TLC ENGINEERING SOLUTIONS PTY(LTD)

SOLUTIONS SOFTWARE TECHNOLOGY

Advanced Monitoring of Critical Electrical Loads

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Abstract

A number of mission critical processes rely on the continuous operation of essential equipment. Were this critical equipment to fail, the process can shut down with consequent financial losses. Advanced monitoring of key equipment can provide advanced warning of impending problems. These can then be attended to before an unscheduled breakdown occurs. This paper will examine how advanced monitoring of large electrical loads can be performed. Two case studies will be presented to illustrate how measurements are taken and data is analysed to determine if equipment is operating optimally.

Introduction

Machine condition monitoring and fault diagnostics can be defined as the field of technical activity in which selected physical parameters, associated with machinery operation, are observed for the purpose of determining machinery integrity [1]. Most equipment is required to operate within a relatively close set of limits. These limits, or operating conditions, are designed to allow for safe operation and to ensure design specifications are not exceeded. They are usually set to optimize product quality and throughput without overstressing the equipment. The main reason for employing advanced monitoring and fault diagnostics is to generate accurate, quantitative information on the present condition of the equipment. Advanced monitoring can provide measurement detail which gives more confident and realistic expectations regarding equipment performance. This information allows the following questions to be answered with confidence:

- How does the equipment respond to an overload?
- What influence does a electrical supply disturbance have on the equipment?
- Should equipment be removed from service for maintenance now or later?
- Are any maintenance activities required?
- What is the expected time to failure?
- What is the expected failure mode?
- Are any changes to the equipment design required?

Costs of Downtime

Critical electrical loads are central to the continued operation of the plant and process. When this equipment fails, the process is interrupted and large financial losses can occur due to production loss, damaged equipment, increased maintenance spending and hidden costs such as product recalls. While it is unrealistic for equipment to operate continuously without any failures, it is possible to schedule downtime to attend to any potential problems when convenient. Backup or standby equipment can be brought into service during this period to minimise any disruption to the process. In difficult financial times, the implementation of real-time equipment monitoring solutions can maximise plant performance and availability to provide the greatest revenue for the lowest possible operating expenditure.

Advanced Real-Time Equipment Monitoring

Condition monitoring for rotating equipment is a well-established field that is decades old [2]. The most basic practice was to take periodic vibration measurements of machine shafts or bearing casings. The readings were compared with historical baseline values to detect changes in equipment condition. This practice evolved over time to examine the frequency spectrum from vibration sensor which could correspond to particular mechanical components of the equipment. The objective was to identify the signatures of impending problems in time to enable preventative maintenance action rather than running the equipment until a failure occurs. Historically other sensor inputs were added and these include oil analysis, electric voltages and currents, infrared thermography and ultrasonic measurements.

Continuous condition monitoring has historically only penetrated only a small fraction of the electrical loads found in processes. The high cost of permanently mounted sensors and continuous monitoring measurement systems has limited its penetration to only the most critical 1 to 5 percent of equipment [3]. With the advent of high speed computer-based data acquisition systems and wireless sensors, the cost of providing a large number the number of simultaneous measurements has declined substantially. With ever higher sample rates, larger storage capacities, improved signal processing techniques and sensor technology, the quality of information provided is continuously improving. The objective of real-time monitoring can be summarised as follows:

- Predict and prevent equipment failures to maximize performance and availability
- Improve equipment performance with predictive fault detection
- Reduce unscheduled downtime & detect and diagnose the root causes of poor performance
- Reduce operational and maintenance costs

Advanced Monitoring Equipment

This can be supplied either for permanent installation or for portable use. The installed equipment is often supplied in a standard instrument panel as shown in Fig. 1.

Fig 1: Rack Mounted Advanced Monitoring System

The monitoring system consists of the following components:

- Plant interface which converts the sensor signals to a safe voltage and provide galvanic isolation from the plant.
- Data acquisition. This captures any digital plant signals and digitizes any analog plant signals.
- Signal Processing. The measured plant signals are processed. Combinations of inputs are used to calculate more complex variables. The processed results are compared with trigger and alarm thresholds. Additional high resolution measurements are taken from inputs that are out of limits for further advanced analysis.
- Storage of both trended and high resolution event data.
- Reporting and alarms. Routine and alarm reports are generated for subsequent action.
- External interfaces. These will include a local user interface for setting up and calibration, interfaces to other plant equipment such as SCADA or PLC's and network or GPS time synchronization to ensure the recordings can be compared with results from other recording devices.

