Coal-fired power plant efficiency improvement in India

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Preface

The IEA Clean Coal Centre is an Energy Technology Initiative, which is endorsed by the International Energy Agency. It provides a means for international co-operation on clean coal related issues, and provides objective and independent information on the efficient and sustainable use of coal. This focuses on how to use coal more effectively, efficiently and cleanly, to minimise its environmental impact while providing cost effective energy. This includes the impact of coal related policies and regulations, clean coal technology developments and deployment, emissions control technologies and global coal markets. It is supported by members and sponsors from Australia, Austria, China, the European Commission, Germany, India, Italy, Japan, Poland, Russia, South Africa, Thailand, the UK and the USA.

This report has been produced by the IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

Abstract

This document formed an input to the one-day workshop in Chennai on 16 November 2015, organised by the IEA Clean Coal Centre (IEA CCC) and the United Nations Environment Programme (UNEP) Global Mercury Coal Partnership. The workshop aims were to identify and define the most effective technical approaches to adopt for controlling emissions of mercury and other pollutants from India's coal combustion sector. An important part of this is maximising the thermal efficiency of the fleet, as the specific fuel burn per kWh is reduced and so specific emissions of all pollutants decrease. This document summarised the main influences on efficiency and means available to increase it, with suggestions for future actions. It was used to provide a starting point for discussions at the workshop on how to promote continuing improvements.

Acronyms and abbreviations

APEC	Asia-Pacific Economic Cooperation
APP	Asia-Pacific Partnership
A-USC	advanced ultra-supercritical
BHEL	Bharat Heavy Electrical Ltd
CCC	Clean Coal Centre
CEA	Central Energy Authority
CenPEEP	Centre for Power Efficiency and Environmental Protection
ESP	electrostatic precipitator
FGD	flue gas desulphurisation
HP	high pressure
IP	intermediate pressure
kWh	kilowatt hour
LHV	lower heating value
LP	low pressure
MCR	maximum continuous rating
NASL	NTPC ALSTOM Power Services Private Limited
NTPC	National Thermal Power Corporation
O&M	operation and maintenance
PIE	Partnership in Excellence
PLF	Plant Load Factor (utilisation or capacity factor)
PPIP	Plant Performance Improvement Plan
SWBS	smart wall blowing system
USAID	United States Agency for International Development
USC	ultra-supercritical

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1 Introduction

This document in its original form provided an input to the one-day workshop in Chennai organised by the IEA Clean Coal Centre (IEA CCC) and the United Nations Environment Programme (UNEP) Global Mercury Coal Partnership. The workshop aims were to identify and define the most effective technical approaches to adopt for controlling emissions of mercury and other pollutants from India's coal combustion sector. An important part of this is maximising the thermal efficiency of the fleet, as the specific fuel burn per kWh is reduced and so specific emissions of all pollutants decrease. Efficiency improvement is the main focus of this document. This report has been updated to take account of information gathered from the meeting.

Figure 1 Suratgarh super thermal power station

2 The Indian coal-fired electricity system

India has a large fleet of coal-fired power plants. Since 2011, the capacity has increased from 100 GW, and there is now (2015) approaching 165 GW. Until 5 years ago, all were subcritical, but now a number of supercritical units (7.4 GW as of December 2012) (Patel, 2013) are also in operation. Steam parameters of units supplied by BHEL have reached 25.6 MPa/568°C/596°C (Sukumar, 2011), and Toshiba have recently announced that they will supply ultrasupercritical (USC) technology at Harduaganj in Aligarh district, Uttar Pradesh. As supercritical plants are now deploying in India, the electricity system efficiency should increase. However, progress with their installation is slower than initially expected. The drive to supercritical was therefore reinforced with a recent directive from the Ministry of Power to replace plants over 25 years old with supercritical units of 660 MW and above. However, there are press reports that these plans could already have faltered, and that efficiency improvement at the existing units would be best tackled by using better operating practices. While there are clearly mixed messages emerging, recognition by the Governmentof the importance of efficiency improvement at existing units is clear. Improvement of operating practices is the subject of Chapter 4 of this report.

