Remote Monitoring of Critical Plant Assets

Terry Cousins and Luis Valentim
Directors, TLC Engineering Solutions (Pty) Ltd)

Abstract

Plant automation systems provide for continuous or nearly-continuous operation of machines with minimal manpower. When the plant operation is interrupted it can result in significant financial loss. Consequently it is critical to monitor the health of essential equipment on a continuous basis and be able to detect conditions that may lead to equipment failure in the future. This paper will present case studies demonstrating the benefits of remote monitoring of automated plants assets. This paper will be of interest to production and operations personnel, maintenance engineers as well as consultants.

Introduction

Automation is the use of control systems and information technologies to reduce the need for human work in the production of goods and services. In the scope of industrialization, automation is a step beyond mechanization. Whereas mechanization provides human operators with machinery to assist them with the muscular requirements of work, automation greatly decreases the need for human sensory and mental requirements as well [1].

There has been constant increase in the development of industrial automation through remote monitoring and diagnosis. Monitoring of critical equipment has two main objectives:

- Prevent equipment failure
- Continuously monitor equipment performance to ensure operation is close to or at peak efficiency

Achieving these objectives increases revenue while reducing costs.

Remote monitoring uses sophisticated technologies and tools to assess equipment performance and condition which can be used to predict potential equipment malfunction or failure. Condition monitoring is a key element of predictive maintenance and enables intelligent scheduled maintenance. Imminent damages or failure is identified by a deviation from an established reference value.

While remote monitoring is not able to directly predict failure, it identifies machinery or equipment that is failing or imperfect; equipment with latent problems is at greater risk for failure. Further, it is typically more cost effective to address conditions that could cause failures, rather than repairing once a failure has occurred.

The bathtub curve is widely used in reliability engineering. It describes a particular form of the hazard function which comprises three parts:

- The first part is a decreasing failure rate, known as early failures.
- The second part is a constant failure rate, known as random failures.
- The third part is an increasing failure rate, known as wear-out failures

A graph of the bathtub curve is shown in figure 1 [2].

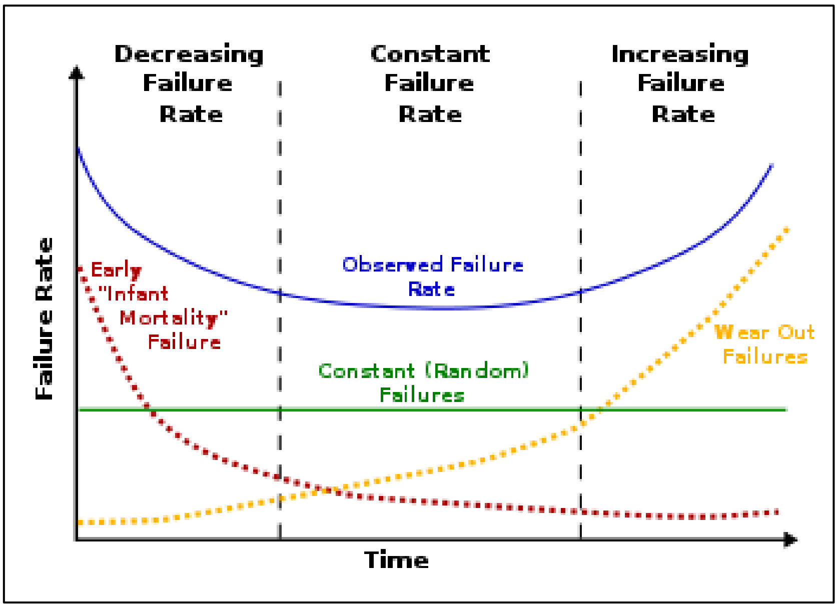

Fig. 1. The bathtub curve hazard function.

The benefit of remote condition monitoring is its potential ability to extend the bathtub curve as is shown in figure 2 [3]. Remote condition monitoring and early diagnosis of impending failures can reduce the observed failure rates by shifting the failure curve downwards to reduce random failures as well as extending the curve to the right through constant preventative maintenance.

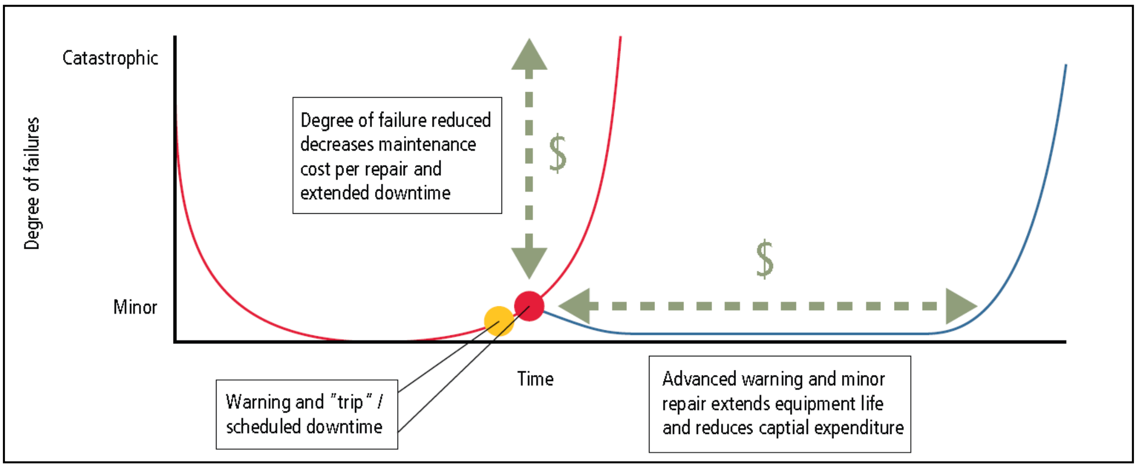

Fig. 2. Extending the bathtub curve with condition monitoring.

This paper examines two cases where remote condition monitoring is being used to monitor critical equipment. The first is the monitoring of electrical equipment feeding the main drive motors at an air separation plant. This uses a highly sophisticated and advanced computer based monitoring system. The second case is the remote measurement of rail stresses using a network of trackside embedded data loggers which send the data to a centralised database and sophisticated control room software which provides status display, generates alarms and triggers automatic maintenance schedules.

