Fleet Management of a Large System of Online Monitors

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Overview

Online monitoring of power networks is a growing necessity to provide information on how systems and assets react to transient events and disturbances caused by weather, plant failures, changes in loads and the move to decentralized, variable sources of generation. Managing the fleet of monitors acquiring this information can be daunting especially if there is a Regulatory requirement to ensure data is recorded and shared should a wide area disturbance occur.
Large Utilities are often divided into Regions each responsible for their part of the network. Managing several hundred monitors is not uncommon. Additionally, many monitors now are multi-function devices generating different data sets ranging from fault records, slow scan disturbance records, impedance and travelling wave fault location and power quality. Integrating the data can provide powerful benefits but it is also necessary to segregate the data such that users from different departments, such as protection, operation and planning, just access what they need for their daily work.
This paper examines the features required for a centralised data collection and analyses centre, the architecture that is best suited to current IT practices and the benefits that can arise. A case study is also included where 2000 devices are managed by one system.

Features Required

A successful centralised data collection and management system must include different communication modes, data download and archiving options, information analyses, display and reporting features, device configuration and general housekeeping functions. Of equal importance is monitoring the 'health' of the network of monitors and to show, at a glance, the parts of the network where event activity has occurred graded by severity and number of incidents. This can, for example, give priority to what data is examined first after a storm where 'information overload' becomes a real problem.

Some Utilities still use dial up modem access either on the public of via a private telephone system. At distribution or sub transmission there may not be a viable alternative but some still persevere with this technique to avoid engagement with the IT department and the risk of cybersecurity restrictions and added costs. However, modem communication is becoming harder to maintain and the data rates and reliability offered do not match the current expectations. Ethernet / TCP/IP is becoming the de-facto standard for most Utilities following the widespread introduction of optical cables in the earth wires of circuits connecting all substations. Sometimes a separate network is created for 'non-control' applications like monitoring equipment but not always. Either way, IT departments become actively involved

and interfacing with them is a key element in most Utilities when establishing a centralised data collection and management system.
Where Ethernet connections are not available there is a growing use of cellular modems and routers still using TCP/IP connections but by the 3 and 4G cellular networks. Speeds and availability have improved while costs are reducing. Several distribution companies use this system for collecting power quality data.
It is to be noted that as many Utility systems evolve over time there is likely to be a mixture of communication modes employed on different parts of the network. All types must be supported to cater for both new and legacy equipment.

Data download is another key area to manage effectively within the limits of the communication channels available and the requirement to get important information in the database for near immediate analysis. As such a combination of techniques tend to be employed. Routine polling of data once or twice per day coincident with ‘quite’ times on the comms channels is the preferred way of collecting ‘routine’ data sets for lower level background analysis. A typical example of this is power quality information where the maximum, minimum and average values of over 800 parameters can be logged every 10 minutes for a single circuit but reporting is only required, say, once per week. The type of data to be downloaded during the poll and the interval can be selected in a dialogue box similar to that shown in Fig 1.

