

# Advanced Condition Monitoring of a Hydroelectric Power Generation Facility

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**SUMMARY:** This paper details the development and application of a Plant Asset Management (PAM) system which turns data into useful information in order to assess asset condition. The system was developed by Matrikon Australia for Meridian Energy Limited, New Zealand's largest state owned electricity generator. PAM was designed to provide advanced condition monitoring and prediction of asset failures for transformers, turbines, governors and generators. The PAM system integrates engineering expertise, IEEE standards and limits, factory test data, mathematical models, rules and historical operation in order to diagnose the current condition of the asset and to predict when the asset is likely to fail. The paper will focus on phase one of the project which involved the advanced condition monitoring of power transformers with benefits already being realised. Other phases which will be outlined include advanced condition monitoring of turbines, governors and generators.

## 1. INTRODUCTION

Safe and reliable power system operation is integral to maintaining a continuous supply of power. Reliability of the power supply is directly linked to the condition of the assets supplying the power namely transformers, turbines, governors and generators. When assets are taken off line due to maintenance or poor operation, power demand may not be met. Also, a poorly operating asset may have serious environmental consequences. Transformer failures can generate excessive amounts of heat which could result in fire or explosion. When assets are new, relatively few things can go wrong. However, as the age of the asset increases, deterioration becomes more apparent. A predictive asset maintenance methodology is therefore desirable, based on examining the condition of the asset. This information can then be used to predict when the asset is likely to fail.

Because of the distributed nature of power generation, assets may be located across vast distances with data coming in from a variety of sources. Many measurements, tests and on-line data are available, but these measurements have to be evaluated in an effective manner. The integration of data from a wide variety of sources is the basis of advanced condition monitoring. Benefits of automated advanced condition monitoring include:

- Establishment of the current condition and rate of deterioration of the assets' "health" providing early warning on changes to equipment condition.

- Recommendations regarding appropriate actions to take in order to extend the life of the asset.
- Assessment and comparison of assets across a wide range of distributed stations.
- Integration of data from a wide variety of sources including computerised maintenance management systems such as Maximo and on-line near real time data sources such as Plant Information Systems PI.
- Reduction in maintenance and labour costs.
- Prediction of impending faults.
- Capture and retention of engineering knowledge before employees leave the organisation.
- Timely, standardised and objective analysis of results for decision making.
- Immediate access to information from various locations through a single web based user interface.

## 2. MERIDIAN ENERGY

Meridian Energy is New Zealand's largest generator and produces approximately thirty percent of the country's total generation using hydro assets in Manapouri and the Waitaki Valley in New Zealand's South Island. Meridian's generation assets underpin both New Zealand's electricity supply and Meridian's retail position through providing high levels of reliability and availability. Assets are distributed across

nine hydro (water) power stations located around the island as shown in Figure 1. Meridian also owns and operates New Zealand's largest operational wind farm (Te Apiti) which is located on the North Island.



**Figure 1.** Meridian Energy generation asset distribution

Because of the distributed nature of the assets, operation is remotely managed at a central control room located at Twizel, at the centre of South Island. The control room is focused on real time demands of New Zealand's electricity market, subsequently operating information supports this and is not typically used to indicate the deteriorating state or "health" of generating assets.

Some of the key assets at each station are approaching thirty to forty years of operational life and are subject to changing operational and market demands.

A condition-monitoring program has operated at Meridian for many years. The introduction of the Plant Asset Management (PAM) system takes this program to a whole new level of decision support delivering alerts and recommendations to the desktops of plant managers and engineers across the business.

The challenge of achieving asset management excellence requires the continuous improvement of plant processes and people. Continuing asset management challenges include:

- Availability and integrity of current and historical data.
- Adoption of a consistent approach when assessing data.
- Avoiding delays in data interpretation.
- Using condition assessment information for proactive rather than for reactive planning.
- Coping with demands on engineering expertise due to increasing number of major refurbishment projects and growth opportunities.

