

IMPROVING COAL UTILITY POWER PLANT FLEXIBILITY AND PERFORMANCE IN INDIA

HIGH-LEVEL FLEXIBILITY ASSESSMENT TOOLKIT GUIDANCE AND TRAINING DELIVERY PLAN

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DR LESLEY SLOSS – INTERNATIONAL CENTRE FOR SUSTAINABLE CARBON (ICSC)
STEPHEN STORM – ELECTRIC POWER RESEARCH INSTITUTE (EPRI)



U.S. DEPARTMENT OF
ENERGY



GOVERNMENT OF INDIA
MINISTRY OF POWER



INTERNATIONAL CENTRE FOR
SUSTAINABLE CARBON

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INTERNATIONAL CENTRE FOR SUSTAINABLE CARBON
27 OLD GLOUCESTER STREET
LONDON
WC1N 3AX
UNITED KINGDOM

+44[0]20 3905 3870

WWW.SUSTAINABLE-CARBON.ORG

PREFACE

The International Centre for Sustainable Carbon (ICSC) was established in 1975 and has contracting parties and sponsors from Australia, China, the European Commission, Italy, Japan, Russia, South Africa, and the USA.

The overall objective of the ICSC is to provide our members, the IEA and other interested parties with definitive and policy-relevant independent information on how various carbon-based energy sources can continue to be part of a sustainable energy mix worldwide. The energy sources include coal, biomass and organic waste materials. Our work is aligned with the UN Sustainable Development Goals, which include the need to address the climate targets as set out by the United Nations Framework Convention on Climate Change.

The ICSC is organised under the auspices of the International Energy Agency (IEA) but is functionally and legally autonomous. Views, findings, and publications of the ICSC do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

ACKNOWLEDGEMENTS

This report is part of a programme of work being carried out by the ICSC on behalf of the US Department of State (USDOS). It relates to a pillar of work intended to provide capacity building to improve the performance of coal-fired power plants in India under flexible operation, to increase grid stability, and to limit any potential increase in pollutant emissions from plants running at below design efficiency.

This work builds on a separate project completed by Electric Power Research Institute (EPRI) on behalf of the US Department of Energy (USDOE) under the Power and Energy Efficiency Pillar of the US-India Strategic Energy Partnership between the USDOE's Office of Fossil Energy and India's Ministry of Power.



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ABSTRACT

The ‘High-Level Flexibility Assessment and Benchmarking Tool’ developed by EPRI is an interactive guide to maximising coal utility power plant performance during flexible operation. Application of the toolkit will ensure that Indian utility managers can ramp the operation of their coal-fired units up and down effectively and efficiently with minimal plant damage. This flexing will help the Indian electricity grid to meet growing power demand as less reliable and dispatchable power sources, such as wind and solar, increase their capacity.

The plan for delivering training and capacity building in India, based around the toolkit, is summarised explaining how it will empower stakeholders in India with the skillset to optimise plant performance.

ACRONYMS AND ABBREVIATIONS

CenPEEP	Centre for Power Efficiency and Environmental Protection, NTPC, India
DOE	Department of Energy, USA
DOS	Department of State, USA
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
FGD	flue gas desulphurisation
ICSC	International Centre for Sustainable Carbon (formerly IEA Clean Coal Centre, IEACCC)
IEACCC	IEA Clean Coal Centre
MIT	Massachusetts Institute of Technology, USA
MS	Microsoft
NTPC	National Thermal Power Company, India
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
SCR	selective catalytic reduction
SEP	Strategic Energy Partnership, India
VGB	Technical Association of Power Plant Operators, Germany
VRE	variable renewable energy

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1 INTRODUCTION

Most existing coal-fired power plants (subcritical and supercritical) were designed to run most efficiently and cost-effectively when operating at steady baseload. Variable renewable energy (VRE) systems, such as wind and solar, are sporadic in their energy output, following often unpredictable weather conditions. The energy from renewable sources is prioritised for input into the grid in many countries, meaning that dispatchable power plants, such as those powered by coal or nuclear sources, must now provide more flexible output to keep the available energy in the network at the required level.