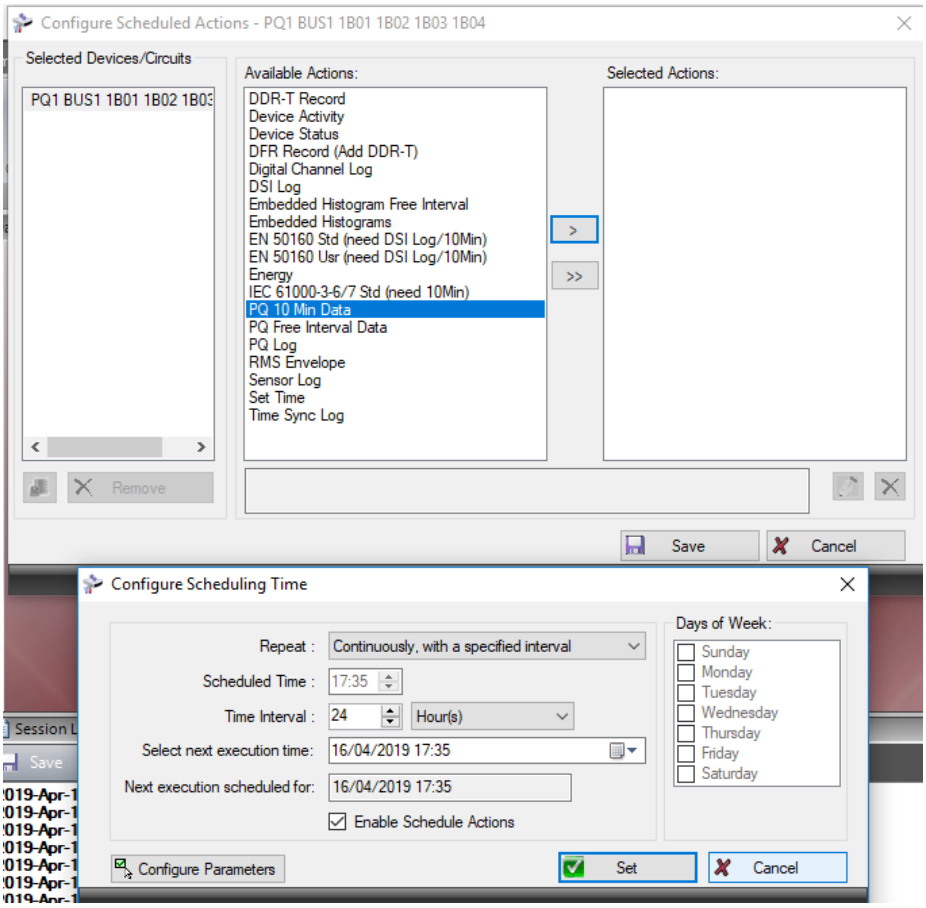


Fig 1 Example of Configuring Scheduled Polling

However, the concept of pushing data up the line when a high priority event occurs is a necessity where urgent analysis is required to decide on the next actions. In such cases, for example fault and distance to fault data after a line trip, it is necessary for the device to automatically send a ‘request to poll now’ message to the central server such that the relevant data can be immediately retrieved and made available for analysis. For that it is necessary to set ‘auto com’ destinations on the device coincident with the location of the central collection system as in Fig 2.

