Predictive Maintenance Programme (PMP) for Energy Sector of Indian Industry: An Economic Perspective

HP Singh and V Bhujanga Rao

In the paper on PMP for energy Sector in India, the authors have dwelt upon thecurrent status of power sector in India including various initiatives of the Government for upgradation of infrastructure and generation capacity. Keeping in view the critical need of a reliable, robust and competitive power sector for sustained growth of the Indian economy, the authors have identified the grey areas and shortfalls in the maintenance of infrastructure. Implementation of a PMP, considering technologies and processes available in the form of CBM, RCM & TPM, has been recommended for various components of the power sector The authors are of the opinion that speedy implementation of Predictive Maintenance Programme in the power sector would on the one hand result in huge savings to the State, while on the other, it would ensure assured availability of energy to other sectors of the economy at a competitive tariff enabling sustenance of the economic growth of the country.

Part I: Current Scenario of Power Sector

1. A large number of power projects in the XI and XII. Five year plans are under implementation to overcome the growing energy requirements in the country. According to the 17thEconomic Power Survey (2007), the energy requirement is projected to grow at a Compounded Annual Growth Rate (CAGR) of 7.5% during 12thplan period reaching from 9,68,658 Giga Watt hour (GWh) in FY 2012 to 13, 92,065 GWh by 2017, while peak load requirement is projected to grow to 2,23,660 MW in FY 2017, at a CAGR of 7.4%. Ministry of Power and Central Electricity Authority (CEA) have projected the total investment requirement of Rs.11,35,142 crores for the power sector during

Commodore HP Singh is Principal Director IT, Integrated Headquarters of Ministry of Defence (Navy)

Dr. V. Bhujanga Rao is Chief Controller R&D, DRDO HQ, New Delhi.

the 12th plan period which also includes investment for generation capacity addition of about 1,00,000 MW (Existing capacity is 1,82,344 Mw). According to Crisil Report[1] (Jun 2010) about 82,000 MW of generation capacity at an investment of Rs.5,10,000 Cr is likely to be added in the five years i.e. during FY 2011 to FY 2015. The Central (NTPC - having the major share), state and private sector are estimated to add about 21,500MW, 15000MW & 45000MW respectively during the next five years.

2. As is well known, about 70% of India's energy generation capacity is from fossil fuels with coal accounting for 40% of India's total energy consumption followed by crude oil and natural gas at 24% and 6% respectively. India will be dependent largely on fossil fuel imports to meet its energy demands by 2030. India's dependence on energy imports is expected to exceed 53% of the country total energy consumption. In 2009-10, the country imported 159.26 million tonnes of crude oil which amounts to 80% of its domestic crude oil consumption. It may be worth noting that 31% of the country's total imports are oil imports. India is facing coal shortages as well. Thegrowth of electricity generation in India has been hindered by domestic coal shortages and as a consequence, India's coal imports have increased by 18%in 2010.

3. Due to rapid the industrial expansion, India is one of the fast growing energy market and is expected to be the second largest contributor to increase in global energy demand by 2035, accounting for 18% rise in global energy consumption. Considering India's growing energy demands and limited fossil fuel reserves, the country has ambitious plans toexpand its renewable and nuclear power industries. India has the world's fifth largest wind power market and plans to add about 20 GW of wind power capacity by 2022. India also envisages increasing contribution of nuclear power to the overall electricity generation capacity from 4.2% to 9%. The country has five reactors under construction and there is a plan to construct 18 additional nuclear reactors by 2025. The initiatives taken by the Government in last few years would enable larger share of nuclear powerin the overall power generation capacity notwithstanding the recent episode at Kudankulam plant.

4. In the medium term, thermal power is likely to remain the major source of generation as the coal based/gas based projects presently have a competitive tariff advantage over renewable energy projects. Thermal based capacity of about 29,000 MW is under construction and about 75,000 MW coal based

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[1] Crisil Research is India's largest independent research house. It offers Independent information, opinions and solutions that help better business and investment decisions.

capacity and 10,000 MW gas based capacity are being planned for the Twelfth plan period. The overall share of thermal power in total installed generation capacity is likely to increase from 64% (FY 2010) to about 74% by the end of the twelfth plan. Despite the efforts being made to ramp up the generation capacity, the country may witness slippage in capacity addition on account of various emerging challenges. Minimisation of Aggregate Technical and Commercial Losses (AT&CL) and effective demand management will remain critical for the sustainable growth of the Sector. Besides generation capacity, we need to look at the transmission and distribution system critically.

