

# Mechanalysis (India) Limited



## Intelligent Condition Management On-Line

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### White Paper WP08

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condition management solutions

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## Intelligent Condition Management On-Line \*

### Abstract

Condition management of rotating machinery is not new to the power sector and is applied with varying degrees of success in India and abroad. The financial benefits have long been recognised and widely reported. However, the cost of implementation, required expertise and continuity of the systems has limited its broader use. To date, the focus has been on detecting the mechanical aspects of a machine (unbalance, alignment, bearings etc) whereas on-line detection of the electrical system has not been available. The Motor Condition Monitor (MCM) applies advanced modelling techniques to the machine's three-phase electrical supply. Electrical motors, generators and transformers, with their associated equipment, can now be monitored on-line without special sensors. The electrical motor or generator is the sensor thus eliminating the cost of multiple sensors, cabling and dedicated cabinets.

After 'learning' the plant's characteristics the MCM identifies impending mechanical and electrical faults by comparison with and deviations to the normal of 'learned' data. Extensive diagnostic information and alarms are available. Systems have been successfully applied to the NASA Space Shuttle Main Engine, helicopter engines and gas turbines etc.

With a low installation cost, takes little space in existing switch gear panels, MCM distributes condition management information by SCADA. Maintenance information is simply presented to personnel thus eliminating many of the complexities of traditional vibration and portable current signature analysis systems.

In addition to enhancing condition management strategies and process uptime, machines operating more efficiently contribute to saving the environment.

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# Intelligent Condition Management On-Line

## 1 Introduction

India's rapid national growth is straining the power sector to keep up with demand. Despite the many constraints to maintain or increase the power load factor (PLF), rotating machines are required to operate at full capacity, continuously. This 'uptime' objective can be achieved if a proactive machinery condition management programme is adopted.

Acoustic based condition monitoring goes back to the birth of the railways when wheel tappers listened for differences in sound to identify cracks in wheels. In the 1960s, IRD Mechanalysis transformed the delicate laboratory scientific instrument to become field tool for use by mechanical engineers and technicians. In the early 1980s, the advent of the PC and microprocessor produced a powerful signal processing capability. This made portable vibration data collectors and on-line monitoring systems excellent machinery diagnostic tools. With this development came increased complexity and so the need for greater expertise. In addition, an increased understanding of machinery performance and limitations of fault detection was recognised. While most vibration analysis systems are sensitive to the development of mechanical defects, the electrical faults are largely ignored or at best left to an occasional check. Although the cost of electronics has come down the installation of on-line systems remains high, particularly with on-line sensor cabling that is often greater than the detection instruments. With advances in technology, both the aforementioned constraints have largely been overcome.

A proven affordable system that addresses both mechanical and electrical monitoring on-line is now available with a low installed cost. The Motor Condition Monitor (MCM) applies advanced modelling techniques to the driver and driven machine's electrical supply to detect electrical and mechanical faults. Electrical motors, generators and transformers, with their associated equipment, can now be monitored, on-line, without specific sensors hard wired to the machine. The electrical machine has become the sensing device thereby eliminating system components and items prone to damage during emergency machine replacement.

It is natural when introduced to a new technology that we will make comparisons with what is presently known. A solution that appears to overcome many of the constraints of existing systems will always be viewed with scepticism. Even though there is, no single technology that can detect all rotating machinery faults, progressively more and more integrated fault detection systems will be developed towards this objective. The Artesis MCM takes machinery condition management a significant step forward by combining electrical and mechanical fault reporting.

## 2 Selecting a Condition Monitoring System

The following summarises the questions a Maintenance Director needs to ask when introducing a condition management strategy for the organisation:

### 2.1 Objectives, Budgets, Skills, Needs

- What do you want to achieve?
- Budget for equipment & Training?
- Core competency? Knowledge level?
- Number of machines to be monitored?
- Type of machines to be monitored?
- Environment (aggressive chemicals, humidity, heat, intrinsically safe etc)?
- Integration with plant processes and maintenance management systems

### Prime Decisions ?

This is whether the process plant is so strategic that it demands continuous protection or lower priority for periodic evaluation when determining maintenance priorities? Taking such decisions must be part of an overall company strategy to improve plant availability. The commitment of

executive office, operations and maintenance managers is essential to returning the benefits or expectations of all stakeholders.