Case 1: Air Separation Plant Electric Drive

The facility is a R1.3bn air separation plant with two large synchronous motors which drive compressors [4]. These synchronous motors are operated as a high power variable speed drive using a load-commutated inverter (LCI). These drives are known as commutatorless motor (CLM) drives and offer benefits such as high efficiency, economic operation, and flexibility of control in high-power ratings. The CLM drives are used in compressors, blowers, fans, pumps, and mill drives for a range of industries as mining, water treatment plants, chemical, paper, textile, cement, rolling mills, and petrochemical plants. However, the power quality problems at ac mains have been the concerns in these drives as the LCI has front-end thyristor converter injecting harmonics in the supply. Critical supply and control signals are monitored at the 132kV supply substation, the 11kV feed to the synchronous motors and the LCI. A number of other plant signals are monitored

The condition monitoring system consists of a several 19” cabinets with rack mount equipment. The 132kV substation data recorder (SSDR) is about 800m from the compressor motor substation data recorder (CMDR). As the recorders need to operate synchronously they are time synchronised using GPS time references and interconnected with a fibre optic data cable. All the data is archived to a central server which also monitors the status of the condition monitor recording system. Configuration of either remote recorder can be done from the central archiver. An adjacent plant is also equipped with an advanced condition monitoring recorder similar to the equipment described in this paper and it is planned to be connected to the same central archiver. A block diagram of the system is shown in figure 3.

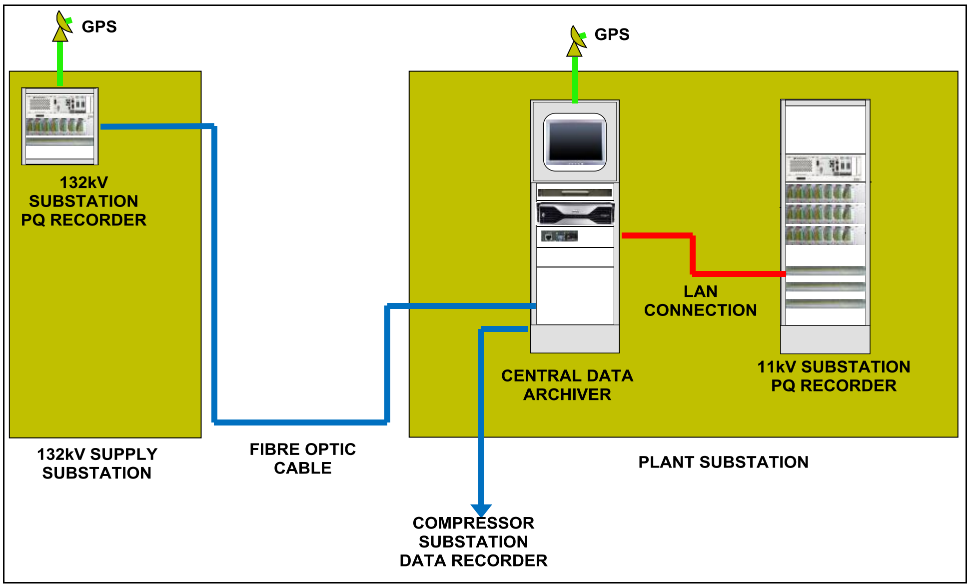

Fig. 3. Block diagram of compressor drive monitoring system.

One of the requirements for the recorder was to ensure that any fault that may occur within the condition monitoring system does not affect the automation plant signals. All plant signals are galvanically isolated with a common mode isolation of 1.5kV. The signal conditioners also have overload protection and anti-aliasing filters. All the equipment is of a modular plug-in construction which facilitates repairs. The data acquisition system uses the modular PXI open platform technology. A total of 32 high speed analog and 48 digital channels are available for each of the four main systems that are being monitored. Not all the channels are used which provides spare channels for future expansion. A picture of the 11kV substation condition monitoring system is shown in figure 4.

Fig. 4. 11kV substation monitoring equipment.

The downtime on this plant can result in significant revenue loss and shutdowns in other sections of the process. A number of other devices are present in both the 132kV and 11kV substations which are also able to record supply and control data. However they are not able to record sufficient detail for a long enough period to enable the plant engineers to identify the cause and effect relationships following a plant trip. The remote monitoring equipment is also connected to a central archiver that provides for the plant historian. The equipment has a number of operating modes. These include the ability to record start-up events in high resolution for up to 2 minutes, capture disturbances with a 10 second fault record and provide mean value recordings for power and process variables. Various triggering options are available to ensure any out-of-limits event is captured.

CLM drives use load-commutated, phase-controlled power thyristor technology to supply power to the stator windings of a high efficiency synchronous motor. The power circuit has a source converter, connected to the power supply and a load converter connected to the motor. During normal motor operation, power flows from the supply to the motor. The LCI controls the motor torque to regulate motor speed. Motor torque is controlled through the DC link current. A block diagram is shown in figure 5. As the LCI drive is susceptible to power disturbances from the supply, the monitoring system can provide detailed waveforms documenting the cause and effect relationship between the input and output of the drive.