Figure 2 NTPC's Sipat project in Chhattisgarh

Although renewable energy projects are also being installed, and there are ambitious plans for further expansion in these, increasing amounts of power generation from coal will be needed for the foreseeable future, from both supercritical and subcritical plants, because of the continuing growth in power demand. The national low carbon growth strategy involves renovation and modernisation of old units and retirement of small, old and less efficient non-reheat plants, as well as the introduction of the more advanced technologies.

2.1 Coal quality

Most indigenous Indian coals are bituminous, with a high ash content, much of which is inherent, and so difficult to remove below 30%. The ash is silicaceous and hard and so the coals require considerable energy for grinding before combustion. This partly accounts for the relatively high auxiliary power consumption of Indian power plants in comparison with many units abroad. The coal sulphur content is generally about 0.5% or lower, as received. However, the low calorific value means that the specific emissions of SO_2 are likely to approach those from international power station grade coals, for which FGD is normally required abroad on power plants. Coastal stations can take imported international grade coals and some of these have sea-water scrubbing FGD.

The distributed nature of the ash in Indian coals makes washing to below 30% ash difficult, but achieving ash contents similar to those of the original design fuels, at 30-34%, is possible. Blending with imported coals has emerged recently in India.

It is understood that there can be differences between analyses sent by the coal suppliers and those determined at the power station. Such differences point to an issue of establishing verification systems in addition to the problem of improving coal quality itself.

The US Department of Energy has for many years been promoting washeries development in India. For example, the Bilaspur Washery was built by a consortium of Indian and American companies. This has been operating for some years, but has not been without opposition on environmental grounds.

With a few exceptions, environmental control systems on coal units in India currently consist mostly of particulates removal only. At most of these, enhancements to existing particle collection systems would be needed to reach EU standards.

3 Thermal efficiency

The thermal efficiency of the Indian coal fleet is lower than the OECD countries' average. Figure 3 shows a graph from a recent update of an ECOFYS report (Hussy and others, 2014) that shows the system-wide efficiency to be 26–28% LHV, gross power basis, calculated for 2009-2011. Note that any gain in the last few years as supercritical units have come on line will not appear in that graph.

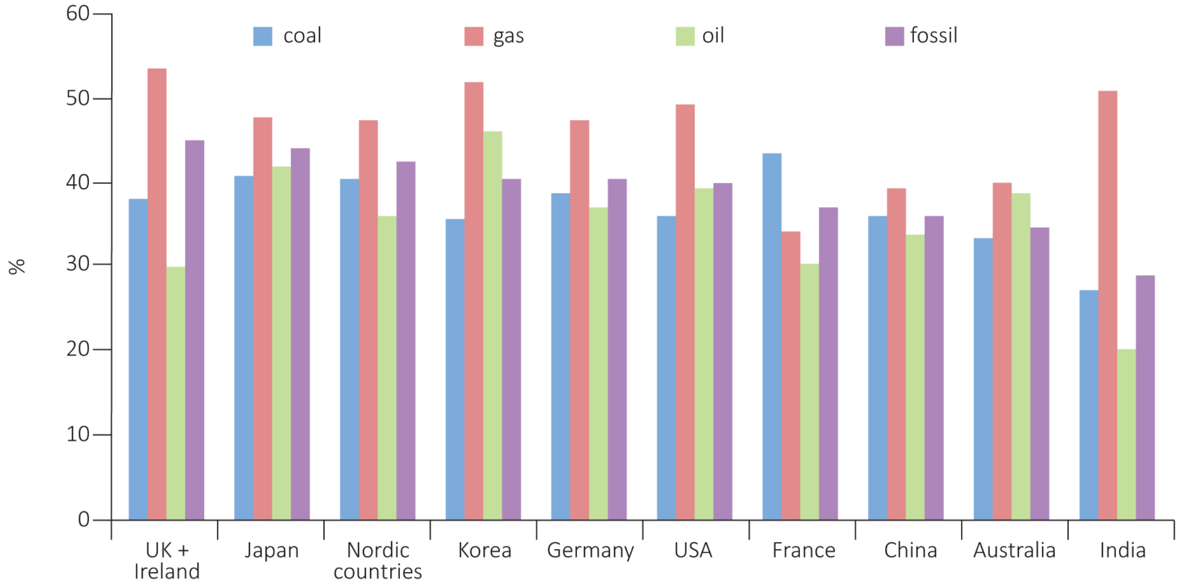

Figure 3 Energy efficiency per fuel source (average 2009-2011) (Hussy and others, 2014)