5. As on date, the transmission network in the country comprises a little over 3187 Circuit Kilo Meter[2] (ckm) in 750 KV segment, 91359 ckm in 400 kV segment and 124201 ckm in 220 kV segment. The ownership ofthe grid is predominantly with Power Grid Corporation of India Ltd (PGCIL) and state TRANSCOs/State Electricity Boards. PGCIL operates around 74,000 ckm of high tension transmission lines and 124 sub stations. The transmission grid is encountering problems pertaining to increasing short circuit levels, operational voltage excursions etc. These need to be arrested for improving performance of the transmission grid.

6. About 75% of the power system faults emanate from overhead lines and underground cables; about 15% originates from power transformers and shunt reactors, about 7% emerges from generators and step-up transformers, and less than 3% from bus bar faults. The protection relays cause nearly 50% of the incorrect operations of the fault clearance system.

7. In India, the failure rate of substation equipment, particularly Current transformers (CTs and CVTs/VTs) is on the higher side compared to Circuit Breaker (CB) and surge arrester. International figure in respect of equipment failure is in the range of 1 to 2%. In India, the failure rate of EHV class transformers (up to 400KV class) ranges upwards of 4%. The causes of failure of transformersof Indian utilities are due to design defects (36%), manufacturing problem (29%), material defects (13%), incorrect maintenance, storage and other technical defects like abnormal overloading, lightning, over-cluxing, external short circuit etc. These account for around 21% failures It has been reported that failure of transformer (150 transformers of 12 Indian utilities) is mainly due to cases such as failure of bushing, inter-turn insulation, On Load Tap Changer (OLTC) and tertiary winding. It is quite interesting to note that most of the failures have taken place in case of transformers, which had served less than 10 years. Therefore, it raises the question about

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[2] Circuit Kilometers is the measurement of the actual path followed by the power transmission lives

the quality control system of manufacturing process and maintenance practices being followed by the utilities. Failure of transformer bushings and leakage of oil have become a major cause of concern for most of the power utilities. Circuit Breaker (CB) is a vital equipment in substation, but probability of CB failure is very low. Major CB failure can take place during normal operation. The failure of substation equipment can cause network reliability problems, damage to other nearby equipment and personnel and can lead to complete shutdown of the station. There is no escape from normal long term ageing process. But premature failure can be avoided by proper maintenance. Basically all equipment needs maintenance which needs to be undertaken holistically.

Distribution Transformers

8 The increase in demand for energy will require more and more power transformers which are key components in power transmission and distribution system. The failure of vital equipment like transformer in the EHV substation could be catastrophic to the concerned utility in terms of cost and time (say few weeks to replace, if spare is available, or months to a year to repair or build a new one). Much importance is required to be given on quality and maintenance of such vital equipment. **Extending the useful life of power transformers is the single most important strategy for increasing life of power transmission and distribution infrastructures**. Determining the existing condition of power transformers is an essential step in analysing the risk of failure. The Degree of Polymerization (DP) and Furan analysis are two of the diagnostic tests for transformers which provide valuable information about residual/remaining life of transformer.

9. Age is an important factor generally considered for replacement decision of equipment. It is also one of the indicators of the remaining life and upgrade potential of the equipment to current state-of-art. Electrical equipment and machineries of power transmission system are generally designed for service life of about 25-35 years. Average expected life span of static equipment, like power transformer is about 35 years, that of a Circuit Breaker (CB) is about 25 years and transmission lines including conductors and insulators, towers is about 35 years and so on. Beyond this period they are not expected to render their services up to expected desired efficiency. Actual service life of equipment varies widely depending on the manufacturer's design, quality of assembly, materials used, operating history, current operating conditions and maintenance history, etc. As per the data available in public media, in the last five years, sixteen Generator Transformers (GTs) of a leading Generating company have failed, out of total population of about 100 nos. (400 kV

class –46 nos. and 220 kV class –53 numbers GTs), at various stations in the country and maximum failures are attributed to winding failures because of split core design resulting into hot spots or due to inadequate maintenance.

10. Besides the generation machinery and transmission system related problems, the distribution network in the country has also been experiencing inefficiency. The Ministry of Power has signed MOUs with the States in the past to undertake time bound distribution reforms. As on date, 16 SEBs/ Electricity departments have been unbundled and corporatized. The overall distribution loss levels, while remaining high in absolute terms have shown marginal improvement on account of improvement in the areas of energy audit, system strengthening, rural load management and prevention of theft.

Productivity performance

11. India's Total Factor Productivity[3] (TFP) is 34 per cent when indexed to US standards(MCKinsey report) in generation and 4 per cent in transmission and distribution (T&D). This is quite low. Based on the data available it is felt that India could achieve a potential TFP of 86 per cent of US levels in generation and, due to much lower demand per consumer, 42per cent in T&D at current consumption levels. In fact, some private players (both Indian and foreign best practice companies) are already achieving close to these levels.