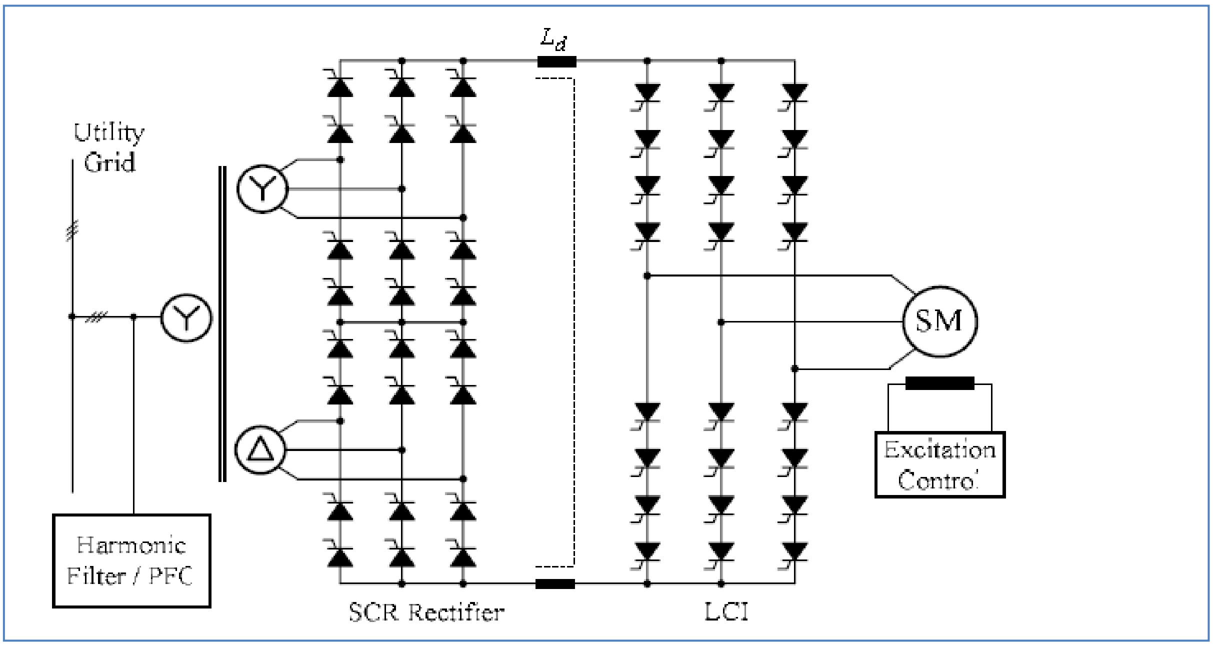

Fig. 5. Block diagram of a LCI fed synchronous motor.

The monitoring system is used to capture waveforms and assist in optimising settings for the drive. During commissioning the system can be used to assist with the drive control and protection settings. Once commissioned, the data obtained from condition monitor can be used to do fine tuning and identify any problems when there is a drive trip. The following recordings are used to illustrate the following:

- problems from supply side to the drive - dips & transients
- problems from drive side to the supply- harmonics

A number of waveforms are shown below to illustrate data capture. The results show only one phase for clarity. The upper graph is the 11kV supply to the motor and the lower graph is the motor current. The vertical dotted line is the trigger point. Recording time is 10 seconds with a 7 second pre-trigger. Sample rate is 78µS. Figure 6 is a display of the initial startup voltage applied from the LCI to the stator with the motor phase current. The values shown are rms. The current waveform is heavily distorted and significant harmonics are injected into the substation supply.

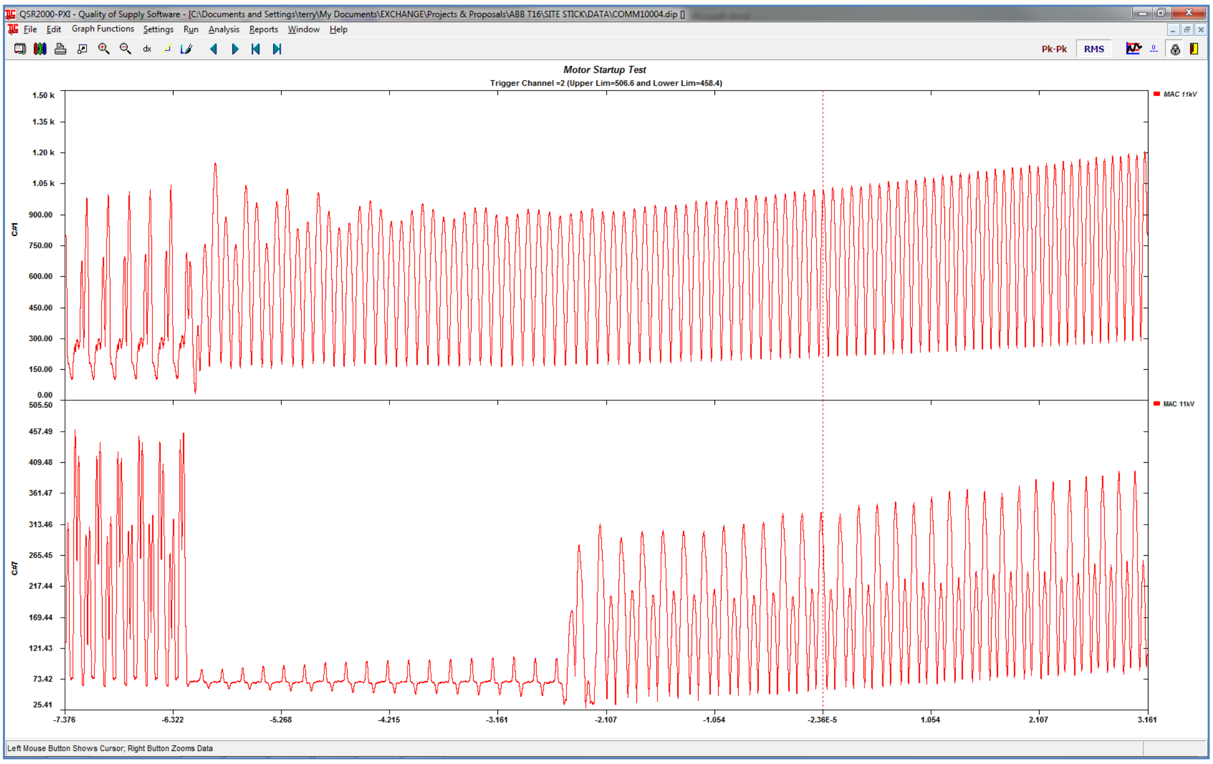

Fig. 6. LCI waveforms from initial starting of the motor.