Portable monitoring systems are used for performance evaluation, troubleshooting or fault finding on equipment that does not have advanced monitoring. Portable systems can have the same measurement and analysis capabilities but will usually have fewer input channels. A portable data acquisition system is shown in Fig. 2.

Fig 2: Portable Advanced Monitoring System

The application of advanced monitoring of critical electrical loads will be illustrated by the following case studies

Case Study 1: Steel Plant

A steel plant located in the Mpumalanga Province is a large load in close proximity to a residential area. A common load in a steel plant is an electric arc furnace (EAF). EAF's are non-linear, time varying loads that often cause large voltage fluctuations and harmonic distortion. Most of the large current fluctuations occur at the beginning of the melting cycle. During this period, pieces of scrap metal bridge the gap between the electrodes resulting in a short circuit. The consequence of these large current fluctuations is to modulate the supply voltage at a frequency in the 0.1 to 10Hz range which results in voltage flicker and a wide range of harmonics. The steel plant makes use of a Static VAR Compensator (SVC) to reduce voltage flicker, actively filter out harmonics, provide power factor correction and stabilize the plant voltage. The SVC performs the required power quality corrections automatically according to various power profiles. An advanced monitoring system is installed at the main intake substation to continuously monitor key parameters and ensure the SVC is performing correctly. The SVC can stop operating correctly due to damage caused by lightning and switching transients as well as failure of components. Alarms are set for flicker and harmonic distortion. This ensures that the electrical pollution generated by the steel mill stays within the limits agreed with the Utility. Failure of the SVC can lead to severe damage to other electrically sensitive loads such as PLC's, computer systems, communications infrastructure and variable speed drives. Damage or failure of these loads is critical to the production process and would result in a loss of revenue. A simplified single line diagram of the supply is shown in Fig. 3.

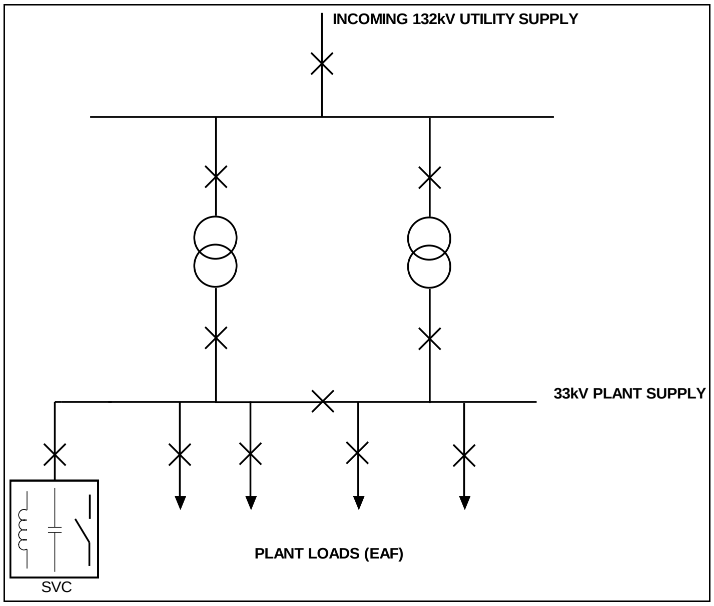

Fig 3: Simplified Steel Plant Incoming Electrical Supply

The measurements taken from the monitoring system are analysed to determine if the equipment is operating correctly. In Fig. 4, the top trace indicates a severe phase to phase voltage dip on the 33kV busbar. This type of dip would be caused from a momentary short circuit between two phases during the smelting operation of the EAF. This is supported by the sudden increase in current as shown by the current trace on the lower window.