12. The main reasons for the low TFP in generation are poor management at SEBs, under-investment in renovation and poor maintenance strategies, excess manpower and construction overruns. In T&D, losses from thefts, poor maintenance and under-investment are the main causes of India achieving only a tenth of its TFP potential.

13. Power is a vital energy input for the economic development of any country and reforms have become an absolute necessity to keep the Electricity Supply Industry growing. For nearly a century in all countries the entire power industry scene in the world has undergone a significant transformation. Obviously all this has resulted from the most essential infrastructural requirement i.e. power requirement in today's world that is, the power requirement for residential customers, agricultural customers, industrial or commercial customers. In the transition from traditional regulated monopoly Electricity Supply Industry to modern deregulated Electricity Supply Industry, competition is more effective than regulation in promoting private sector participation through massive

[3] Total Factor Productivity is a variable which accounts for effects in total output not caused by inputs.

investments and - efficiency in Electricity Supply Industry has increased sharply. But the potential for this kind of industry reform will vary by country-depending on whether the system is Government owned, investor owned or under mixed ownership. To realize the potential objectives of restructuring the power sector in terms of lower electricity costs for consumers, improve the efficiency of power system, recover the State Electricity Board losses, voltage fluctuations, system reliability, obligations relating to safety, supply and stability, reassurance to both consumers and investors in terms of tariff rate and fair rate of return, application of power models and effective maintenance strategies which are of competitive nature and largely self regulating are required on a war footing.

14. The Indian power sector suffers from considerable electricity supply shortages (peak deficit of 15.2 percent and energy deficit of 9.0 percent in 2007-08). The Government of India (GoI) is addressing this problem both through a major green field capacity augmentation program and through rehabilitation of existing coal fired generation capacity. Around two-thirds of India's 65,000 MW of coal fired plant capacity is owned by state government utilities, and a significant part of this is reported to be in a poor condition, with plant load factors of about 70 percent (with some plants having lower than 55 percent) and station heat rates of about 3,000 kcal/kWh (in some cases up to 3,500kcal/kWh).

Plant Loading Factor

15. The Plant Load Factor[4] (PLF) of state-sector thermal power plants in India in 2006-07 was on an average 70.84 percent compared with 89.4 percent for NTPC power plants in the central sector and 86.35 percent for private-sector power plants–clearly indicating the significant scope for improving performance of state-sector power plants. However, there is a wide performance range among the state-sector power plants themselves, with PLF of more than 90 percent for some power plants in Punjab, Gujarat, Rajasthan, Andhra Pradesh and Tamil Nadu. It is also seen that almost all power plants which exhibit high PLF also have better energy efficiency performance as well – typically less than 10% deviation from the design heat rate, compared to up to 50% deviation in some cases. Improving performance of state-sector power plants through interventions aimed at strengthening operations and maintenance practices is essential to ensure optimum performance of the power

[4] Plant Load Factor (PLF) is a measure of average capacity utilization. In the electricity industry, it is a measure of the output of a plant compared to the maximum output it could produce.

plant both from the Availability as well as Efficiency aspects. This holds true for new as well as old power plants. It is estimated that the availability of power in the country can be enhanced by more than 17 percent (as against energy deficit of 9 percent) if all the available generation units can be utilized at an average PLF similar to NTPC units through rehabilitation combined with better O&M practices. Althoughsuch high levels of performance may be difficult to achieve across all state-sector power plants, the potential benefits of focusing on improved power plant performance are clearly immense. Improved O&M practices are also necessary to sustain the benefitsfrom rehabilitation of power plants as well as to sustain good performance of new power plants.

Part II: Existing Maintenance Practices in the Indian Power Sector

16. **Review of existing Maintenance Practices in State Sector Coal Fired Power Plants:** Based on thereview of select power plants by independent consultants it is seen that there is wide variation in existing maintenance practices in state sector power generation plants, although even the relatively better utilities do not exhibit practices comparablewith the industry best practices. It is seen that often documented maintenance procedures have not been developed and deployed even for critical equipment, especially in case of weaker utilities.