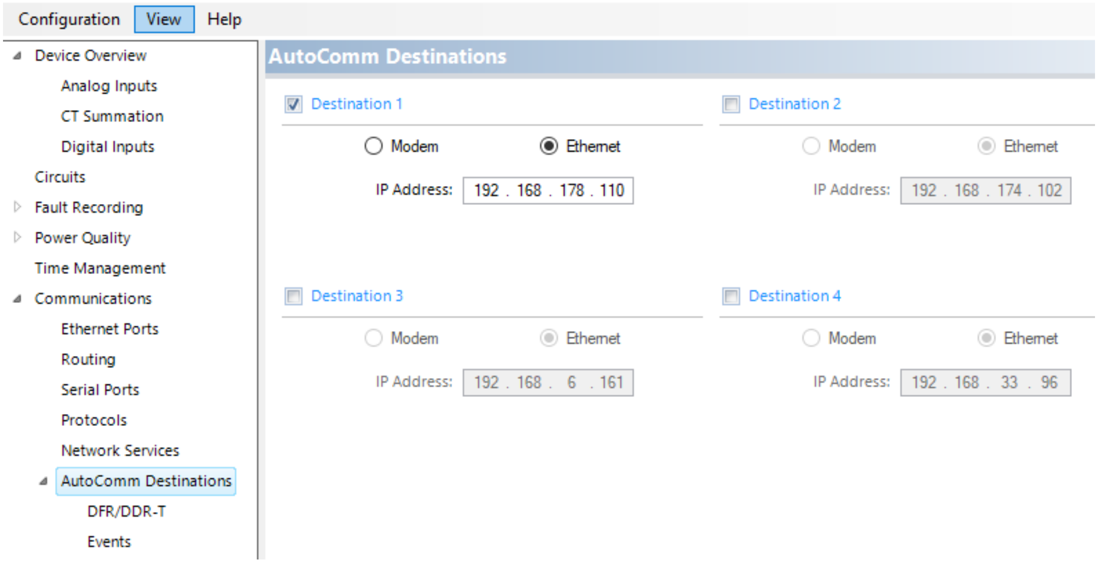
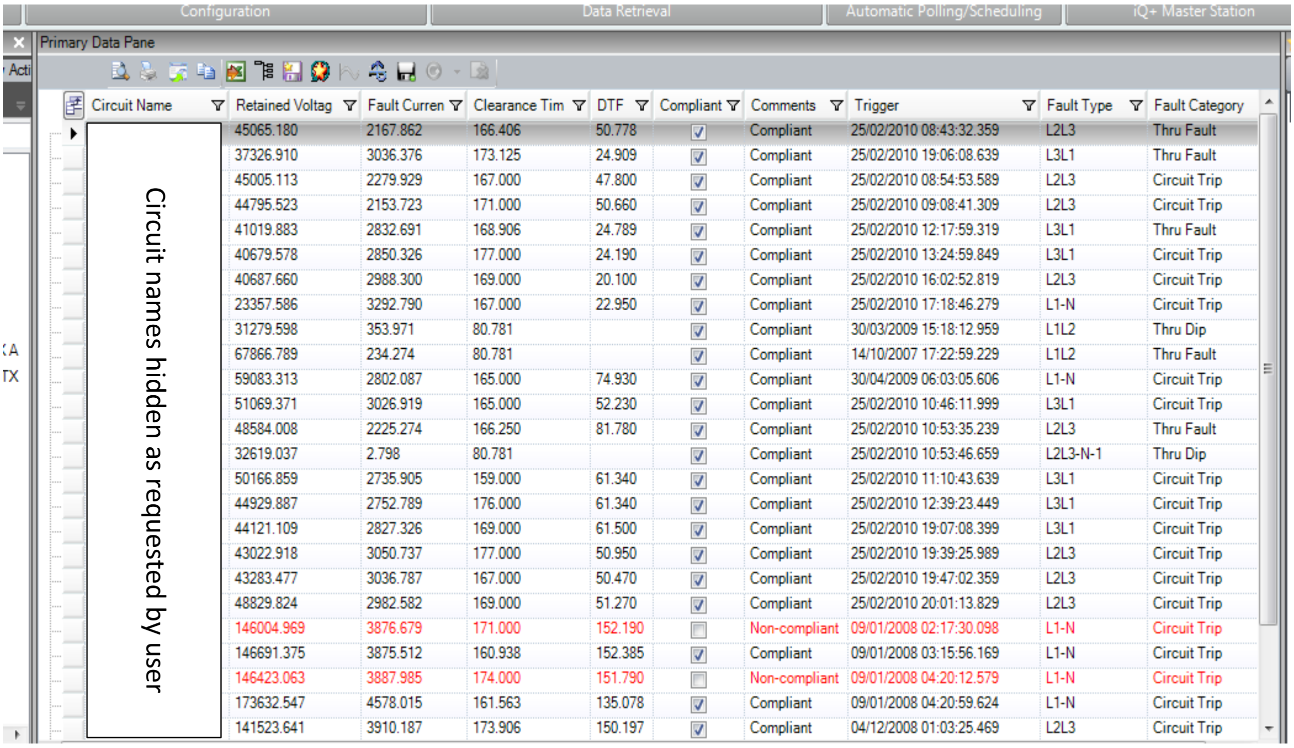


Fig 2 Example of Setting Auto-Com Destinations to Push Data from the Device

A third method that must be supported is a manual override from an operator to retrieve certain data sets from specified device(s) immediately.
Monitoring systems on Utility networks are built up over time and usually involve devices from several different vendors. In such cases the vendor software can be used to download data from their own units and standard protocols used to export that data to a centralised analysis and display application that could be one of the vendor software solutions. COMTRADE (Common Format for Transient Data Exchange) is often used to transfer fault and dynamic disturbance (slow scan) records and PQDIF or csv files used for power quality.

Once downloaded it is common to organise data around a standard database like SQL. Most IT departments have an enterprise license and already have examples of databases running for other applications that they are used to maintaining. It is important that data is organised such that different types of data are accessible by different types of users. Not all data is required by all users.
Note that large amounts of data can be accumulated depending on the settings used on the devices. Good housekeeping Is necessary to manage the volume effectively. Older data sets can be archived and unwanted information deleted.

The analyses of the data remains the most visible function of a centralised collection system. Features for manual display and interpretation of different data sets are necessary where data from specific events or time periods can be viewed, measurements made with on screen cursors and files exported to third party applications for more detailed specific processing. However, with the growing volume of data and the general trend to limit staffing levels, it is becoming more important for algorithms to automatically process information as it is received. This saves operator time by highlighting ‘noncompliant’ behaviour as opposed to ‘compliant’ behaviour. This allows operators to concentrate their time on understanding situations where follow up action is required. For example, every fault record can be processed on receipt to determine the type of event (circuit trip, through fault, voltage dip etc), establishing the salient feature of the event (maximum current, minimum voltage, protection and breaker operate times, clearance time etc) and if the operation was noncompliant, that is behaviour was not as expected. Noncompliant records can be listed separately and prioritised. A summary report of every fault record analysis is available for distribution via email. An example of a list of short summaries from a record analysis process is shown in Fig 3.