The efficiencies in the figure are calculated from IEA gross generation and fuel net calorific value data. The difficulties that are faced here in India are partly inevitable. The indigenous coals and high ambient temperatures have detrimental effects on efficiency, even for plants that are well maintained. Even the efficiency of a new supercritical plant, with steam conditions of 26 MPa/568°/596°C at the boiler, is therefore limited here to around 39-40%, net, LHV basis. At some coastal locations, imported coals, if used, should allow better performance.

While progression to state-of-the-art USC conditions, ie to 600-620°C steam, is just beginning in India, there is a national A-USC (advanced ultrasupercritical) development programme in India aimed at moving to 700°C and higher steam parameters, and a demonstration plant is planned in about five years. Participants in the project are BHEL, the Indira Gandhi Centre for Atomic Research (IGCAR), and NTPC.

The supercritical programmes should gradually raise the efficiency of the coal fleet, but the improvement of existing subcritical plants remains important, and the main focus of this report is efficiency improvement in these. The smallest old units have no steam reheat, and even the 100-200 MW older reheat systems have rather modest steam parameters (around 14 MPa/540°/540°C). This limits attainable efficiencies. However, many plants appear to be running at efficiencies significantly below that for which they were designed, partly because of age-related deterioration, insufficient maintenance and changes in fuel quality.

The original unit designs did take into account around 30% mineral matter in the fuels, but many have had to take higher ash content coals as the quality has decreased. Use of coals of greater than 34% ash was partially restricted by legislation about 15 years ago, but poorer coals are still being fired and will continue to be fired in many locations. The originally generous boiler design sizes can be inadequate for firing some of these indigenous coals, with resulting reduced output, efficiency and availability at many sites. While tower boiler designs can more readily reduce erosion, two-pass designs tend to be ordered in India as they are less expensive.

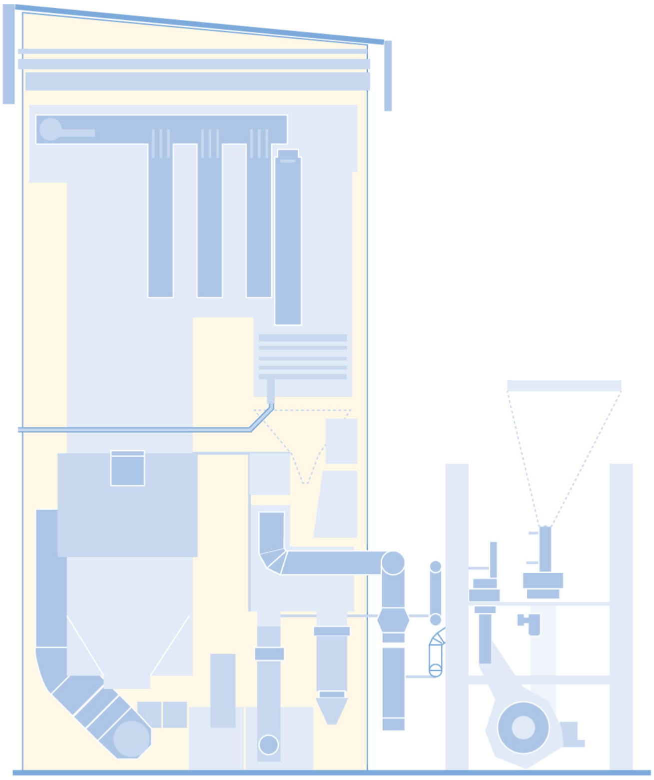

Figure 4 **Two-pass boiler 5 at Suratgarh (BHEL)**

A 2.5–5 percentage points decrease from design for operating subcritical units appears to be common in India, even for high utilisation plants, based on a survey by the author for the IEA for a study in 2006-7 (IEA, 2007) and recent literature reports. A few 50-year-old 60 MWe plants are running in the low 20s% LHV net efficiency because of the combination of the factors discussed earlier. More typical would be around 30% LHV net for 20-year old units.