17. Maintenance Related Operational History of performance trends and failure history is often not available even for critical assets such as mills, pumps and balance of plant. Also, where available data is recorded in hard copy maintenance registers, it is not used for failure history analysis or for monitoring Mean Time between Failures (MTBF). Failure Modes and Effect Analysis is usually absent as an institutional practice. It is seen that typically there is no dedicated maintenance planning department –and even when there is one, it does not effectively contribute to systematic maintenance planning. Mostly, maintenance planning is being carried out by individual maintenance groups (boiler/turbine/electrical etc). Long term planning for overhaul is done 2-3 years in advance, though inadequate planning and preparation often leads to extension of shutdown-schedule. Spares-planning is carried out on the basis of past experience rather than a systematic analysis of spares requirement, leading to imbalance in availability of spares. Spares for planned-maintenance are planned 6-8 months in advance by the individual maintenance groups. There is a limited appreciation of the commercial linkages of plant level availability and the reliability of individual equipments. Often the commercial implications of productivityloss (impact on fixed cost recovery) and reduced heat rate due to poor equipment performance (for example underperforming mills) is not objectively assessed in the maintenance decision-making process. Prioritization of maintenance areas based on a paretoanalysis of failures is

also not undertaken. Also since most of these plants are relatively old, there is inadequacy of modern measuring equipment and where available, such equipment is often not used on a regular basis. Absence of adequate condition monitoring systems leads to reactive maintenance practices rather than pro-active maintenance practices.

18. One of the hallmarks of top performing generating companies worldwide is their successful efforts to establish a Predictive Maintenance Program, one that uses their equipment reliability, cost and efficiency data to supplement the recommendations of the equipment manufacturers and the utility's firsthand experience. There is a need to establish a Strong Maintenance Planning Department (MPD) at the Plant. The Maintenance Planning function at the Plant should be strengthened in terms of placing it as the nodal point in both target review and daily decision making process for day-ahead maintenance plan, in association with Operations and Efficiency (O&E) Cell. The MPD would be responsible for the overall planning of the maintenance activities both short-term and long-term. This includes developing predictive maintenance schedules and ensuring their compliance, formulation of overhauling strategy (for example preparation of six year maintenance rolling plans), spare parts etc.

19. In the succeeding paragraphs, a brief description of various types of maintenance strategies has been dwelt upon to examine what could suit the best to an organization. Maintenance is a combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function. Maintenance can be carried out in different ways. While preventive maintenance is carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item, the predetermined maintenance is preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation. Predetermined maintenance is an option if a failure is age-related and the probabilities of failure in time can be established. Depending on the consequences of a failure, different maintenance intervals can be chosen. If the consequences of a failure are not too severe and the cost for Maintenance predetermined tasks is high one might choose to allow theintervals between tasks to be longer than if the functional failure leads to a safety hazard which has consequences that can't be tolerated. Examples of predetermined maintenance tasks are scheduled restoration and discard tasks. These tasks involve restoring or replacing the asset at determined intervals of time.

Predictive Maintenance (PM)

20. Predictive Maintenance, or condition-based maintenance, attempts to evaluate the condition of equipment by performing periodic or continuous (online) equipmentcondition monitoring. The ultimate goal of PdM is to perform maintenance at a scheduled point in time when the maintenance activity is most cost-effective and before the equipment loses performance within a threshold. This is in contrast to time-and/or operation count-based maintenance, where a piece of equipment gets maintained whether it needs it or not. Time-based maintenance is labour intensive, ineffective in identifying problems that develop between scheduled inspections, and is not cost-effective. The "predictive" component of predictive maintenance stems from the goal of predicting the future trend of the equipment's condition. This approach uses principles of statistical process control to determine at what point in the future maintenance activitieswill be appropriate. Most PdM inspections are performed while equipment is in service, thereby minimizing disruption of normal system operations. Adoption of PdM can result in substantial cost savings and higher system reliability. RCM, emphasizes the use of predictive maintenance (PdM) techniques in addition to traditional preventive measures. When properly implemented, RCM provides companies with a tool for achieving lowest asset Net Present Costs (NPC) for a given level of performance and risk.

21. Condition Based Maintenance (CBM) is predictive maintenance based on performance and/or parameter monitoring and the subsequent actions. When dealing with non-age related failures condition based maintenance tasks are often used. CBM or on-condition tasks are performed by inspecting assets to determine if any potential failures have occurred. Some common methods include using human senses such as listening for unusual noise or condition monitoring of the asset. These tasks do not help postpone a failure but can detect that a failure will occur and thereby make it possible to act in order to avoid the consequences of a failure. Condition based maintenance can be continuous, scheduled or on request. If CBM is scheduled, intervals for conducting condition based maintenance tasks could be chosen.