We will now look at present practices, their strengths and weaknesses

## 2.2 Off-Line Vibration System Comparison

Understanding the benefits and limits of any system will set the expectation realistically; the table below identifies the main strengths and weaknesses of off-line vibration data collection:

<b>Strengths</b>	<b>Weaknesses</b>
1. Portability	1. Taking the correct reading (prone to error)
2. Unlimited readings	2. Limited diagnostics with critical machines
3. Non invasive	3. Focused mainly on mechanical faults
4. On the spot visual faults can be noted	4. Hand held sensor readings limits detection range
5. Data Collection is relatively simple	5. Difficult to take shaft relative readings
6. Powerful mechanical analysis capability	6. Labour intensive, especially data analysis
7. Basic training takes 5 days	7. False alarms can be due to process variables
8. Relatively low initial investment	8. Faults are only reported when looked for
9. Lower initial cost per measurement	9. Analysis will be limited without phase data
	10. Data is seldom visible to Operations
	11. Seen as a Maintenance tool not Production benefit

## 2.3 On-Line Vibration Protection System Comparison

The strengths and weaknesses with On-Line Vibration System are far from exhaustive but the main issues need to be appreciated as they influence the selection and investment decision.

<b>Strengths</b>	<b>Weaknesses</b>
1. Undertakes machine protection duties	1. Generally only overall vibration readings measured
2. Continuous, consistent data acquisition	2. High initial investment
3. Instant alarms of impending machine faults	3. Limited to installed sensors
4. Communicates with Distributed Control System	4. Eddy current probes are invasive, needs shutdown
5. Data Visible to Operations	5. Set to detect only mechanical faults
	6. Alarm relays seldom connected to trip machines
	7. On-Line Diagnostics doubles the system price

It can be seen that both off and on-line vibration based condition monitoring systems are designed to detect mechanical faults which are generally the result of contamination, lost lubrication, wear, and thermodynamic changes in the machines. The electrical condition of rotating plant is seldom considered but faults can be detected by vibration measurement when at an advanced stage. However, this is hardly suitable for a proactive maintenance strategy.

## 3 On-Line Protection Monitoring Procurement vs. Intelligent MCM

A typical traditional vibration on-line protection monitoring installation will consist of numerous customised elements. Bringing these together often involves Consulting Engineer, Engineering Contractor, Tender, Procurement, Evaluation and finally Purchase. Then there is the Delivery, Commissioning and Operator Training that can be a torturous process, time consuming and costly. From start to finish for a simple 18-channel system, it can take at least 6 months.

The following simple bill of materials, which would be more complex if eddy current probes are specified; this is typical of a motor / pump or fan vibration monitoring system.

Bill of Materials	Pump1	Pump2	Pump3	Pump4	Totals	Comments
Motor Sensor X-Y	4	4	4	4	16	Accelerometers
Pump Sensor X-Y	4	4	4	4	16	Accelerometers
<b>Total Channels</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>24</b>	
Sensor Cables	8	8	8	8	24	With flexible conduit
Junction Boxes	2	2	2	2	8	IP65 enclosure
Cable to Panels	2	2	2	2	8	Est. 800 metres armoured
Cable Racks	1	1	1	1	4	Custom made on site
Monitor Modules	4	4	4	4	16	Dual Channel
Monitor Racks					2	19" Rack
Panel					1	Takes 3 Racks Wiring etc
Installation						Labour & Commissioning

Often the installation cost is equivalent to the price of the on-line sensors and monitor system hardware.

The Protection Monitor System Architecture will look like this:

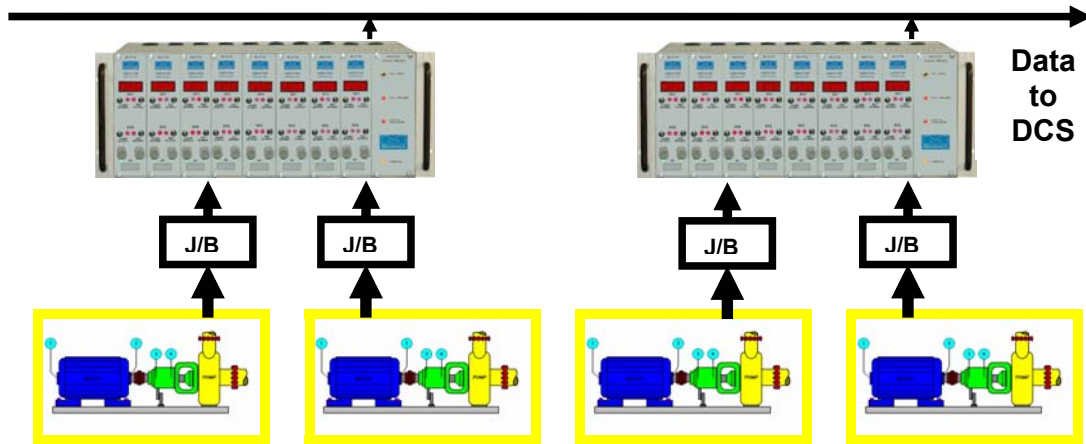


FIGURE 1 – Vibration Protection Monitors

The above system measures overall unfiltered vibration levels to detect mechanical faults such as unbalance, misalignment, defective bearings looseness etc. The alternative that measures both mechanical and electrical stresses based on 'learned' performance is MCM that is installed into the electrical switchgear panel. The Bill of materials below can be compared with that above.

**Intelligent MCM**

Bill of Materials	Pump1	Pump2	Pump3	Pump4	Totals	Comments
<b>MCM Units</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>4</b>	<b>Install in Switch Panel</b>
<b>SCADA</b>					<b>1</b>	<b>Distributed Software</b>



FIGURE 2 – Intelligent MCM

It can be seen that the MCM is simply one meter per machine detecting both electrical and mechanical defects. The MCM unit is set installed in the existing motor switch panel taking only 96x96x140D (mm) space and connected to the existing current transformers. Wiring is minimal.

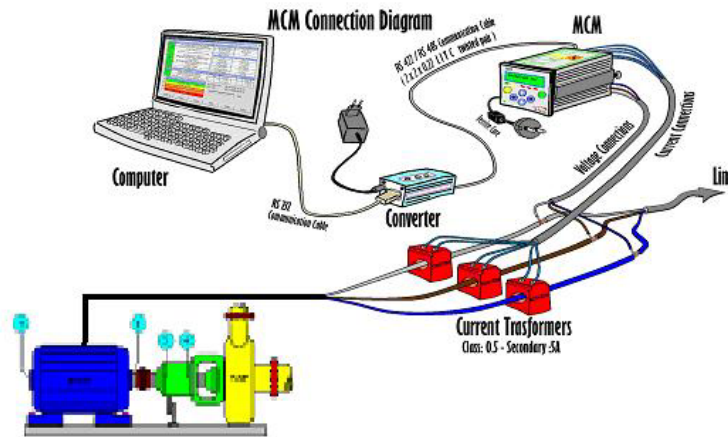
## 4 MCM – An Intelligent Approach to Condition Monitoring

As we have discussed traditional vibration based condition monitoring and protection involves mounting sensors on the motor and driven machine and measuring the overall vibration energy. Analysis of the spectrum using an external device with expert skills is very effective and can identify many faults developing. Meaningful analysis often requires the observation of measurements made over a long period of time, most often manually.

Portable Motor Current Signature Analysis has sometimes been used to complement mechanical vibration based programme. This approach is based on analysis of the line current supplied to a motor. The variances in the stator-rotor air gap are reflected back in the motor's current through the air gap flux affecting the counter electromotive force, so that current carries information related to both mechanical and electrical faults. Faults will therefore exhibit a change in the frequency spectrum of the current at specific frequencies.

Although data acquisition is simple in current signature analysis since only electrical signals are measured, it is invasive and in many instances the plant need switching off to connect the sensing devices. Interpretation of the data requires expert personnel and is as time consuming as vibration analysis. Just like vibration analysis, current signature analysis is an output assessment only. **It can be difficult to determine whether an abnormal signature is due to a problem in the motor or to unexpected harmonics in the supply voltage or some process change.**

MCM was developed to eliminate the shortcomings of both on and off-line vibration and the current signature analysis systems, by taking a radically different approach. Using a model-based fault detection and diagnostics technique where the expected dynamic behaviour (model) of the three-phase system (see Figure below) under varying conditions, such as load, is determined and compared with the measured dynamic behaviour to monitor abnormalities.



**FIGURE 3 – MCM Connects to CTs of 3 Phase Supply**

The MCM first learns about the motor-driven system to which it is connected for a period by acquiring and processing real-time data. Data is analysed using a set of advanced system identification algorithms in order to allow the calculation of expected dynamic behaviour and model parameters. Changes in the parameters of the system can be used to indicate any abnormalities developing in the system. Further processing of these parameters is used for fault diagnosis.