Circuit Name	Retained Voltag	Fault Curren	Clearance Tim	DTF	Compliant	Comments	Trigger	Fault Type	Fault Category
	45065.180	2167.862	166.406	50.778	☑	Compliant	25/02/2010 08:43:32.359	L2L3	Thru Fault
	37326.910	3036.376	173.125	24.909	☑	Compliant	25/02/2010 19:06:08.639	L3L1	Thru Fault
	45005.113	2279.929	167.000	47.800	☑	Compliant	25/02/2010 08:54:53.589	L2L3	Circuit Trip
	44795.523	2153.723	171.000	50.660	☑	Compliant	25/02/2010 09:08:41.309	L2L3	Circuit Trip
	41019.883	2832.691	168.906	24.789	☑	Compliant	25/02/2010 12:17:59.319	L3L1	Thru Fault
	40679.578	2850.326	177.000	24.190	☑	Compliant	25/02/2010 13:24:59.849	L3L1	Circuit Trip
	40687.660	2988.300	169.000	20.100	☑	Compliant	25/02/2010 16:02:52.819	L2L3	Circuit Trip
	23357.586	3292.790	167.000	22.950	☑	Compliant	25/02/2010 17:18:46.279	L1-N	Circuit Trip
	31279.598	353.971	80.781		☑	Compliant	30/03/2009 15:18:12.959	L1L2	Thru Dip
	67866.789	234.274	80.781		☑	Compliant	14/10/2007 17:22:59.229	L1L2	Thru Fault
	59083.313	2802.087	165.000	74.930	☑	Compliant	30/04/2009 06:03:05.606	L1-N	Circuit Trip
	51069.371	3026.919	165.000	52.230	☑	Compliant	25/02/2010 10:46:11.999	L3L1	Circuit Trip
	48584.008	2225.274	166.250	81.780	☑	Compliant	25/02/2010 10:53:35.239	L2L3	Thru Fault
	32619.037	2.798	80.781		☑	Compliant	25/02/2010 10:53:46.659	L2L3-N-1	Thru Dip
	50166.859	2735.905	159.000	61.340	☑	Compliant	25/02/2010 11:10:43.639	L3L1	Circuit Trip
	44929.887	2752.789	176.000	61.340	☑	Compliant	25/02/2010 12:39:23.449	L3L1	Circuit Trip
	44121.109	2827.326	169.000	61.500	☑	Compliant	25/02/2010 19:07:08.399	L3L1	Circuit Trip
	43022.918	3050.737	177.000	50.950	☑	Compliant	25/02/2010 19:39:25.989	L2L3	Circuit Trip
	43283.477	3036.787	167.000	50.470	☑	Compliant	25/02/2010 19:47:02.359	L2L3	Circuit Trip
	48829.824	2982.582	169.000	51.270	☑	Compliant	25/02/2010 20:01:13.829	L2L3	Circuit Trip
	146004.969	3876.679	171.000	152.190	☐	Non-compliant	09/01/2008 02:17:30.098	L1-N	Circuit Trip
	146691.375	3875.512	160.938	152.385	☑	Compliant	09/01/2008 03:15:56.169	L1-N	Circuit Trip
	146423.063	3887.985	174.000	151.790	☐	Non-compliant	09/01/2008 04:20:12.579	L1-N	Circuit Trip
	173632.547	4578.015	161.563	135.078	☑	Compliant	09/01/2008 04:20:59.624	L1-N	Circuit Trip
	141523.641	3910.187	173.906	150.197	☑	Compliant	04/12/2008 01:03:25.469	L2L3	Circuit Trip

Fig 3 Example of a Record Analysis Summary Listing

Reporting functions are essential for power quality otherwise the amount of data becomes overwhelming. Weekly reports to a standard or custom design can be distributed giving an overview of performance and highlighting any parameters that exceed thresholds set by the user or based on a standard like EN50160.

Distance to fault results are often linked to fault records when they are impedance based but there is a growing usage of travelling wave devices that generate separate automatically calculated results and produce waveforms that can be further used for manual analysis. This data set also requires support.