22. Condition based maintenance has been described as a process that requires technologies and people skills that integrates all available equipment condition indicators (diagnostic and performance data. operator logged data, maintenance histories, and design knowledge) to make timely decisions about maintenance requirements of important equipment. Condition based maintenance assumes that equipment failure modes will follow one or more of the classical degradation styles and that there is sufficient local knowledge of the equipment's historical performance to perform an extrapolation of its remaining life. This in itself

is a form of prognostics based partially on science, and partially on elicited experience of the plant staff. These measurement techniques, observations, tests, and operator intuitions are what forms the plant's condition based maintenance programme. The goal of condition based maintenance is to optimize reliability and availability by determining the need for maintenance activities based on equipment condition. Using "predictive techniques", technologies, condition monitoring, and observations can be used to project forward in an effort to establish the most probable time of failure and this act to enhance the ability of the plant to plan and act in a proactive manner. PdM/CBM assumes that equipment has indicators that can be monitored and analyzed to determine the need for condition directed maintenance activities. Condition based maintenance allows the lowest cost and most effective maintenance programme by determining the correct activity at the correct time.

23. Condition based maintenance is accomplished by integrating all available data to predict impending failure of equipment as well as to avoid costly maintenance. This process depends to a large extent on the ability to recognize undesirable operating conditions as measured by diagnostic monitoring systems. The process also allows equipment to continue operating in an undesirable condition while it is being monitored until maintenance can be scheduled. The primary objectives of an optimized maintenance strategy programme that includes predictive and condition based maintenance are:-

(a) Improve availability
- (i) Reduced forced outages
- (ii) Improve reliability

(b) Enhance Equipment Life
- (i) Reduce wear from frequent rebuilding
- (ii) Minimize problems in disassembly and reassembly
- (iii) Detect problems as they occur

(c) Save Maintenance Costs
- (i) Reduced repair costs
- (ii) Reduced overtime
- (iii) Reduced parts inventory requirements

24. EA Technology, USA claims to have saved millions of dollars by adopting the CBM for their oil filled 11 KV switchgear. The CBM for switchgear maintenance allows operators to extend service intervals by many years, while actually improving reliability and safety. By contrast , conventional regimes, based on shutting down equipment regularly to inspect and maintain system,

can reduce reliability , increase health and safety risks, and cause unnecessary downtime and disruption. Optimising maintenance regimes on the basis of condition cut costs by more than 80 percent, from around 850 pounds per switchgear set to less than 110pounds accounting for 100million pounds savings for approximately 200000units in Britain.

25. **Reliability-centred maintenance**, often known as *RCM*, is a process to ensure that assets continue to do what their users require in their present operating context. Itis generally used to achieve improvements in fields such as the establishment of safe minimum levels of maintenance, changes to operating procedures and strategies and the establishment of capital maintenance regimes and plans. Successful implementation of RCM will lead to increase in cost effectiveness, machine uptime, and a greater understanding of the level of risk that the organization is presently managing. The late John Moubray, in his industry leading book, characterized Reliability Centered Maintenance as a process to establish the safe minimum levels of maintenance. This description echoed statements in the Nowlan and Heap report from United Airlines. It is defined by the technical standard SAE which sets out the minimum criteria that any process should meet before it can be called RCM.

26. Reliability centred maintenance is an engineering framework that enables the definition of a complete maintenance regime. It regards maintenance as the means to maintainthe functions a user may require of machinery in a defined operating context. As a discipline it enables machinery stakeholders to monitor, assess, predict and generally understand the working of their physical assets. This is embodied in the initial part of the RCM process which is to identify the operating context of the machinery, and write a Failure Mode Effects and Criticality Analysis (FMECA). The second part of the analysis is to apply the "RCM logic", which helps determine the appropriate maintenance tasks for the identified failure modes in the FMECA. Once the logic is complete for all elements in the FMECA, the resulting list of maintenance is "packaged", so that the periodicities of the tasks are rationalised to be called up in work packages; it is important not to destroy the applicability of maintenance in this phase. Lastly, RCM is kept live throughout the "in-service" life of machinery, where the effectiveness of the maintenance is kept under constant review and adjusted in light of the experience gained.

27. Reliability Centred Maintenance can be used to create a cost-effective maintenance strategy to address dominant causes of equipment failure. It is a systematic approach to defining a routine maintenance program composed of cost-effective tasks that preserve important functions. The important functions (of a piece of equipment) to preserve with routine maintenance are identified, their dominant failure modes and causes determined and the consequences

of failure ascertained. Levels of criticality are assigned to the consequences of failure. Some functions are not critical and are left to "run to failure" while other functions must be preserved at all cost. Maintenance tasks are selected that address the dominant failure causes. This processdirectly addresses maintenance preventable failures. Failures caused by unlikely events, non-predictable acts of nature, etc. will usually receive no action provided their risk (combination of severity and frequency) is trivial (or at least tolerable). When the risk of such failures is very high, RCM encourages (and sometimes mandates) the user to consider changing something which will reduce the risk to a tolerable level. The result is a maintenance program that focuses scarce economic resources on those items that would cause the most disruption if they were to fail. RCM emphasizes the use of Predictive maintenance (PdM) techniques in addition to traditional preventive measure. The transmission system is the back bone of the power.