Programmes have been implemented in India to improve the situation. There are limits to how rapidly older plants can be closed because of severe local demands on power, but they can and are being improved, and some examples are given later. According to the CEA, 18.965 GW were being renovated under the 11th Five-Year economic plan (to 2012) and 4.971 GW are being renovated under the 12th plan (to 2017) (Mathur, 2011). This is a total of 23.936 GW by 2017. By 2015, 2.741 GW had been renovated under the 12th plan (CEA, 2015).

The R&M programme is primarily aimed at overcoming problems due to:

- design deficiencies;
- non-availability of spares;
- poor quality of coal.

Areas regarded as the most important to focus attention on at the subcritical plants in India are (Srivastava, 2010):

- combustible losses in furnace and ash;
- excess air control;
- feed water temperature;
- leakages of steam/water;
- boiler insulation;
- condenser vacuum;
- steam parameters;
- reheat attemperation.

Table 1 below shows the benefits expected from improving a typical 210 MW unit (Srivastava, 2010).

Table 1 Expected benefits in improving a typical 210 MW unit in India (Srivastava, 2010)

Description	Pre R&M	After R&M (target)	% improvement
Turbine heat rate, kcal/kWh	2240	2000	12
Boiler efficiency, %	82-84	85	
Unit heat rate, kcal/kWh	2700	2300-2500	7-14
CO_2 emissions, g/kWh	992	848-918	7-14

Retrofits offer opportunities to incorporate technology advances made since a unit was built. Such projects are common in many countries. Despite involving substantial outlay (typically US$100-200 million in OECD countries, but less costly here), retrofits will provide a positive return through restored (or enhanced) generation and fuel savings.

Table 2, from an APEC study indicates that a typical overall efficiency improvement of 3.5% points could conservatively be expected from major retrofits of plants in the APEC Region.

Table 2 Potential efficiencies from plant improvements in APEC countries (Boncimino and others, 2005)

Category	Area of improvement	Net efficiency gain (% points)
Combustion system	Pulveriser and feeder upgrades	0.3
	Air heater repair or upgrade	0.25
	Sootblower improvements	0.35
	Excess air I&C	0.2
Steam cycle	Feedwater heater repairs	0.4
	Heat transfer tube upgrades	0.6
	Steam turbine blades	0.5
	Cycle isolation	0.5
	Condenser repairs	0.4
O&M	O&M training	
	Computerised maintenance and management systems and reliability centred maintenance	Included in combustion and steam cycle gains. Efficient operation realised over the long term.
	Distributed control systems	
Combined total		3.5

Summarising, there have been programmes and projects, taking advantage of the best of knowledge from both within the country and abroad (some are described later), yet there is still the situation that the outturn efficiency of the system appears low even allowing for local physical factors.

3.1 Market factors affecting efficiency and pollution control

An important aspect to be addressed that was raised at the workshop was that the new supercritical plants are not performing to their maximum potential because they are operating at lower than base load. This is because considerable capital costs were incurred in their construction, but there is not an effective financial reward mechanism to enable them to hold their own in the merit order of operation on the grid system. Operating at reduced load then reduces thermal efficiency, and so they are further penalised with higher operating costs and higher emissions than projected.

For any plants, power purchase agreements were also said to present problems in maintaining adequate revenues. The power price may be agreed in advance of fixing coal supply prices without appropriate linkage, causing reduced profits or even losses as in Gujarat. NTPC have long-term fuel supply agreements to obtain the lowest prices. The coals are procured from local sources, and the purchase price can be controlled by the Government.