## 2. THE PAM SYSTEM

The *Plant Asset Management System (PAM)* was developed by Matrikon Pty. Ltd. in order to address the key issues of asset management and integration of existing systems proposed by Meridian Energy. *The PAM system turns masses of data into useful information which can be acted upon.*

The PAM system provides more than simple condition monitoring of core assets (transformers, turbines, governors and generators). It also provides a predictive monitoring capability for each of the assets. Additional assets can be added to the system at any time.

Key functionality of the PAM system includes:

### Data Integration:

- Data from variety of sources (Maximo, PI).
- Factory test data.
- IEEE standards and limits.
- Historical operation.
- Data sources available through industry standard interfaces (OPC DA and HDA).
- Easy addition of data sources via a comprehensive extendable software development kit.

### Diagnostics:

- Sound engineering knowledge.
- Model based methods (first principles).
- History based methods.
- Addition of different diagnostic techniques and new models.

### Visualisation and Notification:

- One easy to use, extendable<sup>1</sup> web based user interface.
- Allows for comparison across units and stations.
- Identification of worst performing asset.
- Indication of poor analysis results or test which were missed.
- Dashboard customisation to a particular plant or specific equipment that is of interest to the user.

Benefits of the key functionality include standard data entry, objective and consistent assessment of results and consistent results presentation and notification.

In order to achieve the key functionality several platforms were integrated as shown in Figure 2. Platforms which were integrated include:

<sup>1</sup> Matrikon's ProcessNet, Microsoft ASPX and XML Webservices technologies are used to provide an extendable user interface configuration and development environment.

- **Maximo**<sup>2</sup> for maintenance management.
- **PI** Plant Information
- **ProcessMonitor** and **ProcessDoctor** for complex calculations and controller monitoring.
- **ProcessGuard** for alarm management.
- **Common Knowledge**<sup>3</sup> for rules and decision table development.
- **ProcessNet** for data distribution, data access and web based visualisation.

By integrating these different platforms the benefits and functionality of each system could then be utilised in order to provide a complete health monitoring solution which ranges from maintenance management through to advanced diagnostics and web based visualisation. The **PAM Control Centre** is the central integration point for all external systems.

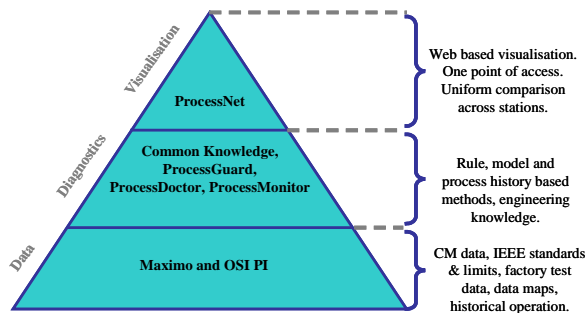


Figure 2. Platform integration

## 2.2 System Operation

The *sequence of events* which characterises PAM system operation is illustrated in Figure 3.

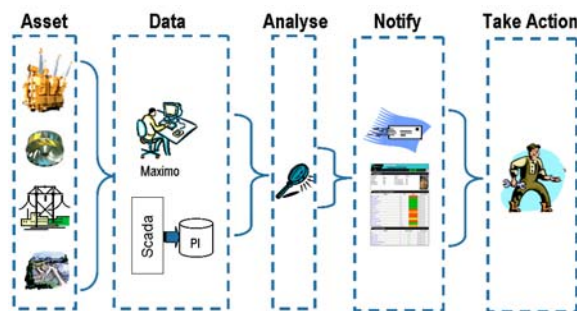


Figure 3. Sequence of events

<sup>2</sup> Maximo is developed by MRO Software (<http://www.mro.com/>).

<sup>3</sup> Common Knowledge is developed by Object Connections Pty Ltd. (<http://www.objectconnections.com/>).

The PAM system was developed in order to support analysis based both on *on-line* and *off-line* data. An on-line analysis is run at a pre-scheduled interval configured within the control centre and an off-line analysis is run following user input into the maintenance management system<sup>4</sup>. The data is then routed to the PAM system where complex calculations are then performed using *ProcessMonitor* and/or test results classified using *Common Knowledge*. Following the analysis of test results an email notification is sent alerting specific users of test result classification and providing a link to the corresponding *ProcessNet* page for visualisation of analysis results.