28. **Total Productive Maintenance (TPM).** TPM is often defined as "productive maintenance involving total participation". Frequently, management misconstrues this to mean workers only and assumes that PM activities are to be carried out autonomously on the floor. To be effective, however, TPM must be implemented on a companywide basis. Unfortunately, some firms abandon TPM because they fail to support workers fully or involve management. A complete definition of TPM includes the following five elements: -

(a) TPM aims to maximize equipment effectiveness.

(b) TPM establishes a thorough system of PM for the equiment's entire life span.

(c) TPM can be implemented by various departments (engineering, operations, maintenance).

(d) TPM involves every single employee, from top management to workers on the floor.

(e) TPM is based on the promotion of PM through motivation management: autonomous small group activities.

29. The word "total" in "total productive maintenance" has three meanings that describe the principal features of TPM: Total effectiveness indicates TPM's pursuit of economic efficiency or profitability, total maintenance system includes maintenance prevention (MP) and maintainability improvement (MI) as well as preventive maintenance and total participation of all employees includes autonomous maintenance by operators through small group activities. In India, the maintenance department is generally responsible for carrying out PM. This reflects the concept of division of labour, an important feature of labour unions, Japanese-style PM, or TPM, on the other hand, relies on

everyone's participation, particularly autonomous maintenance by operators. If a company is already practicing productive maintenance, TPM can be adopted easily by adding autonomous maintenance by operators to the existing system. If a company has not yet implemented preventive or productive maintenance, however, a sudden shift from breakdown maintenance to TPM will be extremely difficult, although not impossible.

Optimal Maintenance Strategy

30. CBM and RCM approaches are being used world over as an assessment tool. The approach is to carry out analysis of major equipment groups taking into account function of equipment, failure mode, failure effects, failure consequences, and preventive tasks and default actions and then decide the maintenance strategy to be adopted. By adoption of appropriate maintenance strategy our energy sector can improve productivity of the plants and save millions of dollars to the exchequer. World over firms dealing in various sectors are adopting CBM, Predictive maintenance, RCM and now TPM to improve plant productivity, enhance safety of personnel and make substantial savings to the state. NASA's Marshal Space Flight Center through implementation of a Predictive Maintenance for its pressurised systems achieved substantial reduction in maintenance and operating costs of aging equipment within critical testing facilities while also increasing safety, reliability and efficiency. The project enabled NASA to save over 300000Dollars annually.

31. We need to have a look at various components of a power generation, transmission and distribution system to decide the type of maintenance strategy which would enable substantial saving in overallcosting. Electric Power Plants have a number of components in common and are an interesting study in the various forms and changes of energy necessary to produce electricity.

Generation

32. (a) **Boiler Unit.** Almost all of power plants operate by heating water in a boiler unit into super heated steam at very high pressures. The source of heat from combustion reactions may vary in fossil fuel plants from the source of fuels such as coal, oil, or natural gas. Biomass or waste plant parts may also be used as a source of fuel. In some areas solid waste incinerators are also used as a source of heat. In a nuclear power plant, the fission chain reaction of splitting nuclei provides the source of heat.

(b) **Turbine-Generator.** The super heated steam is usedto spin the blades of a turbine, which in turn is used in the generator to turn a coil of wires within circular arrangements of magnets. The rotating coil of wire in the magnets results in the generation of electricity.

(c) **Cooling Water.** After the steam travels through the turbine, it must be cooled and condensed back into liquid water to start the cycle over again. The water is returned to the body of water 10-20 degrees higher in temperature than the intake water. The water falling through the tower provides the cooling effect.