These assertions may appear somewhat contradictory, but the main message here is that market factors are the main mechanism responsible for low efficiencies in plants and for lack of resources to upgrade where needed.

It was noted that money was being invested in a major Clean Power Initiative covering solar power, but there was need for a similar initiative to encourage clean coal.

There was no obvious financial mechanism for increasing efficiencies or improving environmental performance at power plants. Tax incentives were suggested as needed for cleaner power to be achieved through adding modern pollution control systems.

The view was put forward that anecdotal estimates of electricity theft, at 35-40% of generation were higher than really the case, with it perhaps masked by higher transmission losses than acknowledged by the public distribution companies. However, differences between power generated and power sold nonetheless need addressing. The issue of losses was said to be less serious for Government owned plants, although it will depend presumably on the relevant transmission grid conveying the power.

3.2 Pollution regulations

Regarding the current regulations, a clear view was that enforcement was a major problem. State Governments have limited money to invest in follow-through of requirements. For example, wet ash disposal was supposed to be banned from some years ago, but this had not been achieved because of problems at the local level not being fully appreciated.

There was no clear timeline for environmental regulations. However, availability of financial resources to achieve them was a barrier anyway.

4 Operational influences on efficiency

The situation outlined in the previous section begs the question: Why is average efficiency still relatively low in India? So maybe, as well as talking about technical solutions, we should also be trying to identify any unrecognised non-technical factors that could be holding back progress, despite all the past initiatives to improve the situation.

Technical staff in India are second to none, but sometimes a perception change may be beneficial. For example, recognising that insistence on accepting only coals of quality within design range is important, even for the generally low-cost, poor quality indigenous coals, or that repairing a high pressure feedwater heater, while costing money in the short term, will increase efficiency and reduce fuel costs.

Maintenance of correct steam conditions, terminal temperature differences of feedwater heaters, etc. is vital for maximising operational efficiency. Excessive use of spray attemperation (to counter the effect of high ash coals causing too little heat absorption through radiation to the furnace waterwalls) will reduce efficiency. An attemperation rate of 10% of main flow leads to a 2% increase in turbine heat rate for main superheater and 18% for the reheater. While burner tilting can provide a more satisfactory solution, is attemperation perhaps too readily regarded as the easier option?

Goswami and others (2009) have recommended continuous monitoring in the following areas:

- temperature, pressure and flow of air-fuel mixtures at all burners to ensure homogeneous mixing and balanced firing;
- flue gas temperature, flow and oxygen and CO contents;
- steam parameters and flow;
- vibration monitoring of critical rotating equipment including pulverising mills, turbines, fans, pumps.

Is this occurring, a year after improvement works may have been carried out?

Periodic monitoring is likewise needed in the following areas to identify developing areas of potential future failure as well as declining efficiency Goswami and others (2009):

- boiler tube thickness;
- vibration of less critical rotating machinery;
- detailed vibration analysis of turbine for detection of misalignment, lack of balance, etc;
- temperature measurements on valve bodies;
- identifcation of valve leakage by acoustic and other means;
- boiler feedwater quality;
- condenser vacuum;
- data records for trend analysis.

Boiler tube failure databases in OECD countries provide early recognition of emerging problems, enabling a proactive approach to be taken to maintenance strategies. Expertise in India exists for condition assessment of boiler components. Maybe it needs to be used more. BHEL (Bharat Heavy Electrical Ltd) have described a remnant life assessment based plant performance improvement programme (PPIP), developed for application to the older Indian thermal units under 200 MWe. Repeated tube failures can indicate lack of observance of correct O&M practices, wrong preventive actions, or absence of suitable failure reporting and monitoring systems.

One of the factors limiting efficiencies at the older plants in India is the low utilisation (referred to as Plant Load Factor – PLF – in India) of these plants. It is well known that part load and on/off operation reduce efficiencies (and increase maintenance requirements). While this can be caused by inadequate grid connections, poor siting of a new plant, failure of coal supplies and so on, in older units, it tends to be due to a circle of low revenues leading to lack of maintenance. Inadequate revenue and so lack of sufficient funds for maintenance remains a problem in India and it will continue to limit advances in efficiency until it is corrected.