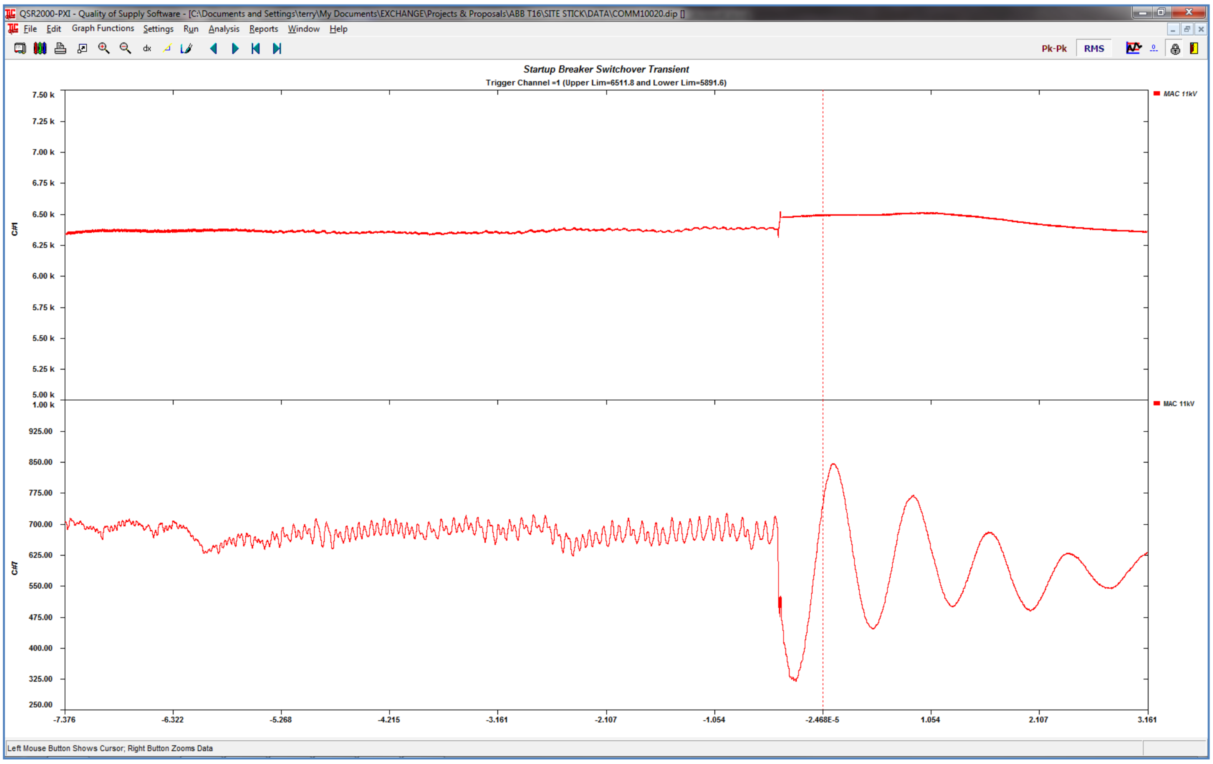

Fig. 7. Motor current waveform during LCI bypass switchover to substation supply.

Figure 7 illustrates the drive at the moment of changeover from LCI supply to direct phase supply. There is significant current oscillation for approximately 1 second before the motor settles down. Note that these are not cycle by cycle waveforms but rms plots.

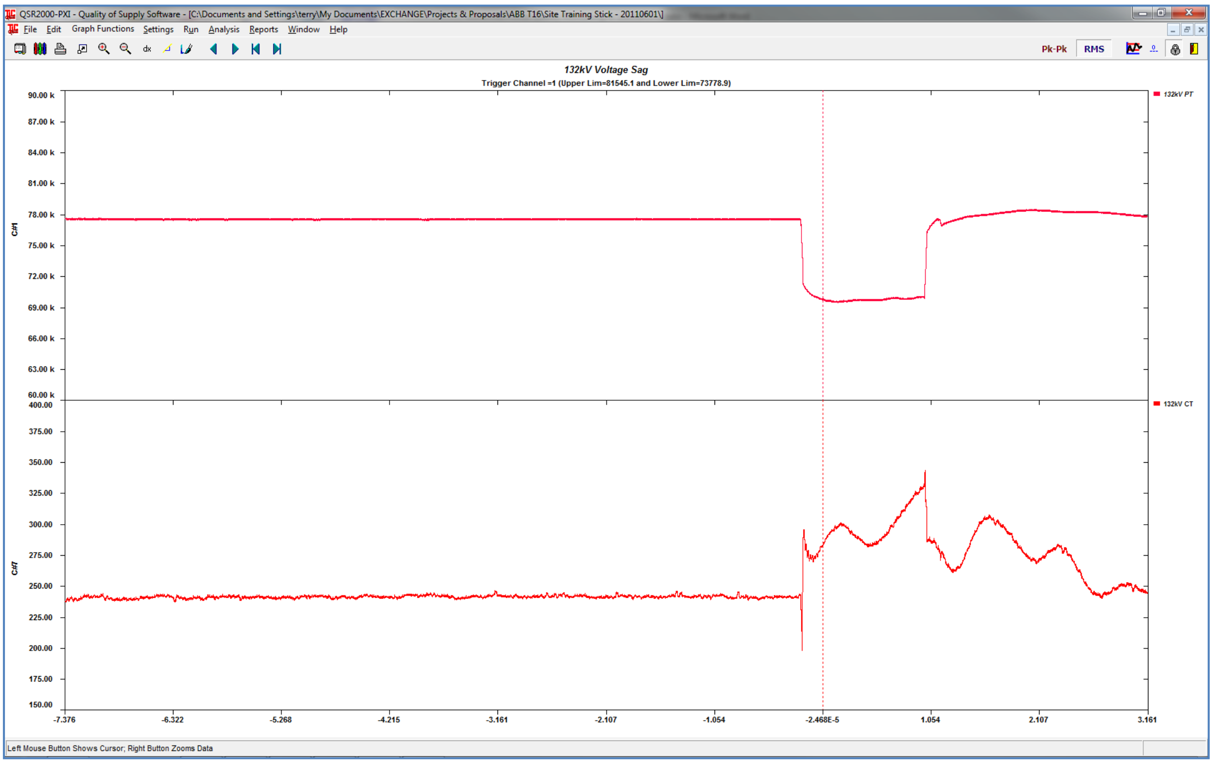

Fig. 8. Supply current (rms) to drive during a dip on 132kV substation supply.

Figure 8 displays the change in supply current when the supply voltage experiences a voltage dip. There is a sudden initial increase in current from 240A to 285A and then up to a peak of 325A. These waveforms were used to adjust the settings on the overcurrent protection to allow the drive system to ride through disturbances like this. The drive system was tripping prior to this analysis.