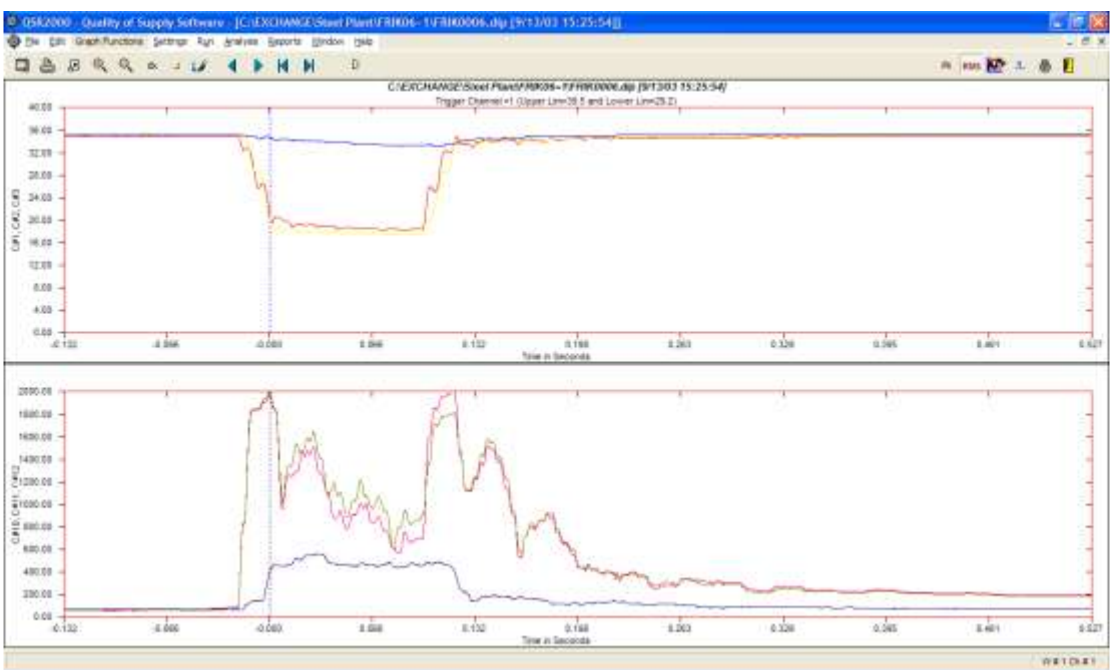

Fig 4: Phase to Phase Voltage Dip on Steel Plant Supply

Voltage flicker measurements over a 24 hour period are shown in Fig. 5. The red line indicates the short term result or Pst. This is typically measured over a 10 minute average. The green line is the long term value or Plt. The utility requires the Plt value to be less than 1.5.

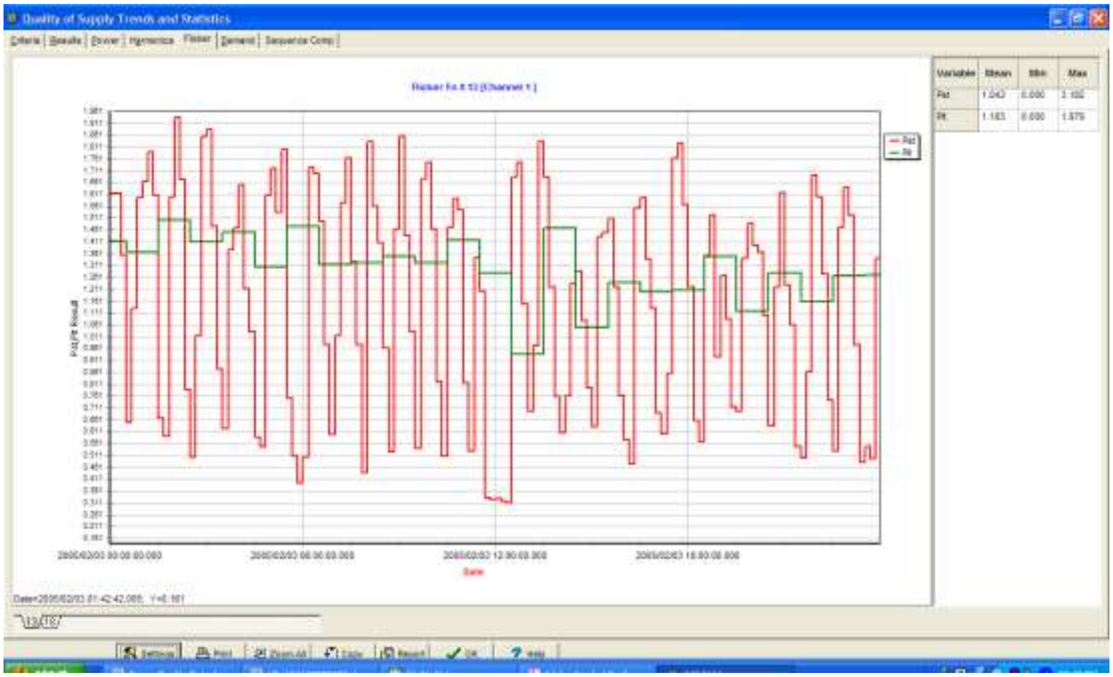

Fig 5: Voltage Flicker on Plant Supply

The above measurements illustrate how continuous advanced monitoring is used to evaluate and determine if the critical equipment is operating correctly.