5 Upgrading by major works

One of the most common types of upgrade projects around the world involves turbine modernisation. Turbine-related improvement technologies offered by manufacturers are:

- **Advanced sealing (shaft and blading)** – changing to a retractable shaft seal can avoid damage caused by thermal expansion and vibration; leakage around moving or fixed blades in modern reaction designs is minimised through use of shrouding or covers brush sealing;
- **Major upgrading**, involving fitting new blades with advanced profiles, replacement inner casings, replacement steam valves; over the last 10 years or so, designs of HP and IP turbine systems have improved greatly; manufacturers will replace selected blade rows, adding around 10% output at a cost of typically $50-100 million in OECD countries; heat rate improvements of 2-4% can be achieved in LP turbines by retrofitting improved fixed and rotating blades, better sealing, and longer last stage blades; 1-1.5% point improvement in overall plant efficiency can be expected from such measures;
- **Condenser optimisations** – reconfiguring, tube replacement; elimination of air in-leakage.

turbine blades with shrouding

segmented labyrinth seal (Siemens)

improved tip seal (Doosan)

Figure 5 Some turbine retrofit measures

These are popular, not only for environmental reasons, but also because they can have a positive economic payback. Advanced design features can be incorporated. HP and IP systems are being upgraded commonly because 3D-blading is bringing major efficiency improvements to them.

Of course, in India, the combustion and steam generation area is equally worthy of consideration, and significant gains in efficiency and output can be obtained from these.

The technical measures related to the boiler area of the plant that may be applied include:

- Modern burner designs;
- Upgrading of fuel milling (quality and flow capacity);
- Improved coal and air flow management, more advanced monitoring, reduction of air in-leakage;

- Upgrading of fans;
- Redesign of heat transfer surfaces, additional area, better materials; air heater improvements; smart sootblowing.

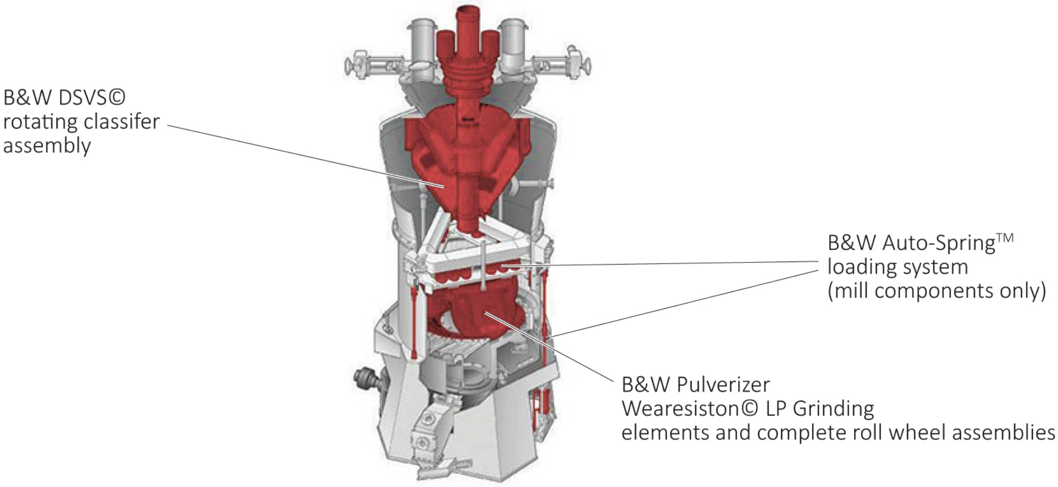

Figure 6 Pulveriser upgrade by B&W at Suralaya, Indonesia – see Section 7.4

Example projects are given later.