## 3. KEY ASSETS AND TESTS

Two of the key assets which are being/will be monitored within PAM include transformers and hydroelectric turbines as illustrated in Figure 4. The following sections will provide examples from transformer and turbine monitoring.

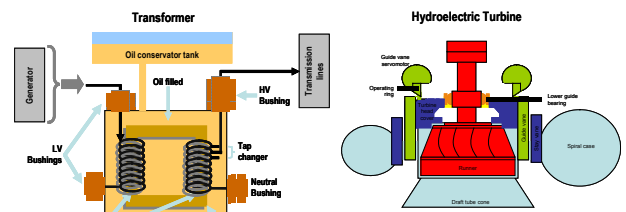


Figure 4. Key assets

From a maintenance perspective a transformer can be considered as an oil filled tank containing an iron core (insulated with cellulose) which is used to conduct a magnetic field separating two windings. The windings are insulated with cellulose. A tap changing mechanism allows for voltage adjustment. Bushings are the means of connecting the windings internal to the transformer to the outside world and provide an insulation mechanism between the outside frame of the transformer and the live connections. Because the transformer is oil filled (the oil removes heat and provides insulation) the transformer is attached to an oil filled tank. All of these components are subject to wear, ageing and deterioration due to operating conditions (Sparling, 2004).

When transformers are new, relatively few things can go wrong with them. There are no moving parts that wear. However, as transformers age the insulation system starts to break down and can eventually fail. Failure can be dangerous and can result in considerable heat being generated within the transformer, which poses serious hazards to both people and the environment.

<sup>4</sup> Maximo in the case of Meridian Energy.



trending information in support of improved reliability

- *Strategic engineering* to assist with planning and updates to the Asset Management Plan, i.e. maintenance may be deferred or brought forward as a result of improved knowledge of the asset condition.
- *Generation controllers* in order to see alerts as they arise and know the general health of the sites.
- *Administrators* in order to deal with model behaviour and changes to functionality.
- *Management* in order to view the overall site and asset health.

Integral to the success of any condition monitoring system is clear results presentation and event notification. Visualisation of analysis results has been achieved within PAM via the use of dashboard displays which have been developed within *ProcessNet* and the use of *Key Performance Indicators (KPI's)*.

The *Corporate Overview (Station)* (Figure 6) is the first screen that personnel will see when they log onto PAM. It has been designed to focus the user's attention on the worst performing station which reflects the worst performing asset at a particular station. By selecting a station the user is then provided with a *Station Overview* screen which includes all assets at the selected station.

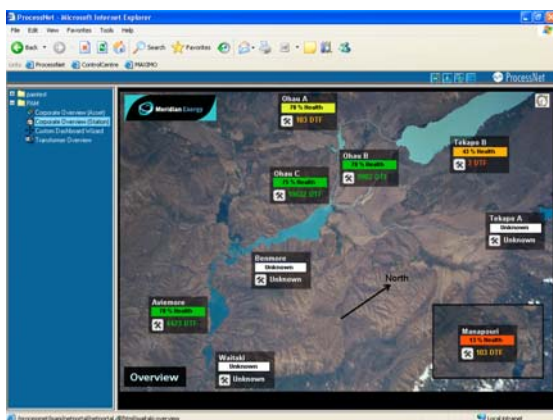


Figure 6. PAM display - Corporate Overview

The *Transformer Overview* display (Figure 7) summarises the health of each transformer at a particular station. From Figure 7, the worst performing transformer at Tekapo B is transformer 1097837 with a "Health %" of 43% and 3 "days to failure". These details are reflected up onto the *Corporate Overview* for station Tekapo B in Figure 6.<sup>5</sup>

<sup>5</sup> Note that sample screenshots do not currently incorporate turbines, governors or generators at this stage.