Flexible operation of a coal plant to balance the grid has impacts on plant efficiency, component lifetimes and pollutant emissions. Repeated cycling or ramping of a coal power plant increases wear and tear of the components. This must be assessed and monitored, especially in older units, to mitigate potential costly damage to the plant and to promote safe, efficient, and problem-free operation. Thus, increased plant cycling can incur cost penalties for maintenance and repair as well as increased risk of outages and elevated emissions of pollutants. It is therefore vital that the Indian coal fleet prepares to minimise the potential issues which may arise as it is called upon to provide more flexible power. This will require the integration and alignment of people, processes, and technologies to manage major assets, materials, and environmental systems. This challenge will be significantly reduced by the application of methodology to improve the operational flexibility of the existing coal fleet.

Figure 1 shows the potential roadmap towards increased flexibility of the existing coal utility capacity in India.



Figure 1 The road to flexibility (EPRI, 2020)

First (Step 1, Figure 1), the sector must define its aims. For example, if the mission is to increase the use of VRE, then sufficient baseload and dispatchable sources, as well as energy storage options, need to be identified to ensure that capacity demands are met at all times. Next (Step 2), the baseload fleet of coal plants should be assessed to determine their ability to meet the increased demand for flexibility. Since many of the changes required to maintain capacity will be challenging with respect to cost and deliverability, the sector needs to determine which adjustments are most critical and should be prioritised (Step 3). The sector then has to leverage resources and deal with potential roadblocks (such as affordability, materials availability, and expertise) to ensure that the fleet performance can be optimised (Step 4). By following this roadmap, the ultimate result should be a coal fleet which is coordinated and optimised to provide power in a flexible manner, as and when needed.

As a means to accelerate the journey along this road, the US Department of State (USDOS) has provided a grant to the **International Centre for Sustainable Carbon** (ICSC) formerly IEA Clean Coal Centre (IEACCC) for a programme of work that aims to reduce emissions from the coal utility sector in India. As part of this work, the ICSC will deliver workshops in India to provide skills in improving flexible plant operation. Under a separate project, the US Department of Energy (USDOE) and the Electric Power Research Institute (EPRI) have developed a ‘High-Level Flexibility Assessment and Benchmarking Tool’ – an interactive methodology that uses plant-specific information and data to evaluate current and future actions needed to improve operation and maintenance, performance and efficiency of coal power plants. The toolkit has been developed with the support of NTPC (India’s largest power company, formerly known as National Thermal Power Company Ltd) and CenPEEP (the NTPC Centre for Power Efficiency and Environmental Protection). Practical experience with the toolkit was trialled at nine subcritical and four supercritical NTPC coal-fired power plants in India prior to publication to ensure that it met the needs of the Indian fleet.

The flexibility toolkit which comprises a series of interactive templates, is freely available as a download from the EPRI website (*see* Section 3.1). However, since implementation of the toolkit requires a relatively detailed approach to data collation and interpretation, users will benefit significantly from hands-on training. To this end, this project includes delivery of a series of workshops to provide free training with the toolkit to Indian stakeholders (utilities, regulators, energy and environmental ministries). The training will help power plant staff to streamline the initial assessment, conduct annual benchmarking, and initiate continuous improvement of industry standards. These strategies are currently not well defined within India. The training will empower stakeholders to identify and address areas of plant vulnerability that require prioritised attention. Although the toolkit cannot provide detailed advice on how to correct all engineering and plant performance issues, the training will include examples of best practices and relevant case studies.

Chapter 2 provides stakeholders with an overview of the importance of flexibility in coal-fired power plants and how plant performance can be optimised to improve efficiency while reducing both costs

and emissions. Chapter 3 outlines the toolkit and summarises the contents of the proposed training programme, and Chapter 4 outlines the plan for delivery of the training workshops directly to Indian stakeholders.