6 Efficiency improvement project examples in India and elsewhere

6.1 Torrent Power Sabarmati D station, India - up-rating from 110 MW to 120 MW

NASL, which is a joint venture of NTPC (National Thermal Power Corporation) Ltd, India, and Alstom Power Systems GmbH has carried out a number of projects in India, including 30 boiler RLAs (residual life assessments) and 30 turbine RLAs. This project was completed by the company a few years ago (NASL, 2013).

Sabamarti has four units. Unit D is the oldest one, opened in 1978. The scope of the retrofit works, carried out in 2003, included:

- turbine retrofit comprising new HP/IP/LP rotors;
- redesign of the reheater;
- installation of new control system;
- burner management system.

The results of the work have been as follows:

- machine successfully operated at 120 MW, with better than guaranteed heat rate and output;
- machine has operated over several years at rated capacity;
- unit has recorded continuous operation of 185 days;
- average PLF ~ 95% after retrofit.

6.2 Renovation and modernisation of 2x110 MW Units and upgrading of units 3 and 4 at Guru Nanak Dev TP, PSEB Bathinda, India

The objective of this project, also executed by NASL, was to restore the 110 MW rated output of the units 1 and 2 and upgrade units 3 and 4 to 120 MW. The station, owned by Punjab State Power Corporation Ltd (PSPCL), which takes its coal from Jharkhand, 1500 km away, was commissioned during the 1970s.

Figure 7 GNDTP, Bathinda, India (Punjab State Power Corporation Ltd)

The R&M works on the first two units were completed in 2006 and 2007. The R&M is providing improved availability, reliability and emissions, through boiler improvements, turbine retrofits and other works:

- addition of a third pass to the air heater;
- upgrading of the mills;
- installation of additional passes to the ESP;
- new HP rotor with modern reaction blading;
- LP turbine retrofitted with new profile blades and diaphragms;
- new valves;
- replacement HP feedwater heaters;
- new control system.

After the works on unit 1, the PLF reached over 98% during some months in 2006 and the first two units are now running at near full capacity. The upgrading of unit 3 was completed in 2012 and of unit 4 in 2014. Costs for the R&M have been published, at Rs. 229 Crore (US$42 million) for units 1 and 2 and Rs. 465 Crore (US$85 million) for units 3 and 4 (PSPCL, 2014).

6.3 Raichur Thermal Power Station, India - smart wall blowing system for improving heat rate

BHEL has developed a smart wall blowing system (SWBS) that is installed at Raichur TPS, Karnataka. Raichur is an 8 x 210–250 MW station, commissioned between 1985 and 2009 (Henderson, 2003; APP, no date). Sootblowing control by the SWBS is based on monitoring of superheater spray flow and furnace heat absorption in different zones. The system helps to maintain the furnace heat absorption at optimum level thereby maintaining the super heater and reheater sprays within limits. The system is described in the best practice manual, produced in India under the USAID (United States Agency for International Development) and APP (Asia

Pacific Partnership on Clean Development and Climate) programmes. The SWBS results in a steady SH/RH steam temperature, giving improved boiler efficiency in addition to reduced superheated steam consumption due to fewer blowings with an accompanying reduction in tube erosion.

6.4 PT. Indonesia: Suralaya power plant

PT. Indonesia's bituminous coal-fired Suralaya power plant consists of 8 subcritical units, opened between 1983 and 2011. The boilers of the first two 400 MW units, opened in 1983 and 1984, were upgraded by Babcock and Wilcox Power Generation Group (B&W PG) to restore their efficiency, increase maximum steam flow and extend their life, while reducing NOx emissions and ensuring operation with coals of variable characteristics (Borsani, 2012). The rehabilitation involved the redesign of the convection pass sections and of the combustion systems for NOx emissions reduction, upgrades to the pulverisers, and refurbishment of the air heaters.

The benefit from the airheater work was particularly noteworthy. The reduced leakage and lower exit gas temperature provided fan power savings of 1000 kW at MCR for both units and a 0.7% point improvement in boiler efficiency, giving a 0.8% reduction in fuel consumption.