As opposed to traditional vibration and current signature analysis, this approach is based on a cause-effect (input-output) relationship that is immune to ambient or input noise. Additionally, the difference between expected and actual behaviour filters out and enhances only abnormalities

generated by the system allowing the presentation of both earlier and more accurate alerts. The expert system approach eliminates the need for database or record keeping, expert personnel, and time-consuming data gathering and analysis. It provides comprehensive fault coverage (mechanical and electrical as well as the driven system), even though it measures only voltages and currents. MCM addresses many of the objections raised by the use of vibration-based and portable current signature analysis systems:

- **Ease of installation** – Industry-standard current and voltage transformers can be used. The MCM can be used anywhere on electric motor driven systems. It is usually mounted in the control cabinet as it does not need to be in close proximity to the machine.
- **Ease of use** - The expert system approach makes it possible for MCM to automatically establish a database and monitor changes in these parameters. Fault levels are presented on a simple and intuitive sliding scale by the device itself, reducing dependence on highly skilled specialists.
- **Repeatability** - The MCM results are highly repeatable. There are no external or background effects that can interfere with the capability of the monitor systems.
- **Comprehensive fault coverage** - Both electrical and mechanical faults can be detected using a single device.
- **Advanced warning** – Alarm thresholds are not affected by the operating conditions of the system, allowing MCM to provide early and accurate alarms.
- **Integration to factory automation systems** - MCM units are easily connected to an external acquisition system for continuous monitoring using industry-standard network cabling. This, together with its simple method of fault indication, making MCM an ideal device for use with factory automation systems.

## 5 How MCM works

MCM uses model-based fault detection and diagnosis techniques. The illustration below shows the principle approach to compare the dynamic behaviour of the mathematical model of the machinery or process with the actual, measured dynamic behaviour.

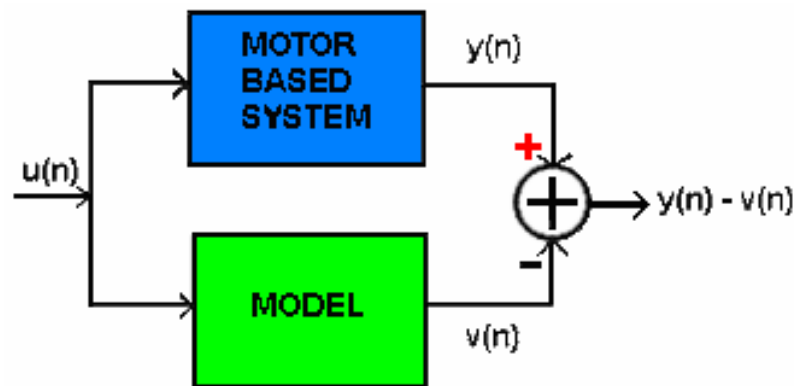


FIGURE 4 – MCM Model

In **FIGURE 4**,  $u(n)$  is the input voltage to both the mathematical model and the actual motor-based system.  $y(n)$  corresponds to the output of the motor-based system, the measured currents, and  $v(n)$  is the current calculated by the model. Therefore,  $y(n) - v(n)$  is the difference between the measured and calculated currents. The model consists of a set of differential equations that describes the electromechanical behaviour of the motor/generator. System identification algorithms for the calculation of model parameters processes the real-time data acquired from the system.



Faults developing in the motor or in the motor-driven system affects the model parameters, allowing the motor itself to be used as a condition monitoring sensor.

MCM first learns the characteristics of the motor-based system for a period by acquiring and processing the motor data. The results are stored in its internal database and a reference model established. This is represented by the values of a number of model parameters, in terms of both mean values and standard deviations. While monitoring, MCM processes the acquired motor data and compares the results to the data stored in its internal database. If the results obtained from the acquired data are significantly different from the reference model, MCM indicates a specific fault level taking into account the magnitude and the time duration of the difference.

MCM monitors and compares 22 different model parameters that are classified into Three Groups.

**Group 1:** The eight 'electrical parameters' are the network equivalent parameters and are correlated to the physical parameters of the motor, like inductances and resistances. These parameters are sensitive to electrical faults developing in the motor. MCM evaluates and analyzes the differences between the model parameters at any instant and the average value of the same parameters that are obtained during the learn stage. These differences are normalized with respect to their standard deviations obtained during the learn stage. The processed values indicate the number of standard deviations they are away from the average values obtained during the learn stage. If they exceed threshold values, an alarm is given. Changes in their values are associated with faults that are developing in the system, an isolation problem in winding affecting the parameters associated with resistances for example. This would allow MCM to detect the isolation problem at an early stage. Though they are primarily used to detect electrical problems, they also can indicate mechanical incipient faults. For example, an imbalance or gear problem would cause dynamic eccentricity in the air gap, resulting in a change in the induction parameters and therefore in the model parameters. By monitoring the changes in these model parameters imbalance can be detected very early, avoiding damage to other machine components such as bearings.