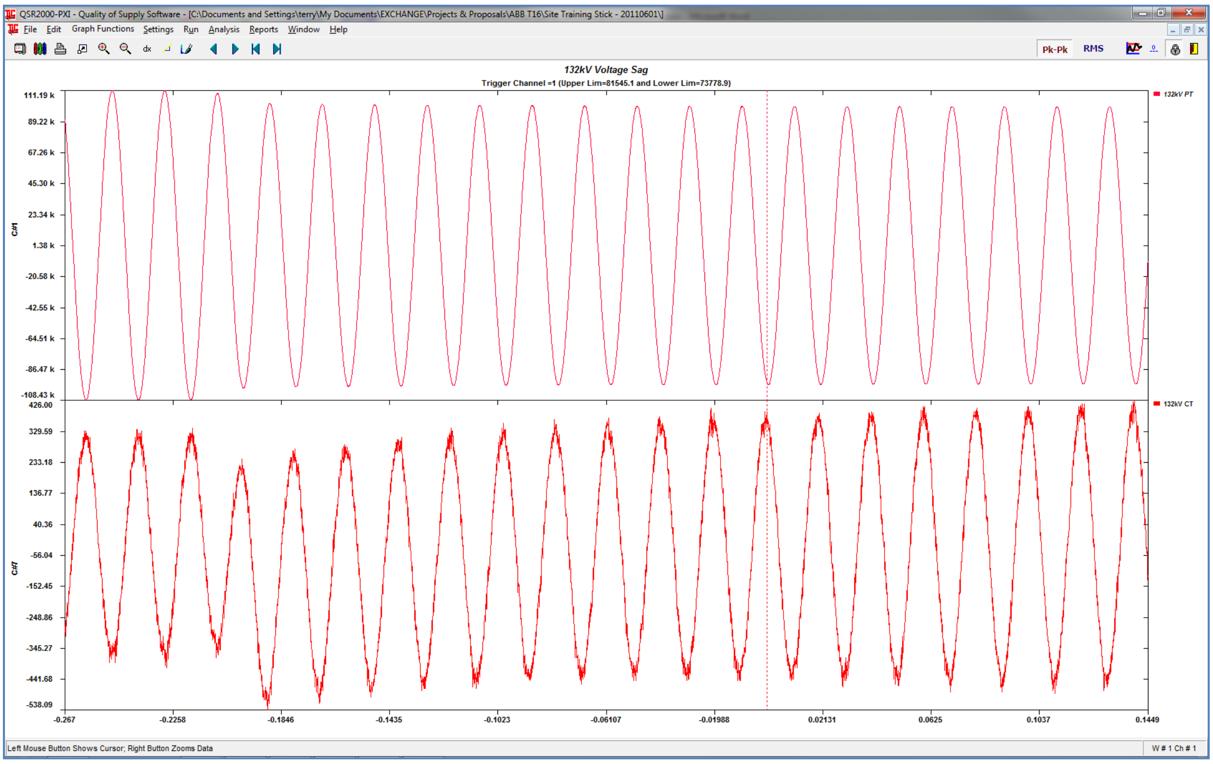

Fig. 9. Supply current waveform to the drive during a dip on 132kV substation supply.

The graph in figure 9 is a cycle by cycle view of the same event which shows that only the amplitude of the supply current waveform changes during the voltage dip.

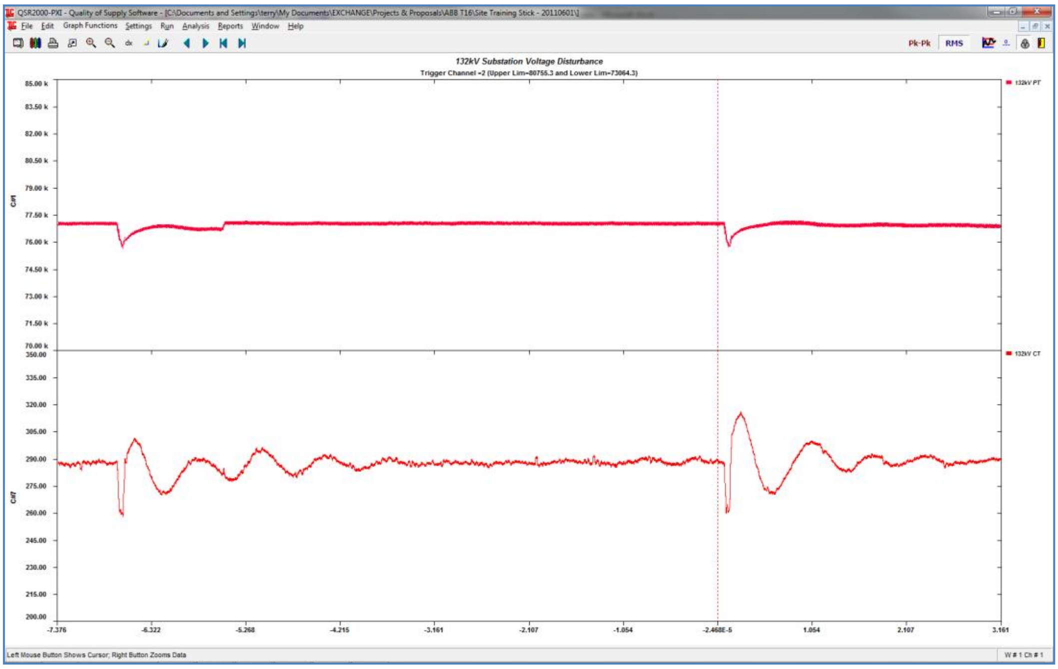

Fig. 10. Drive current (rms) response to multiple 132kV substation supply dips.

The ability of the drive to recover from a supply dip depends on the connected load, system inertia and the energy stored in the drive DC link. The graph in figure 10 illustrates the current oscillations and settling time in response to two supply dips approximately 6 seconds apart. The current oscillations settle in about 3 seconds. If the voltage dips were closer together than this the drive may trip. The drive control system can be tuned to ensure that the oscillations are damped.

The above graphs have illustrated transient or event based recordings. The recorder also collects mean value graphs for power quality trends. The graph in figure 11 illustrates the change in rms supply voltage at the 132kV intake substation over a period of 7 days. The variation in supply voltage is just over 1.5%. Alarms can be set in the monitoring system to notify if the supply voltage changes by more than a preset percentage.