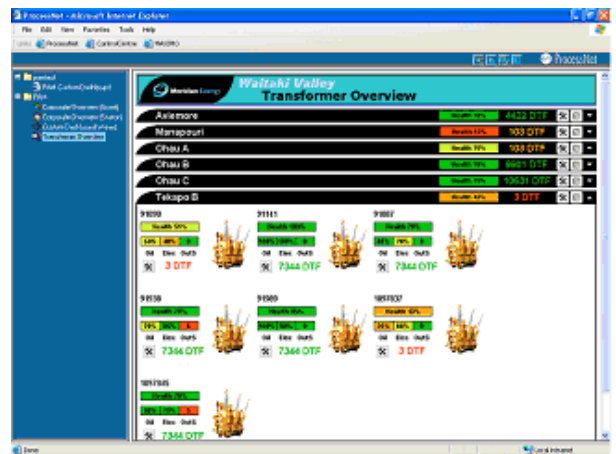


Figure 7. PAM display - Transformer Overview

Each transformer in Figure 7 has a predicted "Days to Failure" (DTF) which is derived based on certain key tests performed on the transformer<sup>6</sup>. Each transformer also contains two horizontal bars that represent the "Condition Index" and "Health %" for the transformer. The *Condition Index (CI)* is made up of three components:

1. Oil test results ("Oil").
2. Electrical test results ("Elect").
3. Outstanding tests count ("OutS").

The percentages for the *oil* and *electrical test* component of the CI are derived using algorithms which examine each individual test result on the detailed *Transformer Overview* shown in Figure 8. *Outstanding tests* is a count of any enabled tests which have not been conducted on a particular transformer or test results which have expired. The *Health %* is formed by averaging the *oil* and *electrical tests* components of the condition index to give an indication of total transformer health.

Figure 8 represents a *detailed Transformer Overview*. Each test results which has been analysed is assigned a *Key Performance Indicator (KPI)* which represents the status of the test result where a:

1. Green KPI represents *acceptable*.
2. Yellow KPI represents *questionable*.
3. Orange KPI represents *warning*.
4. Red KPI represents *alarm*.

<sup>6</sup> Note that DTF indicates days until a tests' "alarm" threshold is being reached not the total failure of the asset.

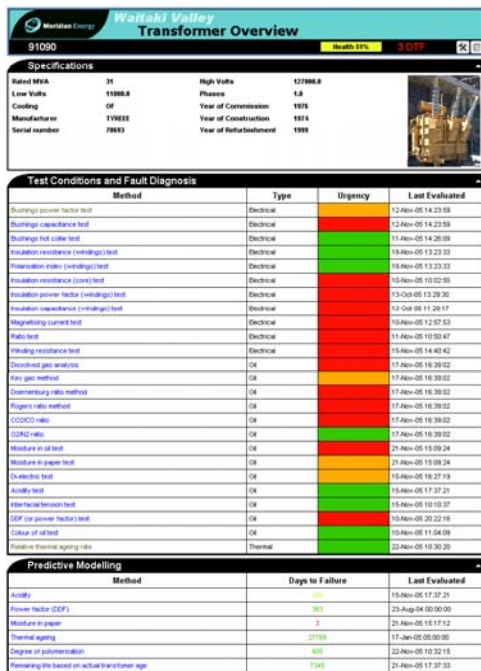


Figure 8. PAM display - Transformer Overview

The *Custom Dashboard* represented in Figure 9 provides powerful functionality that enables users to create their own specific view of assets that are of particular interest to them. For example an engineer may want to observe / track the condition of a particular ‘type’ of transformer at several locations or a single transformer at one station. Similarly a plant manager may only want to see assets at the station that they are responsible for.



Figure 9. PAM display – Custom Dashboard Wizard

Drilling down on individual test *methods* (Figure 8) provides the user with a *detailed test display* as shown in Figure 10<sup>7</sup>. The detailed display provides a list of

<sup>7</sup> Figure 9 is a drilldown screen from the “DDF (or power factor) test” in the “Test Conditions and Fault Diagnosis” section or “Power factor (DDF)” link in the “Predictive Modelling” section of Figure 8.

individual raw data values which are used within the analysis calculation and allows for trending of values (not shown). The display of Figure 10 also shows a customised *output* display which provides a indication of when the predicted value will cross the alarm threshold which indicates *days to failure*.