33. **Transmission**. These networks use components such as power lines, cables, circuit breakers, switches and transformers. The transmission network is usually administered on a regional basis by an entity such as aregional transmission organizationortransmission system operator. Transmission efficiency is hugely improved by devices that increase the voltage, and proportionately reduce the current in the conductors, thus keeping the power transmitted nearly equal to the power input. The reduced current flowing through the line reduces the losses in the conductors. According toJoule's Law, energy losses are directly proportional to the square of the current. Thus, reducing the current by a factor of 2 will lower the energy lost to conductor resistance by a factor of 4. This change in voltage is usually achieved in AC circuits using a*step-uptransformer*.A transmission grid is a network ofpower stations, transmission circuits, and substations.At thegenerating plantsthe energy is produced at a relatively low voltage between about 2.3 kV and 30 kV, depending on the size of the unit. The generator terminal voltage is then stepped up by the power stationtransformerto a highervoltage(115 kV to 765 kV AC, varying by country) for transmission over long distances.Transmitting electricity at high voltage reduces the fraction of energy lost toresistance, which averages around 7%.For a given amount of power, a higher voltage reduces the current and thus theresistive lossesin the conductor. For example, raising the voltage by a factor of 10 reduces the current by a corresponding factor of 10 and therefore the I^2R losses by a factor of 100, provided the same sized conductors are used in both cases. Even if the conductor size (cross-sectional area) is reduced 10-fold to match the lower current the*I2R*losses are still reduced 10-fold. Long distance transmission is typically done with overhead lines at voltages of 115 to 1,200 kV. At extremely high voltages, more than 2 MV between conductor and ground,corona dischargelosses are so large that they can offset the lower resistance loss in the line conductors. Measures to reduce corona losses include conductors having large diameter; often hollow to save weight, or bundles of two or more conductors. In an alternating current circuit, theinductanceandcapacitanceof the phase conductors can be significant. The currents that flow in these components of the circuitimpedanceconstitutereactive power, which transmits no energy to the load. Reactive current causes extra losses in the transmission circuit. The ratio of real power (transmitted to the load) to apparent power is thepower

factor. As reactive current increases, the reactive power increases and the power factor decreases.For systems with low power factors, losses are higher than for systems with high power factors. Utilities add capacitor banks and other components (such asphase-shifting transformers;static VAR compensators; physicaltransposition of the phase conductors; andflexible AC transmission systems, FACTS) throughout the system to control reactive power flow for reduction of losses and stabilization of system voltage.

34. **Distribution**. Adistribution substation transfers power from the transmission system to the distribution system of an area. It is uneconomical to directly connect electricity consumers to the main transmission network, unless they use large amounts of power, so the distribution station reduces voltage to a value suitable for local distribution. The input for a distribution substation is typically at least two transmission or sub transmission lines. Input voltage may be, for example, 115 kV, or whatever is common in the area. The output is a number of feeders. Distribution voltages are typically medium voltage, between 2.4 and 33 kV depending on the size of the area served and the practices of the local utility. The feeders run along streets overhead (or underground, in some cases) and power the distribution transformers at or near the customer premises. In addition to transforming voltage, distribution substations also isolate faults in either the transmission or distribution systems. Distribution substations are typically the points ofvoltage regulation, although on long distribution circuits (of several miles/kilometers), voltage regulation equipment may also be installed along the line. The downtown areas of large cities feature complicated distribution substations, with high-voltage switching and backup systems on the low-voltage side. More typical distribution substations have a switch, one transformer, and minimal facilities on the low-voltage side.

35. **Consumer End Equipment**. The consumer equipment receiving power from the distribution system plays a very important role in rationalization of the overall energy requirements. A well maintained machinery and equipment will consume much low power than the ill maintained equipment. For instance an air conditioning system with well maintained compressor motors, pumps, filters and cabling will have a predictable amount of power requirements. There is a plethora of machinery and equipment which if maintained utilizing predictive maintenance strategy would enable reduction in power consumption to a very large extent.

Part III: Recommendations

36. As brought out earlier, the maintenance strategy used by various companies/ agencies in energy sector in the country is very primitive ranging

from a reactive one to the preventive maintenance. Some of the leading corporations have realized the importance of utilizing predictive maintenance to optimize their production and save huge amount of resources and have benefitted immensely with the changeover. There is a huge scope for implementation of predictive maintenance in the power sector ,in India to reap benefits from the technology and processes. While the implementation of predictive maintenance is more of a mindset, the returns are tangible and substantial. The cost incurred can be recovered within few months of implementation and thereafter there remains a significant scope for savings. It is felt that it would make a strong economic sense to implement the Predictive Maintenance Programme (PMP) in all components of the power generation, transmission and distribution systems. Some of the tangible benefits that would invariably accrueto the system are summarized here.