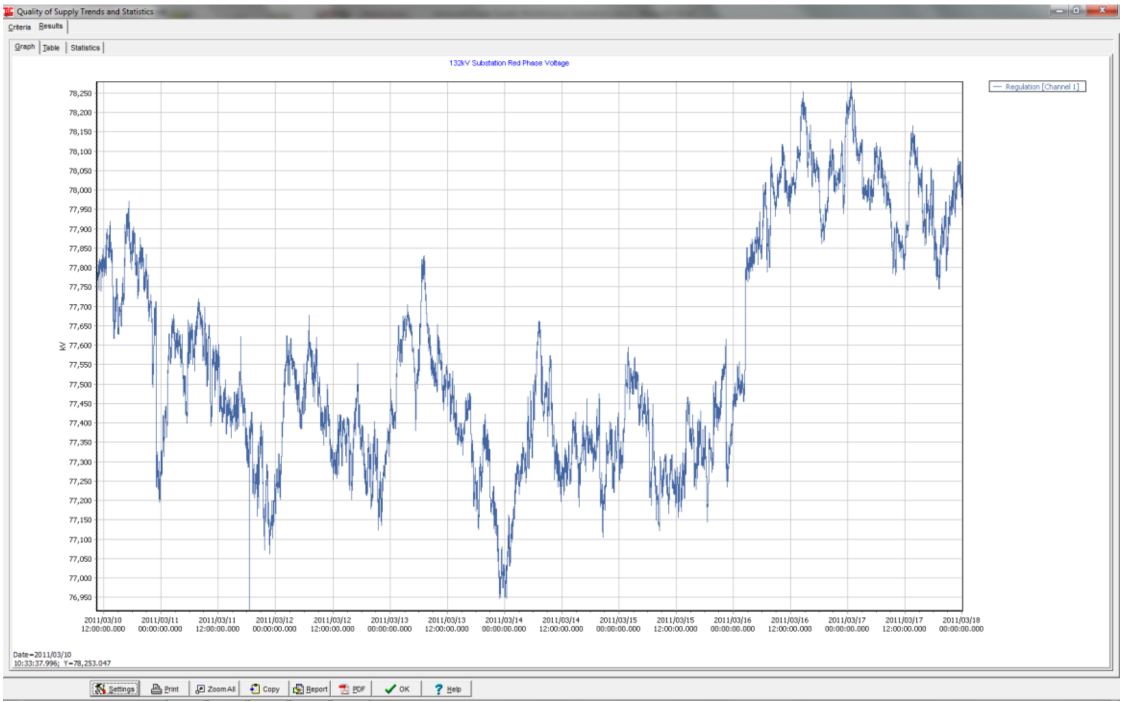

Fig. 11. 132kV substation supply voltage (10 minute mean value) variation with time.

It is also useful to determine the number of supply disturbances (dips and surges) that are present on the supply and plot these in a magnitude – duration graph as shown in figure 12. The magnitude duration plot has minimum dip immunity tolerance zones as per the NRS048 [3] displayed. Based on the NRS document motor drive should be able to tolerate supply voltage disturbances up to 20% magnitude in the S and Z1 zones. The graph below indicates only one captured event that exceeded this for the time period under study.

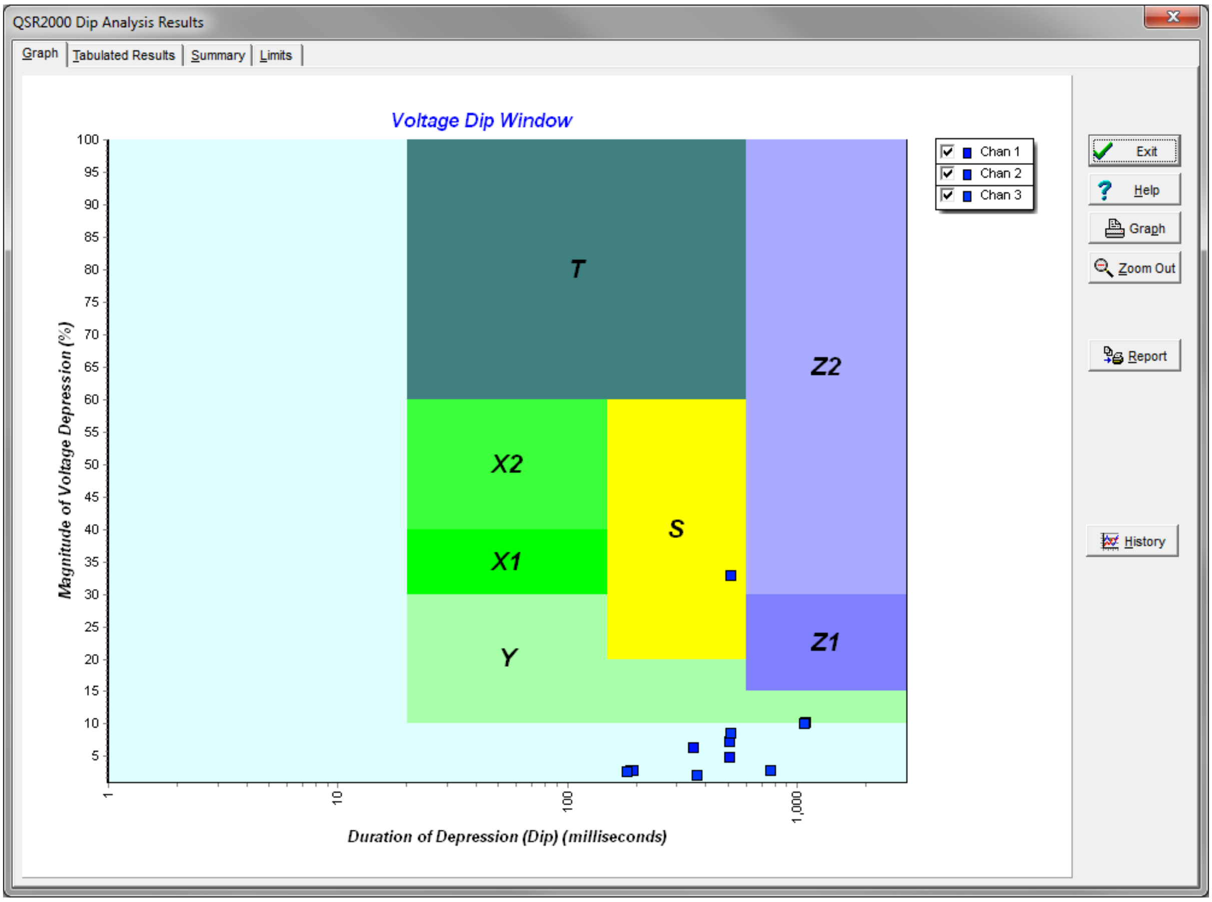

Fig. 12. 132kV substation supply disturbances – magnitude vs. duration.