Data overload is a common criticism of centralised data collection systems. There is so much information but where do I start looking? To assist in this a 'system overview' dashboard helps to summarise what has happened across the network. Devices are listed along with a summary of what each monitor has recorded over a specified time period, for example the last 12 hours. The number of fault and slow scan records generated, the number of power quality events (voltage dips, occasions where harmonic levels exceeded limits etc), the number of travelling wave distance to fault results calculated all give a picture of what activity has occurred where on the network. A short cut feature allowing a user to drill down to the detail of each data set with a single click, along with the results of the automatic fault record analysis, greatly improves the efficiency of working through the backlog, identifying potential problems with the network / assets and routing results through to the relevant departments for further analyses / remedial actions.

Fig 4 gives an example of a System Overview screen for travelling wave fault location activity.

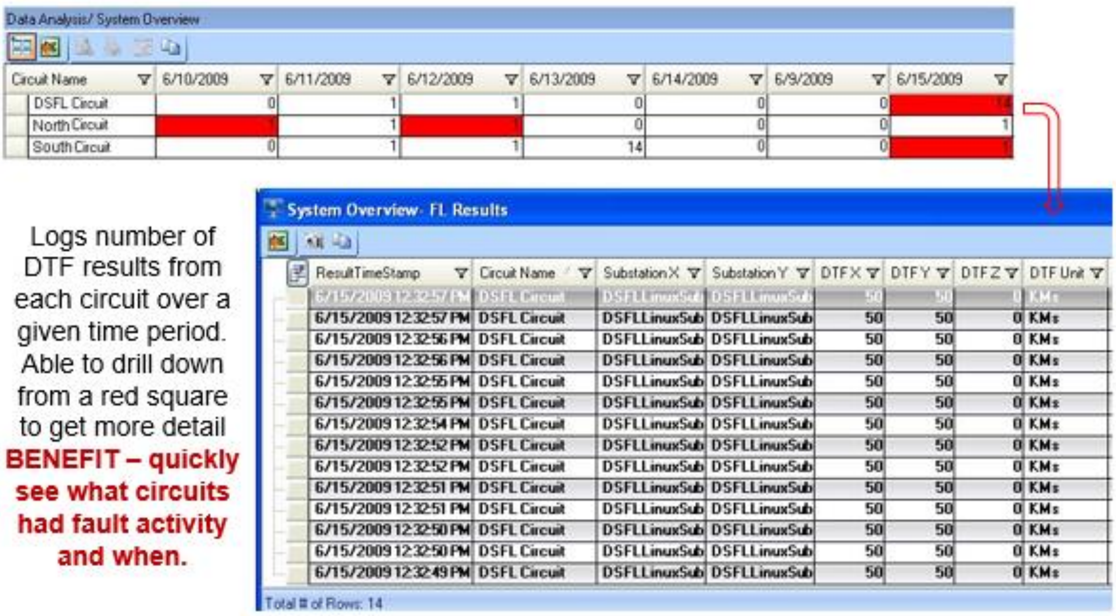


Fig 4 Example of Fault Location Overview with Short Cut to More Detail

Figure 5 is an equivalent view for power quality events. Note that the device names have been blurred at the request of the user.