37. **Power Generation**. With implementation of PMP, the Plant Loading Factor can be improved. As brought out earlier, in India, state-sector thermal power plants have PLF of 70.84 percent on an average compared with 89.4 percent for NTPC power plants in the central sector and 86.35 percent for private-sector power plants, clearly indicating the significant scope for improving performance of state-sector power plants. It is also seen that almost all power plants which exhibit high PLF also have better energy efficiency performance as well –typically less than 10% deviation from the design heat rate, compared to up to 50% deviation in some cases. Improving performance of state-sector power plants through predictive maintenance is essential to ensure optimum performance of the power plant both from the Availability as well as Efficiency aspects. As can be seen from the table 1 at appendix-A , a saving of 24,463 crores will accrue if plant loading factor improves by 2% by utilizing PMP in the generation machinery of the power sector. The energy thus saved would be around 6272 MW. With the implementation of PMP, the generating machinery can be maintained more efficiently ensuring enhanced availability and improved PLF. There is tremendous scope for improving plant productivity through effective maintenance management.

38. **Transmission and Distribution**. It is well known and documented that transmission and distribution losses constitute a large portion of the generated power, close to 20-22% and there is a huge scope for reduction of the same in order that the cost of power to the consumer is reasonable and competitive.A transmission grid is a network ofpower stations,transmission circuits, and substationsconsisting of switch-gear, power transformers and various types of breakers besides the transmission lines. The implementation of PMP for switch gear and various transformers can reduce the transmission losses and improve availability of energy to the end user. Similarly the distribution network

comprises of downstream switchgear and transformers and the PMP implementation on the distribution network can greatly enhance the reliability and availability of the system while reducing the losses. Since the major portionof T & D losses comprises of losses in distribution system (16-18%), it is very critical that PMP be implemented on distribution network.As brought out earlier, EA Technology claims to have saved millions of dollars by adopting the CBM for their oil filled 11KV switch-gear.

39. **Consumer End**. The consumer end machinery and equipment needs to be maintained well in order that consumption of power is minimal. If the machinery is not well maintained, it would consume more power. Misaligned pumps, faulty compressors, machinery without of limit vibrations is going to consume more energy and would be a drag on the scarce availability of resources. The poorly maintained machinery such as agricultural pump sets consume much more energy than they are designed for. When we consider the population of such pumps across the length and breadth of the country, there would be millions of such systems and they consume power far in excess to what they should or would if predictive maintenance is undertaken suitably. It is therefore paramount that PMP is implemented in all sectors of industry which constitute the major portion of the consumer base. This would ensure that availability of power is improved and the same can be supplied to the entire spectrum of consumer base with a competitive tariff. There will be huge saving to the state if the PMP is taken up for implementation in a time bound manner and with full understanding of the nuances.

40. In conclusion, it may be stated that there is substantial scope for the implementation of Predictive Maintenance including CBM in the energy sector of the country. The economic growth of the country requires an efficient and reliable power sector infrastructure so as to ensure the availability of power at a competitive rate. The assured availability of power with minimal interruptions at a low cost will enable other sectors of industry such as Steel, fertilizers, petrochemicals, agriculture etc to be efficient and competitive. World over implementation of Predictive maintenance in the power sector has accrued huge returns in the form of higher Plant loading factor, minimum T & D losses, efficient substation machinery resulting in assured availability of power at competitive prices. The various components of the power generation, transmission and distribution system in the country require urgent consideration for implementation of PMP in a phased manner with an overall objective of sustaining the economic growth of the country with a robust and efficient power sector.

Appendix-I

(A) Total Installed Capacity of Power Generation (2012) - Sector-wise

Sector	MW
State Sector	83,563.65
Central Sector	56,572.63
Private Sector	42,208.84
Total	**1,82,344.62**

(B) Total Installed Capacity of Power Generation (2012) - Category-wise

Fuel	MW	%age
Total Thermal	**118695.98**	**65.09**
Coal	99,753.38	54.70
Gas	17,742.85	9.73
Oil	1,199.75	0.65
Hydro(Renewable)	38,706.40	21.22
Nuclear	4,780.00	2.62
RES (MNRE)"	20,162.24	11.05
Total	**1,82,344.62**	**100**

MNRE –Ministry of New and Renewable Energy

RES - Renewable Energy Source.

Appendix-II

MONETARY SAVING THROUGH PMP POWER GENERATION SIDE (2011-12)

S.No		Installed Capacity (MW)	PLF	No.of Hrs of Plant run	Total Units of Energy (MWh)
1	Without PMP	182344	70	10000	1276.41
2	With PMP	182344	72	10200	1339.13

Total energy savings = 62.726 million Mwh (1339.13-1276.41)

Total monetary savings = 62.726m MWh * 3900@ Mwh

= approximately 24463.1crores

Equivalent Power generation (EPG) : 6272.6MW since energy saved is energy generated.

Note:

*	:	2%increase in PLF due to PMP
+	:	2%increase in plant uptime
MW	:	Mega Watt Power
MWh	:	Mega Watt Hour = 1000KWh
PLF	:	Plant Load Factor