The equipment has been able to record a number of events that have enabled the plant engineers to optimise protection settings and indentify faulty equipment which is replaced before it results to a plant shutdown.

Case 2: Continuous Welded Rail Stress Monitoring

The advantages of continuously welded rails (CWR) over conventional non-welded rails are well known and the substantial reduction in total rail lifecycle cost is one of its most attractive benefit. However, CWR has to be managed in such a way that the potential track failures that accompany it do not compromise the safety of the track. Statistics of the coal export line in South Africa revealed that some 50–60 % of all train delays are stress related [4]. An illustration of these delays is shown in figure 13. Track stress is responsible or contributes to the occurrence of rail breaks, track buckling (kick-outs), block joint failures, certain track geometry deviations and component failures in turnouts.

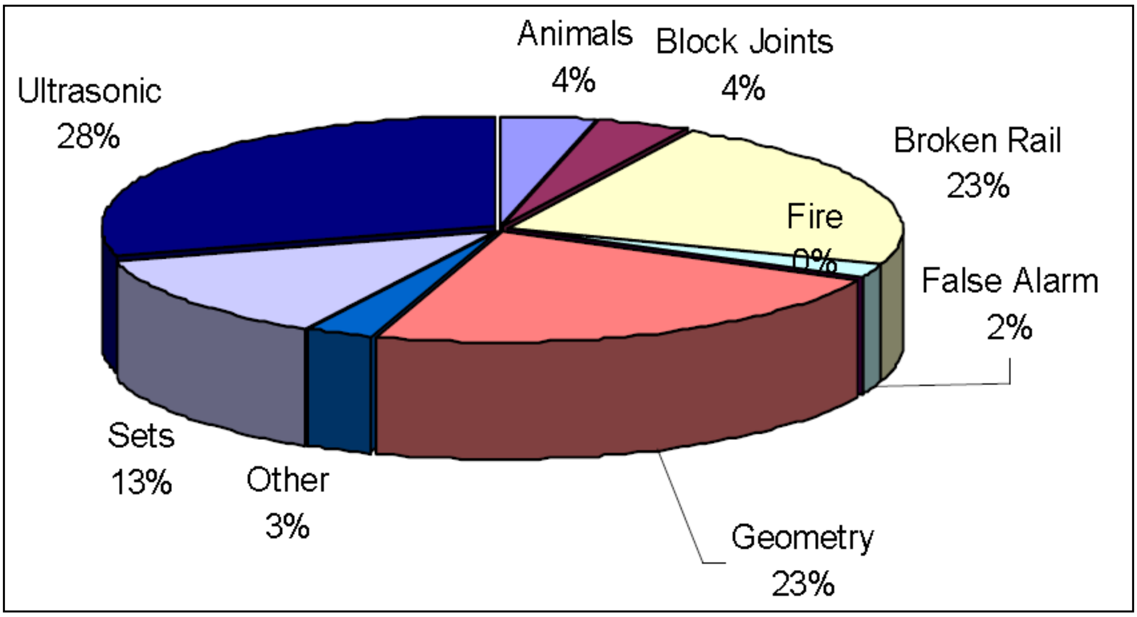

Fig. 13. Train delays due to Infrastructure.

Tracks with continuously welded rails have to be managed for the occurrence of residual rail stresses and bending stresses caused by train loads as well as temperature stresses which are responsible for rail breaks and lateral stability problems such as track buckling. As the stress changes with temperature there exists a temperature known as the neutral (or stress free) rail temperature ($T_{neutral}$) at which the track is neither in compression or tension. The rail force will then be approximately 0. If the rail temperature rises above $T_{neutral}$, the track will be in compression while a decrease in rail temperature below $T_{neutral}$ will result in tension forces in the rail.

The stress in the rail can be determined by:

- Cutting the rail and measuring the resulting gap/overlap
- Using a mechanical measurement system know as the lifting frame method
- Magnetism measurement device using the “Villari” principal.
- Using strain gauges to measure the longitudinal rail strains

Strain gauging is extremely accurate and usable in any stress condition. It is the basis of the condition monitoring system described in this case. The equipment used to perform the condition monitoring measurements consists of:

- Track mounted stress and temperature sensor (Figure 14)
- Lightning protection
- Battery powered data logger
- GSM / Radio / Satellite modem
- Solar panel

Fig. 14. Track mounted rail stress and temperature sensor.

The data logger, wireless modem and solar panel installation is shown in Figure 15.

Fig. 15. Data logger, wireless modem and solar panel installation.

Sites are selected to ensure measurements at high risk locations where derailments would cause severe disruption to the rail line. These include:

- Tunnel entrances and exits
- Track buckling and rail break areas
- Turnouts before and after deviations
- Long bridges
- Inside long tunnels
- Additional sites at regular intervals

Data from each measurement station is sent back to a server located in a control room. Custom written condition monitoring software was developed to provide the following functions:

- Receive data sent from wireless modems at remote measuring stations and to store the different measurements in a database
- Remotely configure measuring stations (Figure 16)
- Visually present data in a simple format (Figure 17)
- Carry out mathematical functions on the data
- Perform trending and forecasting analyses on the historical data
- Present the results of the analyses in such a way so maintenance decisions can be deduced
- Apply specific maintenance and alarm conditions
- Generate user-defined reports on rail condition