**Group 2:** In addition to the above parameters MCM also monitors the supply voltage as well as the load conditions. If the supply voltage changes abnormally, has imbalance or very high harmonic content then it issues a Watch Line alarm. Similarly if the load conditions do not match with the conditions observed during the learn stage then it issues a Watch Load alarm. The Watch Load alarm means that either the load conditions have changed or there is a fault developing in the system. If the user determines that there is a change in the process, then he can add this new load condition into the conditions observed during the 'learn' period.

**Group 3:** Using the measured three phase voltage and current signals, MCM also calculates a set of physical parameters such as rms-values of three phase voltage and current, power factor, etc. This set also includes parameters such as total harmonic distortion, harmonic content of the incoming signal and voltage imbalance that give an idea about the quality of supply power. Active and reactive power parameters in this set might be used for energy consumption estimations. It combines many measurements that are of interest to both production and maintenance operators in a single device.



For all its sophistication, MCM is a small meter suitable for installation on motor control panels. Selected measurements can be displayed on the LCD screen of the device; alarms are presented using LED 'traffic lights' for ease of use.



## 6 Integrating MCM into Plant Information Systems

MCM can be integrated into plant wide operations information system with its own desktop application, MCM SCADA is used for trending and diagnostics. The MCM SCADA also provides the user with reports outlining fault status, diagnostics as well as relevant parameters about the operation of the equipment during a selected period. In addition to trending, it obtains the frequency intervals of mechanical parameters and determines the corresponding faults, such as bearing problems, imbalance, looseness, etc. that are then presented to the user.



FIGURE 5 – MCM SCADA Network

Average values obtained for energy consumption (voltage, current, active power, reactive power and power factor) as well as the power supply quality (THD, harmonics, voltage imbalance & current imbalance) are also provided (see screen display in FIGURE 6).

MCM can automatically send this report when an alarm occurs and at selected periods using e-mail. The MCM SCADA also allows diagnostics data to be monitored from several different computers at remote locations.

Alternatively, MCM can be integrated into factory automation and maintenance management systems using the standard Modbus protocol.