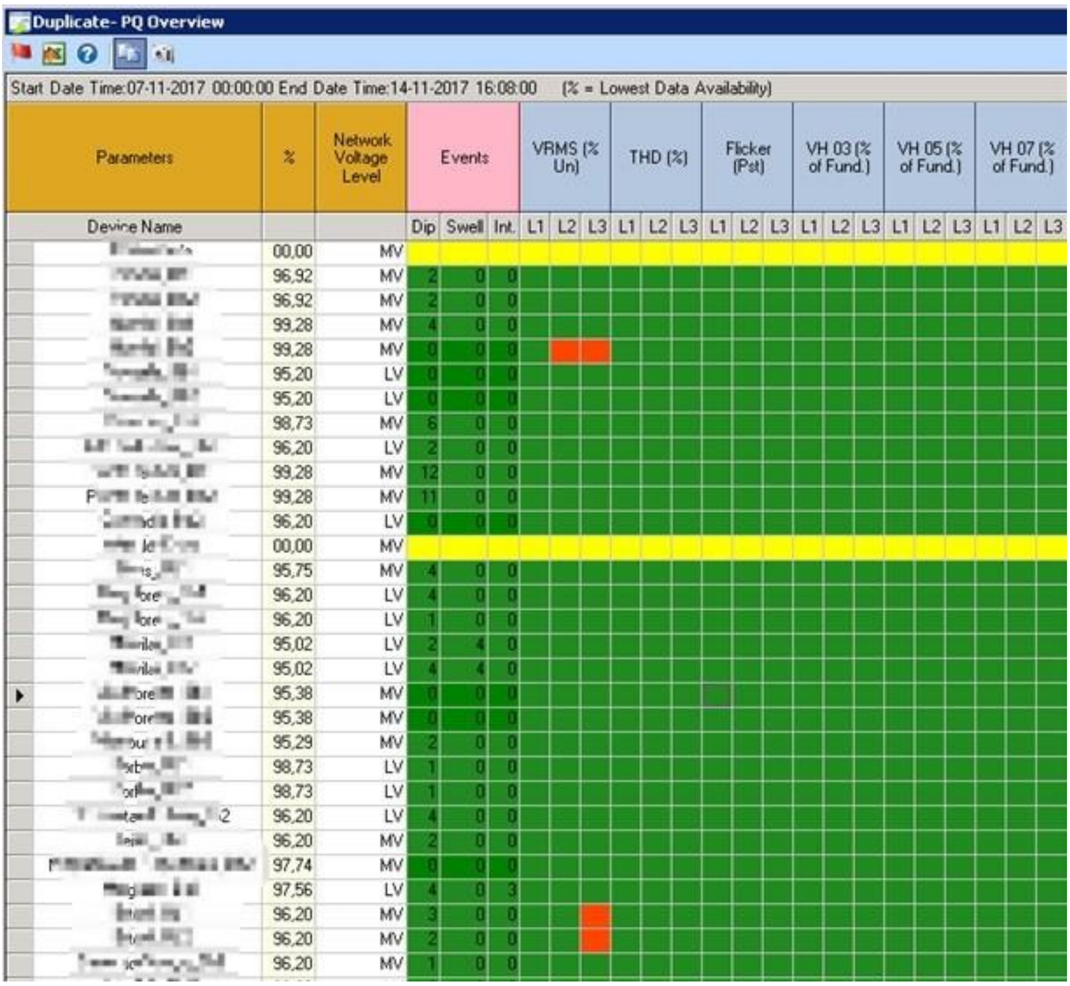


Fig 5 Example of Power Quality Overview

A feature often missing from a centralised monitoring system is the ability to have a background application constantly monitoring the 'health' of the connected monitors. Every time a unit is polled provides an opportunity to test the comms channel and download a diagnostic file with basic information about any device standing alarms, for example loss of clock synchronisation. This information can be presented as a simple dashboard view providing advanced warning of problems that allows time for remedial action to be taken before the next event and the potential loss of important data.

An example of a health check screen from an installation in the Far East is given in Fig 6. Note that the device names and substation names have been blurred at the request of the user.