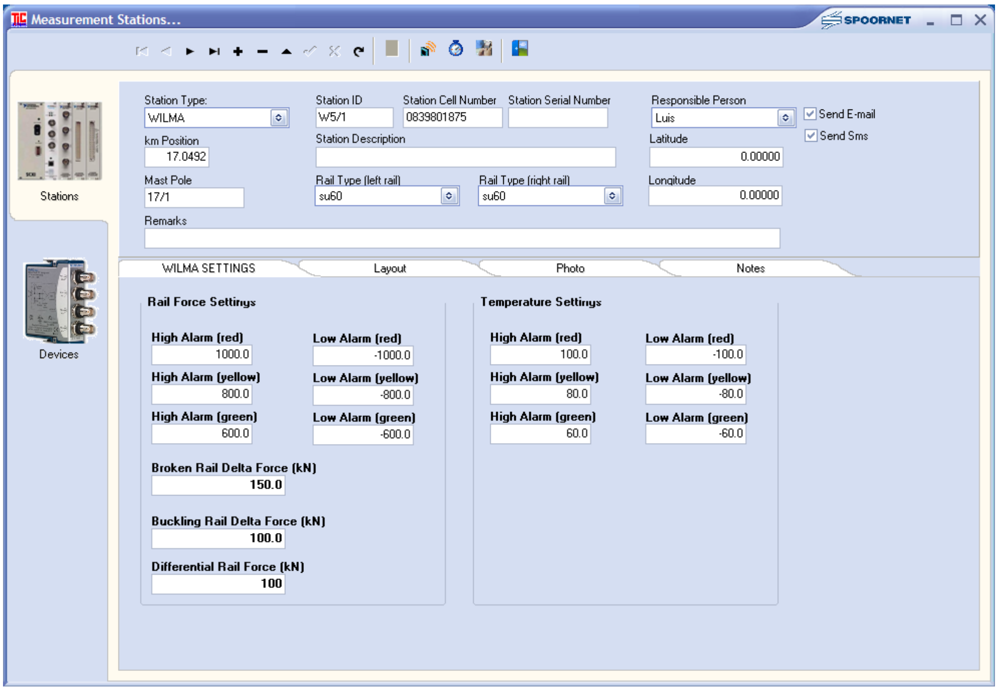

Fig. 16. Remote monitoring site configuration screen.

The control room software comprises four components, namely a database module, calculation and modelling (trending and forecasting) modules, a graphical presentation module with maintenance and alarm conditions and a report generation module.

The operator screen shows the rail track in a horizontal configuration on the main screen in figure 17. Each of the coloured dots represents a measurement site and its colour represents the current status.

Fig. 17. Main display screen with site status.

If the operator wants to determine the detailed status of any site they merely click on the site dot and a detailed display as shown in figure 18 will be displayed.

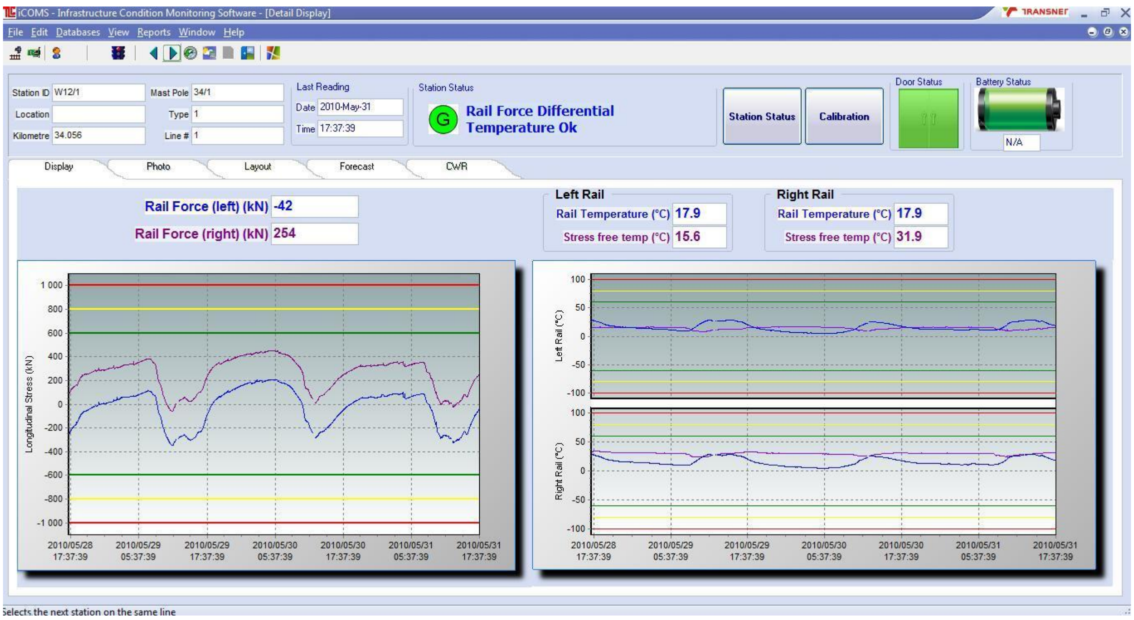

Fig. 18. Site detailed status including history for several days.

The upper and lower alarm limits are configured in such a way that the following maintenance actions and train alarms are generated:

- The enforcement of a speed restriction to lower the risk of a derailment due to rail buckling or a rail break
- The stopping of all trains over the specific track section
- De-stressing of the track when required from conditions of extreme heat or cold
- Offloading of ballast to increase the lateral and longitudinal stability of the track

Additional reports can be generated which display the line health status and a summary of the status of each remote measurement sites.

The remote measurement sites can become faulty due to a number of reasons which include:

- Damage to track sensors from routine track maintenance
- Lightning damage
- Theft and vandalism of equipment
- Equipment failure

The sites are continuously monitored by the control room software and a failure or malfunction of a measurement site will trigger maintenance for its repair.

Conclusions

Real-time remote monitoring can improve the availability and reduce the downtime of automated equipment. This can be achieved by using a range of technologies and communication systems.

Downtime on critical equipment can result in financial losses that result in very short payback times for the equipment. The prevention of a single derailment can pay for the measurement equipment.

Remote monitoring technology is readily available and is easily deployed without impact on the current infrastructure. It can be installed without using sensors or equipment from the automation systems and hence will operate independently and without any interference should it become faulty.

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Contact details

For further information, contact Terry Cousins or Luis Valentim at TLC Engineering Solutions on 011 463 3860 or terry@tlc.co.za / luis@tlc.co.za