Case Study 2: Data Centre Supply

The data processing equipment requires the power supply to be available 24/7. Any interruption in supply results in a loss of revenue that cannot be recovered. Most equipment has a redundant backup which reflects the mission critical nature of the operation. Data centre loads can range from less than 10kVA to over 1 MVA in large installations. In the event of a supply interruption, an uninterruptable power supply (UPS), batteries or inverters are used to supply power to the critical loads. Standby generators start up and once their supplies have been synchronized and are stable, an automatic changeover occurs and the incoming supply is powered from the generators. This takes around one to two minutes to occur. The system can operate for several hours in this mode if required. A recent fire at a substation left the supply to one data centre off for over a week. The limiting factors are fuel supply, heat generation and noise pollution. Once the utility supply is restored, the supply is changed back to the Utility and the generators shut down. The diagram in Fig. 6 is typical of a power supply to a computer data centre.

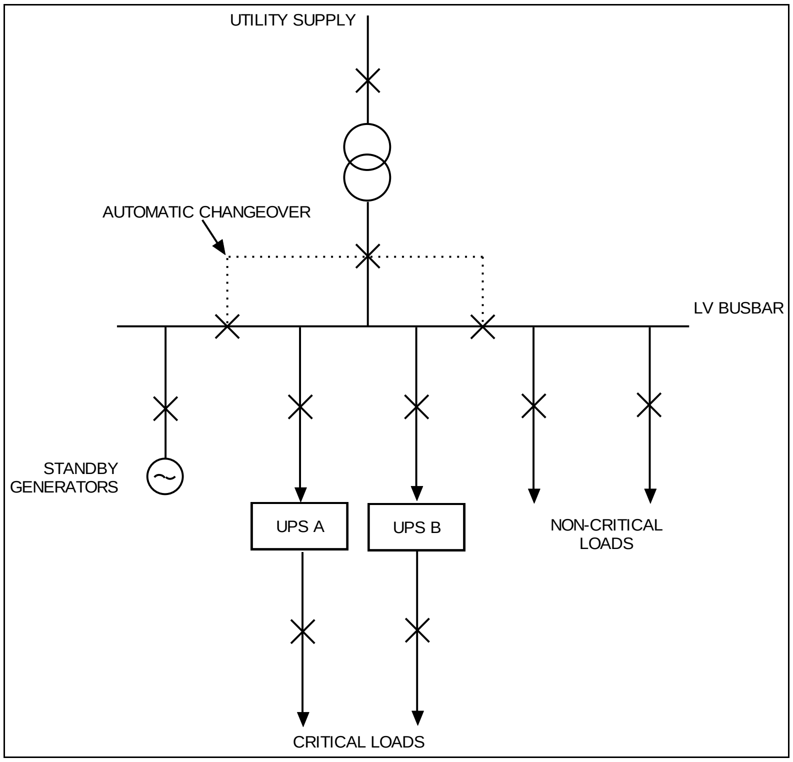

Fig 6: Simplified Data Centre Incoming Electrical Supply

The standby generators and the automatic changeover of supply are normally tested once per week. The tests are done to ensure that the generators start up correctly and are able to take the full load. Advanced monitoring equipment is used to document this process and the data is analysed to determine if there are any potential problems. During normal service the UPS equipment is subjected to lightning and switching surges from the supply. Surge suppression equipment is fitted at the incoming supply to reduce the magnitude. Advanced monitoring equipment is used to record the performance of the surge suppression equipment and the quality of the UPS supply to the critical equipment. This has been highly successful in detecting early failures that could consequently lead to equipment damage and failure. The following graphs illustrate how the UPS output performance was verified during normal operation and during a generator test. The incoming supply in Fig. 7 (upper trace) shows a severe voltage disturbance while the UPS output voltage (on the lower trace) to the critical loads is unaffected. In Fig. 8, the UPS output voltage (lower trace) is stable and unaffected during the total loss of incoming supply (upper trace). When the generator supply is restored, the UPS output voltage in the lower trace of Fig. 9 remains stable.