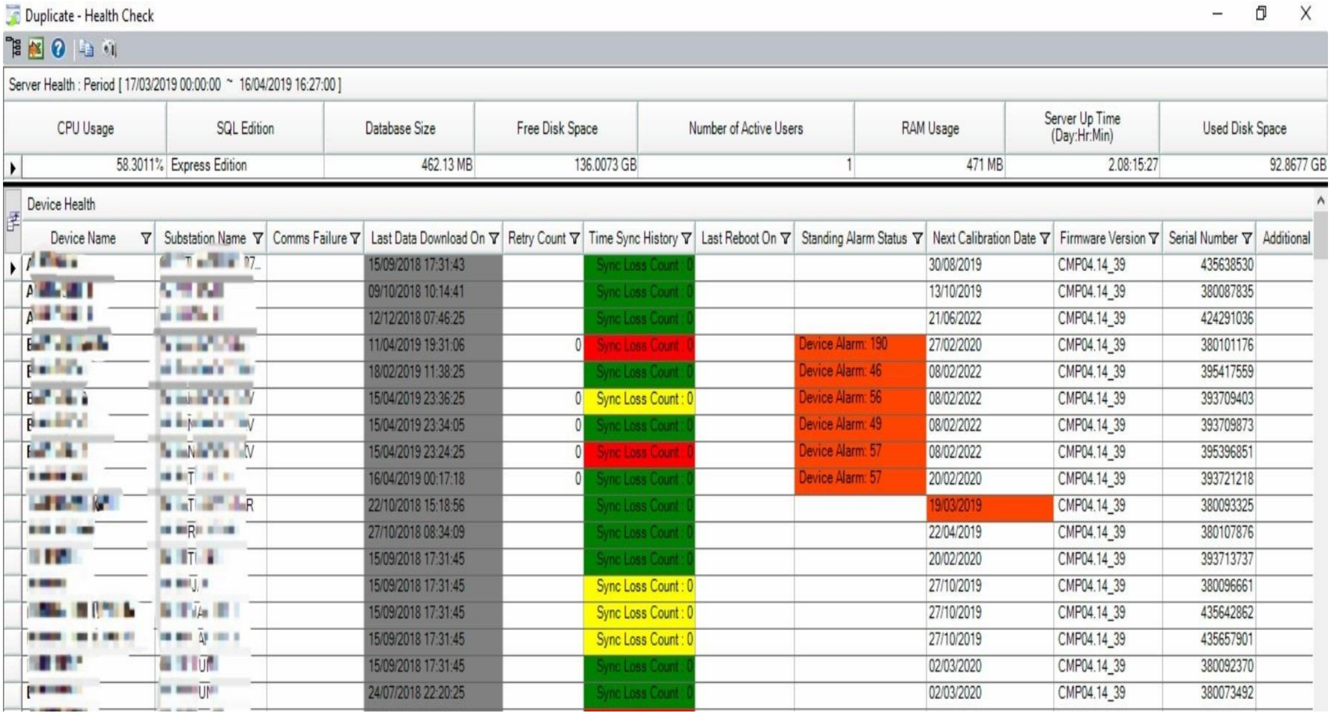


Fig 6 Example Health Check Screen

Architecture

In most Utilities any centralised software-based tool requiring access to devices in substations is nearly always managed by the IT department. As such the architecture used must fit with the normal operational IT practices and the relationship with the users, whether they be anchored to a desktop workstation or mobile with laptop PCs. The best architecture that fits these requirements is client-server. The server, communication managers and associated database can be under the control of the IT department with client software loaded onto the user's workstation allowing access to the data and tools managed by the server via a WAN or VPN connection.
Each client can be setup with individual access rights. This allows the 'administrator' to determine what data sets a user is entitled to access / view and whether they have the rights to manage data download and configure devices. The benefits of a single multifunction recorder ca be maximised by ensuring the relevant date is available to the people that need it.

Although monitors are typically not involved with control actions and therefore not subject to the most stringent cybersecurity restrictions there are instances where the 'secure' comms channels are used for data transfer. In such cases the monitoring system becomes part of the 'controlled' zone and is therefore subject to more stringent checks. Using the centralised server for all communications means it can be kept in the 'secure' zone set by the firewalls. In addition, features that allow certain functions on the device such as FTP, SSH, Telnet and IP forwarding need to be capable of being disabled and unused ports closed off.

Case Study

This vertically integrated Utility is relatively small with a generation capacity in 2017 of 10.2GW with about 800,000 consumers of which 75% are residential and the remainder commercial, industrial and government.
The daily peak demand is 8.2GW with energy consumption in 2017 at 45 GWh split between 47% commercial, 30% residential, 8.3% Government/Hospitals, 6.5% Industrial and 8.2% for Utility internal use to cover losses and auxiliary supplies in the power stations.
The number of customer minutes lost is an impressive 2.68 minutes per year.

This Utility has about 2,000 fault recorders from four different manufacturers installed in 400 substations during the last 20 years. Fifteen hundred of these devices installed in 303 substations are from one vendor.

The data from each fault recorder is transferred to the manufacturer's own Master Station software. This data is then automatically transferred to a single software package provided by the dominant vendor which is used for viewing and analysis of the Fault Records. The COMTRADE file format is used for this process. There are 3 locations for these software sets, the Operations main centre, the Operations Backup centre and the Protection and Maintenance group.
The communications infrastructure is a WAN, based on a fibre optic multiplexed system, each substation link will have between, 64KB/s and 2MB/s bandwidth.

The fault recorders are configured with more sensitive thresholds than the Protection Systems. They trigger and record on smaller deviations from the Power System nominal to ensures no fault data is missed. This helps the maintenance department identify issues at an earlier stage.