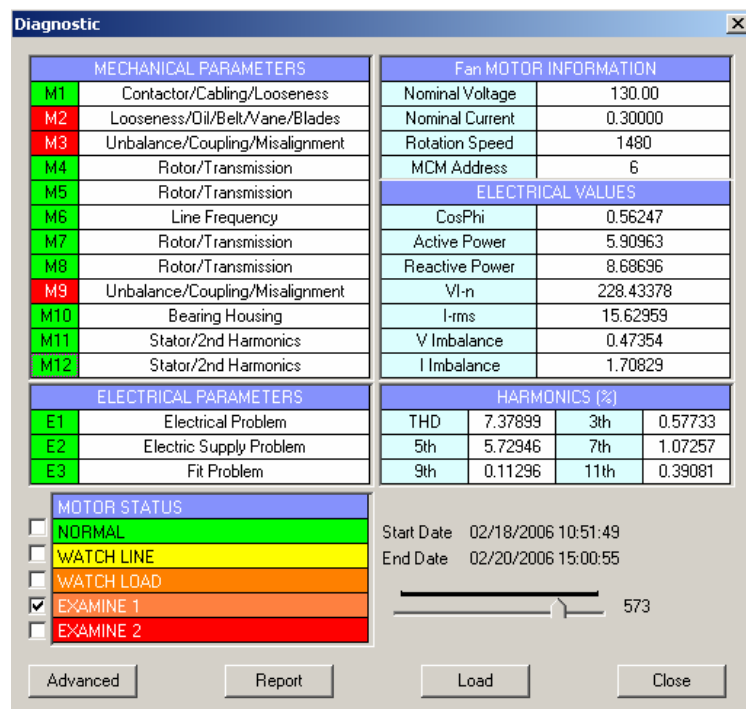


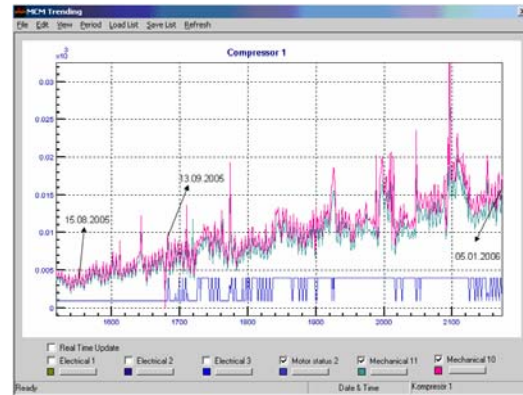
FIGURE 6 – MCM Diagnostic Report

## 7 MCM – Success and Applications

The technology has been successfully deployed in a wide range of industries, some of which have applied condition monitoring for many years (like power, primary metals, and petrochemical processing). They have found MCM very complementary to existing systems, particularly for remote or inaccessible machinery prone to electrical faults. In addition, where equipment is difficult to justify the higher cost of traditional approaches, the MCM is an ideal solution.

The automated diagnostic capabilities of MCM have allowed such users to extend their condition monitoring programs at minimum cost and without increasing the load on already-stretched analysts. As they have better understood the technology, many have been surprised at its ability to give long advanced warning of mechanical faults like bearing degradation, soft foot, imbalance and misalignment, as well as electrical problems such as insulation or capacitor defects.

In the example, **FIGURE 7** it that shows the measurement trend of a compressor that MCM has correctly identified a developing bearing fault and provided a 3 month warning to allow the successful planning of a maintenance intervention. This trend also shows that MCM was aware of the incipient defect for a full month before considering it sufficiently serious to alert maintenance staff.



**FIGURE 7 – Bearing Failure Advance Warning**

MCM has also been especially successful in industries that have not been traditional users of condition monitoring. Examples of this include the food and beverage, building services, water treatment, automotive, marine and general manufacturing sectors. One manufacturer of washing machines has been using MCM to monitor conveyor and fan systems in the paint shop, where equipment failures led to many defects requiring expensive rework. Early fault detection resulted in a reported increase in productivity by 50%. Customer complaints reduced by 25% allowing the system to pay for itself in well under a year. Similarly, water industry customers have been able to reduce maintenance costs by 10% through reductions in emergency repairs, deferred interventions, and reduced spares inventory.

New applications for MCM are being adopted daily. Wind turbines are an obvious one where existing condition monitoring consists of an array of sensors, wiring etc all adding to the cost of the installation. MCM is an ideal single instrument that also learns the process variables inevitable with a wind turbine.

For Hydro turbines, especially older units that did not appear to justify on-line diagnostic systems yet experience more electrical winding failures than over designed mechanical elements; the MCM provides a dual role monitoring system at minimal cost and no intrusion to the rotating machinery.

Sueo Yamaguchi TPM consultant of Japan Institute of Plant Maintenance (JIPM) and advisor to TPM Club of India recently stated that there are too many abnormalities like air and oil leakage, equipment failure etc. A typical Indian CEO strategy is **Manufacturing Cost + Profit = Market Price**. This is not a sustainable strategy; countries like China will soon leave India in its wake unless attitudes change. There must be cost reduction exercises in Indian Industry and a Condition Management Strategy is one of the obvious steps to take across industry and not just the power sector.

## 8 Closing Comments

It is an established fact that rotating machines: fans, pumps, motors, generators etc will consume as much as 15% more energy if misaligned or out of balance. Worn or poorly lubricated bearings will contribute to such losses. Vibration and the MCM Electro-Mechanical Condition Management System will reduce energy consumption, enabling greater machinery availability and improves plant productivity; everyone benefits. In 2006, India generated 118,561MW; just 3% saved would translate to 3,500MW of extra power!

Machinery condition management is a strategic tool to optimise productivity, especially in the power sector. Traditional on and off line vibration monitoring systems have proved their worth yet machines continue to fail at the most inconvenient time. Until now, no single solution has been available for the effective monitoring of both mechanical and electrical process plant.

The intelligent MCM system that 'learns' the machines process characteristics and then gives advanced fault notifications is a new tool in the armour of the Maintenance and Operations Director. By collecting data direct from the three phase supply and using the motor or generator as the sensor, the MCM reduces the total cost on machinery protection and condition monitoring.

System reliability is enhanced; the chance of damaged sensors, cables, ingress of contamination in junction boxes etc and need for extra panel space in control rooms is removed. A small box fitted in the machine's control panel is all that is required. Optional SCADA or MOBUS capability is offered for distributed data reporting systems.

MCM is an economic and technical solution to enable adaptation of a condition management strategy in almost all electrically driven production plants but especially in the Power Sector. It will aid India's drive to becoming more environmentally friendly.

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