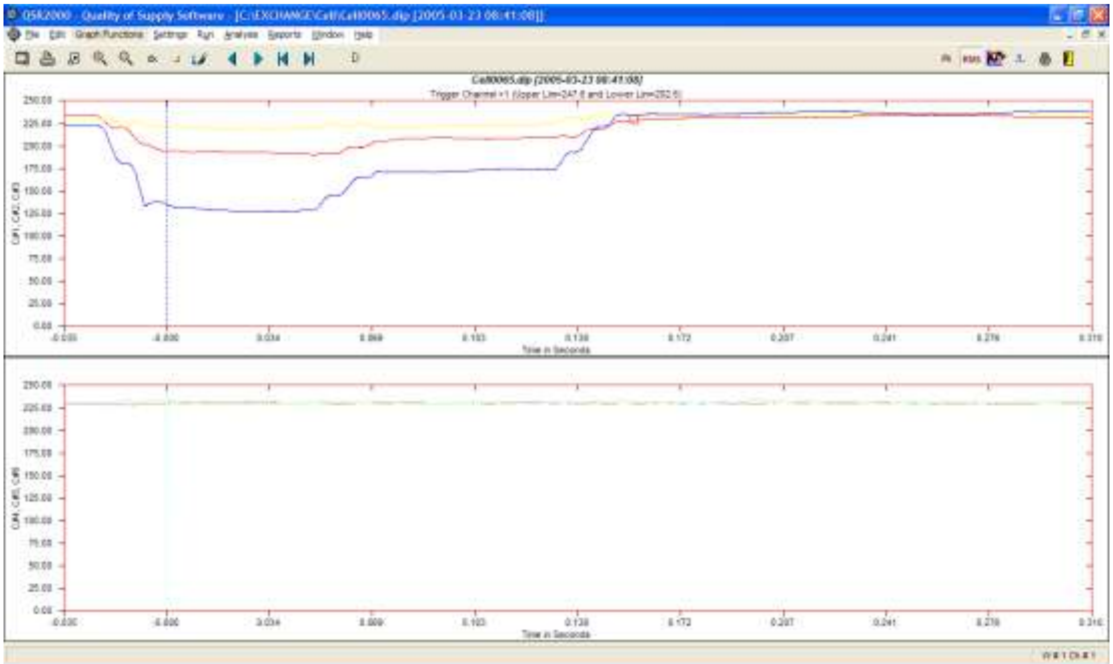

Fig 7: Voltage Dip on Incoming Supply – UPS Unaffected

Fig 8: Loss of Incoming Supply – UPS Unaffected

Fig 9: Incoming Supply Restored – UPS Unaffected

A useful analysis to perform is to plot the magnitude and duration of the incoming supply disturbances and to compare these with the UPS output. In Fig. 10 the supply disturbances have been plotted. The magnitude of the dip and its duration (up to 3 seconds) is indicated on the graph. This can be used to determine the severity of disturbances and if any sensitive equipment directly connected to the incoming supply will be affected by disturbances. A similar analysis performed on the UPS output should not have any values that lie in the coloured zones.

