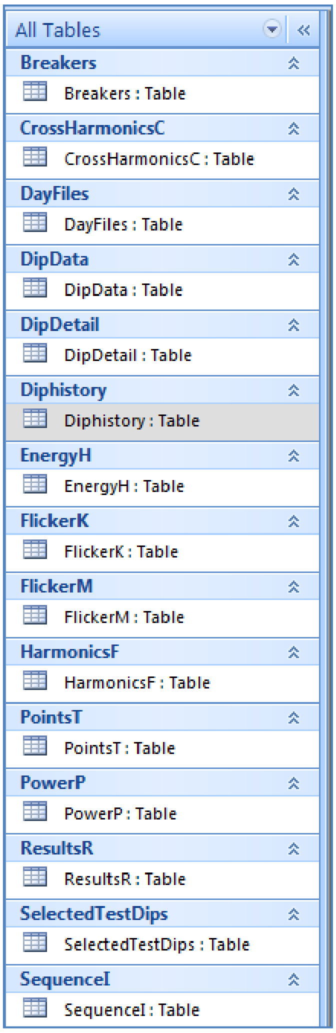


Figure 15: Database Table of Substation Measurements

A database index of all the voltage disturbance files is maintained each site. An example of the table is shown in Figure 16.

TestDips

DipNo	StationNo	DipTestTimeStamp	DipChannel	DipType	DipFilename
1	4203520	40574.675462963	1	DIP	SubStation0000.dip
2	4203520	40612.4457638889	1	DIP	SubStation_20110000.dip
3	4203520	40628.0057638889	1	DIP	SubStation_20110001.dip
4	4203520	40648.8436111111	1	DIP	SubStation_20110002.dip
5	4203520	40666.2896990741	1	DIP	SubStation_20110003.dip
6	4203520	40667.6582175926	1	DIP	SubStation_20110004.dip
7	4203520	40667.510625	1	DIP	SubStation_20110005.dip
8	4203520	40667.5106712963	1	DIP	SubStation_20110006.dip
9	4203520	40672.38	1	DIP	SubStation_20110007.dip
10	4203520	40672.4751157407	1	DIP	SubStation_20110008.dip

Figure 16: Database Table of Disturbance Measurements

A similar index is kept for the daily mean values. This is shown in figure 17.

DayFiles

FileNo	StationNo	Filename
1	4203520	SubStation_201120110310
2	4203520	SubStation_201120110311
3	4203520	SubStation_201120110312
4	4203520	SubStation_201120110313
5	4203520	SubStation_201120110314
6	4203520	SubStation_201120110315
7	4203520	SubStation_201120110316
8	4203520	SubStation_201120110317
9	4203520	SubStation_201120110318
10	4203520	SubStation_201120110319
11	4203520	SubStation_201120110320
12	4203520	SubStation_201120110321
13	4203520	SubStation_201120110322
14	4203520	SubStation_201120110323
15	4203520	SubStation_201120110324
16	4203520	SubStation_201120110325

Figure 17: Database Table of Mean Value Measurements

These tables provide summary information that can be used to present the data on a custom dashboard. The detailed measurements are contained in a data file. These can be examined, analysed and displayed in real-time as the data is received, or post processed when required as per the user's requirements.

Alarms received by the central site can be automatically forwarded to maintenance and operations personnel. This will shorten the time between any event and the response to repair or rectify the problem.

Conclusion

Data from several different substation measurement systems can be displayed in real-time from various IED's at a central control room. This can be implemented in substations where there is no existing substation automation or communication equipment.

The information collected can assist electrical maintenance and operations personnel to better manage the substation assets by using a condition monitoring approach to correcting problems and ensuring equipment is operated correctly. Productivity is improved as the monitored information can be analysed by an internal staff member or outsourced to a consultant. Historical records can be used to scan for trends and ensure equipment is replaced or repaired before it fails.

References

[1] Development of a Plant Health Index for Eskom Distribution Substations, Elton Brand, Ulrich Minnaar and Wilfred Fritz

[2] IEEE Std C37.111-1999. IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems, IEEE, New York, 1999