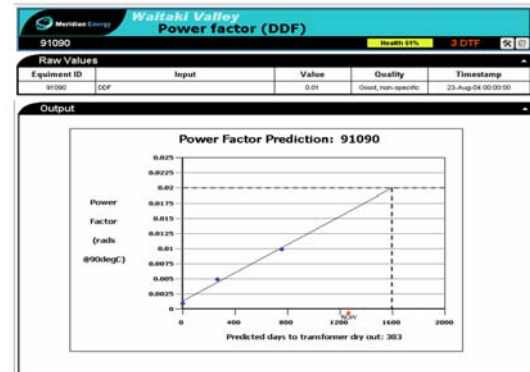


Figure 10. PAM display – Power Factor Prediction

Whenever an off-line (Maximo initiated) analysis result becomes available or whenever an on-line analysis produces an exception or indication of an abnormal event, an alert is made available to the user via an email. A sample of such an email is presented in Figure 11. These emails contain the *test name*, current *KPI*, *test status* (for an off-line test either pass, fail, retest or reschedule) and a *message* description with diagnosis and recommended actions. This email also contains additional information pertaining to the test within the *information* section and a link to the corresponding dashboard display.

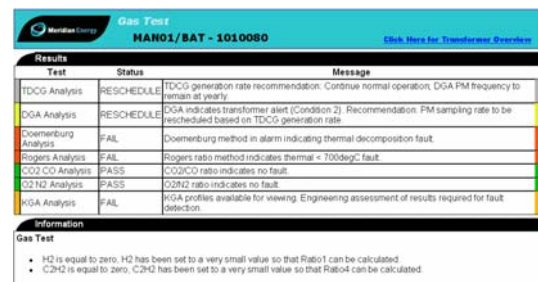


Figure 11. Event notification - sample email

The PAM system has the ability to retrieve maintenance and alert information for immediate access via the web based user interface. This maintenance and alert information can be accessed either at a station (Figure 7) or unit (Figure 8) level by selecting the alert or toolbox icon in these figures.

#### 4. IMPLEMENTATION CONSIDERATIONS

When implementing a system such as PAM it is necessary to carefully evaluate current maintenance practices and instrumentation available at different stations.

Ongoing development issues include:

- Consistency in testing across all units / stations.
- Testing procedure - testing performed incorrectly with faulty testing instruments.
- Instrumentation issues – instrumentation not commissioned, not displaying correct value (eg. oil temperature probe reading air temperature).
- Accuracy and usefulness of current testing and measurements being recorded.
- Integration of existing systems, and processes to achieve maximum benefits

#### 5. CONCLUSION

The PAM system is a decision support application that supports Asset Management by providing the visibility of plant conditions that is required to effectively manage a range of critical assets.

The PAM system:

- Allows for easy creation and modification of models for current and new assets.
- Combines data collection, analysis and integrity checks from multiple sources (PI and Maximo).
- Forces pro-active decision making through decision support e-mails and early detection of impending faults through predictive analysis.
- Aids in maintenance scheduling based on current and historical analysis results.
- Provides access to various asset information through one easy to use corporate interface.
- Allows viewing of summarised data at the corporate level and the ability to drill down to individual condition monitoring points at the analysis level.

- Provides a high performance, load controlled corporate integration layer to both plant (alarm and process) and relational (maintenance and other expert systems) information sources and application services.
- PAM provides a scalable solution where system functions can be distributed to remote nodes and new external systems can be interfaced into PAM without compromising system uptime.

There are systems on the market that deliver some of the functionality described above for some assets. However PAM is unique in that it delivers all of the above in one system that can be continually added to and customised for a range of assets.

The PAM system was successfully installed and commissioned during January 2006 with benefits already being realised. Work is currently underway into turbine governor and generator monitoring. Future phases of the PAM include the addition of other critical plant assets.

#### 5. DISCLAIMER

Note that PAM displays presented in this paper do not represent the current state of Meridian assets. Results have been simulated in order to demonstrate full PAM functionality.

#### 6. REFERENCES

- [1] IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus – Part 1: Oil Filled Power Transformers, Regulators and Reactors.
- [2] IEC 354:1991, Loading Guide for Oil-Immersed Power Transformers (steady state only).
- [3] Sparling, B.D., Understanding the Transformer as a Process, What it means to You, G.E. Canada, April 2004.