6.5 Karlsruhe Unit 7, Germany

This is an example from a western OECD country. Karlsruhe Unit 7 is a 535 MWe/220 MWth bituminous coal-fired subcritical plant owned by EnBW and opened in 1985. It was the subject of a retrofit in 2010 of the LP turbine by Alstom with modern blading. The LP turbine had deteriorated considerably before the project was implemented, and electrical output was increased by the works by over 27 MW. The efficiency increase was 1% point. There were also modifications to the mills, burners and boiler air supply to reduce excess air from 25% to 20%, reducing fan power, while reducing primary NOx (Stamatelopoulos and others, 2011).

7 Programmes to drive efficiency improvements

Programmes to drive efficiency improvements of coal fleets include the USAID CenPEEP programme and the Partnership in Excellence (PIE) Programme.

7.1 USAID CenPEEP programme

The United States Agency for International Development (USAID) assisted NTPC in establishing the Centre for Power Efficiency and Environmental Protection (CenPEEP) in 1994. Under the programme, experts from the US Department of Energy and US utilities have worked with NTPC to improve efficiency.

7.2 Partnership in Excellence (PIE) Programme

The Partnership in Excellence (PIE) Programme was introduced to tackle both the technical and non-technical factors responsible for very low PLF of some plants. The PLF was improved significantly at many of 26 selected plants.

7.3 Asia-Pacific Partnership on Clean Development and Climate

The Asia-Pacific Partnership on Clean Development and Climate (APP) concluded in 2011, but a number of individual projects continue under the aegis of other co-operation organisations. Among the activities of the APP was co-operation with USAID in production of a best practice manual for India by its Task Force on Power Generation and Transmission (APP, no date).

8 Future actions

There appears to be a problem bringing plants nearer to international performance, even after allowing for the local coals and temperatures: in other words, there have been programmes and projects, taking advantage of the best of knowledge from both within the country and abroad, yet the outturn efficiency of the system is low. Further renovations and new plants are clearly needed. However, delegates at the workshop were asked also to discuss why, while many units have been the subject of renovation work, many still under-perform. Some pointers are provided below.

- More units need to be increased in efficiency but, importantly, keeping them operating at higher efficiencies requires consistent coal quality and proper monitoring and maintenance to be ensured. This needs additional income from electricity sales and close accountability. Ways to achieve these need to be considered.
- Ensuring that sufficient financial returns are achievable when environmental control systems are added to the coal-fired units is urgently needed if utilities are to implement these essential improvements.

In connection with both the above points, market-related factors were identified as an important factor at the meeting (see Section 3.1).

Renewed efforts to apply the latest *technical* means available must be made, including:

- HP, IP and LP turbine retrofits, using modern 3-D blading, new valves;
- installation of new control systems (need changing every 10 years);
- new burner management systems;
- air heater improvements (sealing, additional sectors);
- upgrading of mills to reach rated/ increase capacity;
- ESP improvements to reduce energy use and improve collection efficiency;
- HP feedwater heater improvements;
- condenser improvements;
- larger units (>200 MW) with 15 years remnant life need to be retrofitted with NOx and SO_2 control compatible with mercury capture co-benefit.

Additionally:

- New supercritical and USC units need to be required to meet NOx, SO_2 and dust emission levels matching best international standards, with co-benefit mercury control.
- While policies exist to encourage further system efficiency improvements, more needs to be done to make them more successful. Government policies to ensure that all future units constructed are at least supercritical have been suggested from time-to-time in the past, with mixed effect, and it has been recently stated by the Minister of Power that new coal fired

units in the 13th plan period (2017 onwards) will only be based on supercritical technology (CSE, 2015).

- Thus, progress with installation of supercritical units to date has been slower than planned. More success with this would ensure that the generating system efficiency would continue to climb.
- Installation of FGD, greater NOx control (probably by SCR) and particulates control by more efficient ESPs or bag filters is needed on existing and new units. It is understood that India is proposing a new set of emission standards that are, for new plants, broadly similar to those set in the EU and China. Meeting the Minamata requirements on mercury control gives additional urgency, but also an extra incentive to move on with the other gas cleaning technologies to exploit their co-benefits.

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