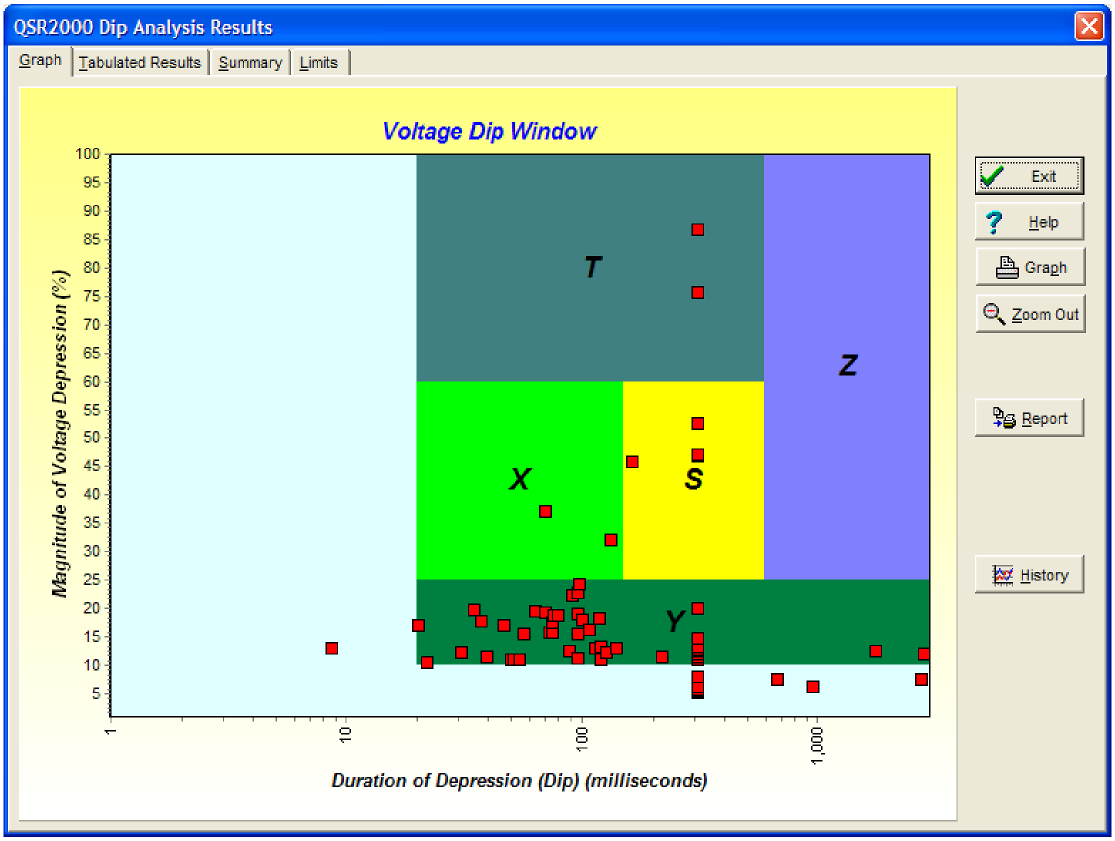

Fig 10: Voltage Dip-Duration Matrix on Incoming Supply

The disturbance data can be summarized and saved in a database. This facilitates analysis as the events can be sorted by magnitude of the disturbance, by date or by the trigger channel. In Fig. 11 a selection of supply events have been sorted by the magnitude of the disturbance with a plot of the interruption.