As a result of normal switching operations and the sensitive settings, the volume of data in fault records alone is considerable. About 200 fault records are generated per day, each about 300 Kbytes, generating 600 Mbytes per day or 216 Gbytes per year. This Utility has chosen to use local storage in the substations for most of the data. Industrial servers managed on a FIFO principal typically store 18 months to 2 years of information. Only high priority fault records are automatically sent to the centralised Master stations. The fault recorder determines the 'priority' of the record based on the type and number of sensors that operated and the status of digital inputs logging relay status. If the priority index exceeds a pre-set threshold then the fault record is automatically uploaded so it is available centrally for immediate analysis.
Data storage in the central Master Stations has an automatic backup function which is user configurable. This Utility decided to backup the records and device configurations every 6 months and store them on a separate, independent server.

At present, all records from 'priority' system events are analysed. The 'backup' data stored in the substations is accessed and examined when necessary.

A fleet of 2000 fault recorders built up over 20 years requires regular maintenance and management. The central software assists in this by automatically performing daily diagnostic updates checking for standing alarms, for example communication status, uptime, time synch information and recorder responsiveness, firmware version and calibration dates. The output is available as a simple dashboard or sent via email.

The monitoring system assists the Utility to meet its targets of customer minutes lost and ensuring high asset availability. The relevant information for a serious event is automatically available for analyses within minutes of it occurring allowing fast and accurate decisions to be made on next steps. Future work will look at best practices to data mine the other data sets stored in the substations to maximise the potential to identify underlying problems.

Summary

Utility requirements for monitoring systems vary according to the type of network they are operating. Although the above case study included many recorders the network covered a relatively small geographical area with adequate generation to supply the load. As such the predominate functionality was fault recording to maximise the performance of the relays and breakers and check fault levels. Other Utilities covering a larger geographical area with long lines, weak interconnections and limited generation capacity need dynamic system monitoring for stability issues and fast, accurate fault location to minimise downtimes as well as the standard fault recording function. Power quality often suffers on such networks due to a higher instance of voltage dips, flicker and harmonics from higher source impedances.

A centralised data collection and management system sorts and makes available system information to allow implementation of remedial actions and to focus capital investment to best improve operational performance.

Future Work

The key improvement area for all centralised data systems is better algorithms to automatically process the data to provide actionable information with minimal operator input. Improvements are needed to fault record analysis software to more reliably categorise the type of event and add sophistication when applying a ‘noncompliant’ label indicating a non-standard operation. Logging transformer through fault history has real value when creating a transformer health assessment and monitoring breaker trip coil currents and auxiliary contacts allows useful breaker condition monitoring to be performed. Combining different data sets gives added benefits. Adding accurate travelling wave fault location results to fault records allows better understanding of what is happening at a single structure after several intermittent faults were detected over the course of a year. Artificial neural networks can be employed to ‘learn’ normal behaviour when switching assets like capacitor banks, reactors or transformers so ‘abnormal’ traits that may indicate an incipient fault can be highlighted.

Finally, better implementation of standard protocols like IEC61850 will make it easier to gather data from different devices therefore providing a larger data set for the ‘clever’ algorithms to work on.

Authors Notes

Peter Glover received a Bachelor of Electrical and Electronic Engineering Degree from Queens University Belfast in 2003. From University Peter joined Qualitrol where he worked as an Application Engineer until he was promoted to Applications Engineer Manager in January 2015. Peter currently manages 14 Engineers in both the pre sales Applications and post sales Technical support teams. Peter has amassed 15 years of experience in the Power Industry focusing on Transmission System Fault Recording. He has travelled extensively working in substations on 6 continents and on many high profile projects such as GCCIA and England-France HVDC Interconnector. In his spare time Peter is a keen runner and he also enjoys reading.

Eric Negro has been an application engineer at Qualitrol in Belfast, Northern Ireland for the last 7 years. He researches and determines product solutions and systems to meet agreed customer monitoring needs. He is also responsible to train customers and to provide customer technical assistance for Qualitrol's products. Prior to coming to Qualitrol, Eric spent 8 years with Siemens Healthineers as a Customer Service Engineer for diagnostic imaging systems based in the South of France. He graduated in 2004 from Polytech Marseille with a Diplôme d'Ingénieur (equivalent to a Masters) in Biomedical Engineering.

David Cole is currently a Senior Technical Application Specialist with Qualitrol focusing on the Grid Monitoring products. After graduating he worked with a UK Distribution Company, researched techniques for locating partial discharge sites in cables and has worked as an application engineer on underground cable fault location. For the past 30 years he has worked with fault recorders, circuit breaker test sets, power quality devices and traveling wave fault locators in both commercial and technical roles.