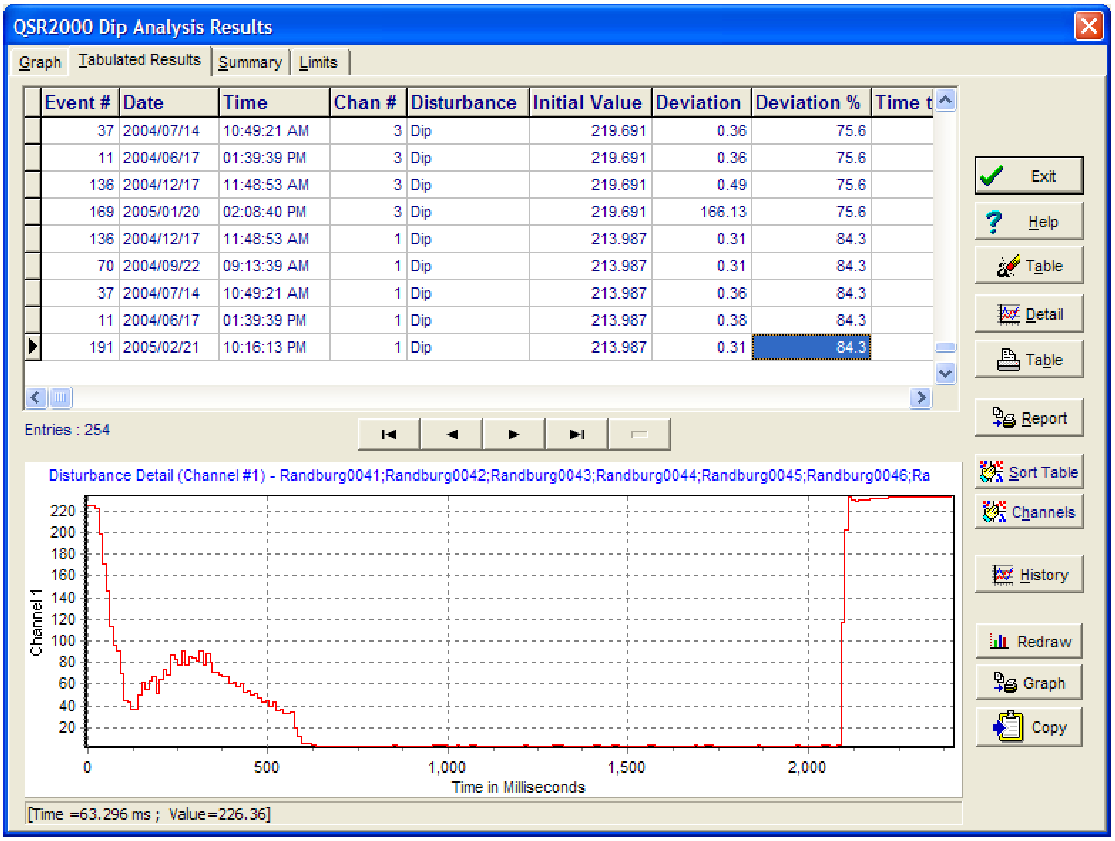

Fig 11: Database Sort of Incoming Supply Disturbances

The data centre server equipment generates a significant amount of heat and cannot operate over a maximum temperature. The air handling and refrigeration equipment is also part of the critical load. While this does not have to be powered by a UPS, it will form part of the critical loads powered by the standby generator. A plot of the load current is recorded which is displayed in Fig. 12. The air chillers are more active during the middle of the day when the ambient air temperature is higher which is reflected by an increase in load is on the current traces.

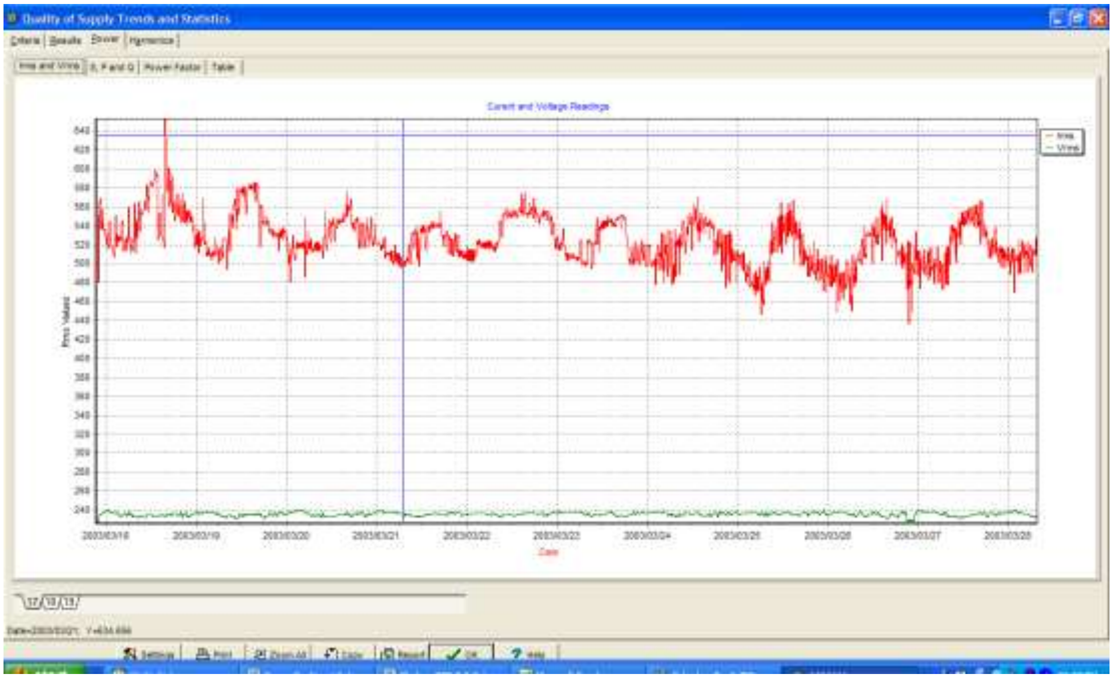

Fig 12: Load Current Profile on Incoming Supply

Conclusion

Advanced monitoring of critical electrical loads is being used very successfully in a number of applications to determine if equipment is operating reliably and to diagnose any potential problems or faults at an early stage. The data from the advanced monitoring systems can be archived for reference and compared with data recorded when there may have been a fault. This aids in the speedy diagnosis and rectification of any faults. Data from advanced monitoring can also be used to assist in upgrades and the design of new plant.

References

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