2 THE CHALLENGE OF FLEXIBILITY

In order to understand why coal plant flexing is a critical issue, it is important to appreciate how the use of the existing coal fleet is changing in many countries. Subcritical and supercritical coal-fired power plants perform best when they run at a steady rate over extended periods of time, closing only for planned maintenance and repair. Many countries now prioritise the use of VRE such as wind and solar over fossil fuel power. VRE systems are not baseload and they are non-dispatchable - this means that they cannot increase or decrease supply to meet changes in demand. As a result, many energy grids require baseload utilities, such as coal plants, to change their operation quickly and at short notice to offset the variability of VRE input and thus balance the overall grid requirement for power.

Coal power plants are called upon to flex to meet demand, not because it is convenient or cost-effective or even appropriate. Rather it is borne of necessity. When it comes to the energy trilemma – balancing the priorities of the cost of power, the environmental consequences of producing that power, and the security of delivery of that power to consumers – energy security always comes first (Sloss, 2020). Economies rely on power and governments will always rank the security of energy supply as critical.

MANY INDIAN COAL PLANTS ARE NOW REQUIRED TO
RAMP THEIR OPERATION UP AND DOWN FAR MORE
FREQUENTLY THAN WAS INTENDED WITHIN THEIR
DESIGN SPECIFICATIONS

The following sections explain the importance of coal plant flexibility and the problems which can arise as the demand for flexibility increases. The majority of this section is based on work completed by EPRI in the USA, who have expertise on the topic, in collaboration with NTPC in India. Many of the coal-fired boilers in India are based on US systems and EPRI also has experience in India and therefore the expertise can be shared readily. This Chapter therefore comprises the relevant EPRI work and also includes experience from other regions which could be of significant benefit to stakeholders in India.

2.1 BALANCING GRID DEMANDS

There are ways to reduce the grid requirement for rapid and unpredictable flexing. Most grid operators try to balance the input and output from the system as much as possible with the most cost-effective methods available. There are four main flexibility options within most grid systems:

- Connection to other networks – for example, between states in the USA or between countries within the EU. As India is a large country, networking is possible between states

which can help to balance capacity demands to some extent. However, India has significant and ongoing grid challenges which will need to be resolved.

- Electricity storage – pumped hydro is available in some regions. India has around 100 hydropower plants providing around 50 GW of hydropower, the fifth largest capacity globally. However, electricity storage is not widely available at scale anywhere. If, and when, new means of large-scale energy storage are commercially viable and widely deployed, the energy from VRE sources will become more dispatchable. However, improved energy storage is unlikely within a timeframe which will reduce pressure on the existing Indian coal fleet.
- Changing patterns of demand – reduction in the demand for power to prioritise the available power to where it is needed most. This is commonly achieved through load shedding agreements whereby large electricity users, commonly industry, are paid to reduce their demand when the supply is low but may also be provided cheaper power at times of high or oversupply. This can be an expensive option. Although load shedding is possible in India, it is not desirable since many industries are already affected by regional power shortages.
- Flexible fuel-burning generation in the form of reliable, dispatchable power coal, oil, and gas-fired plants as well as other flexible sources, such as nuclear and hydro, where available.

The last option, increased flexibility in the existing coal fleet, is becoming critical to ensure that capacity demands are met as other dispatchable sources are limited in India.

When electricity demand increases suddenly, or when power production from VRE sources suddenly curtails, the grid calls upon available sources of power, regardless of the cost or environmental consequences. Germany in 2013 is a good example of how significant changes in power capacity from different sources can create challenges for the grid. The German government has set some of the tightest environmental standards in the world and has invested heavily in VRE and clean energy sources. In 2013, Germany prioritised power from VRE sources into the grid, when available. The remaining demand was met by a combination of baseload sources, such as coal, gas and nuclear. At the same time, however, the country was closing its coal and nuclear power plants, thus reducing the pool of back-up capacity. Figure 2 shows the mismatch between the available capacity of power in Germany in 2013 and the actual energy production from this capacity.

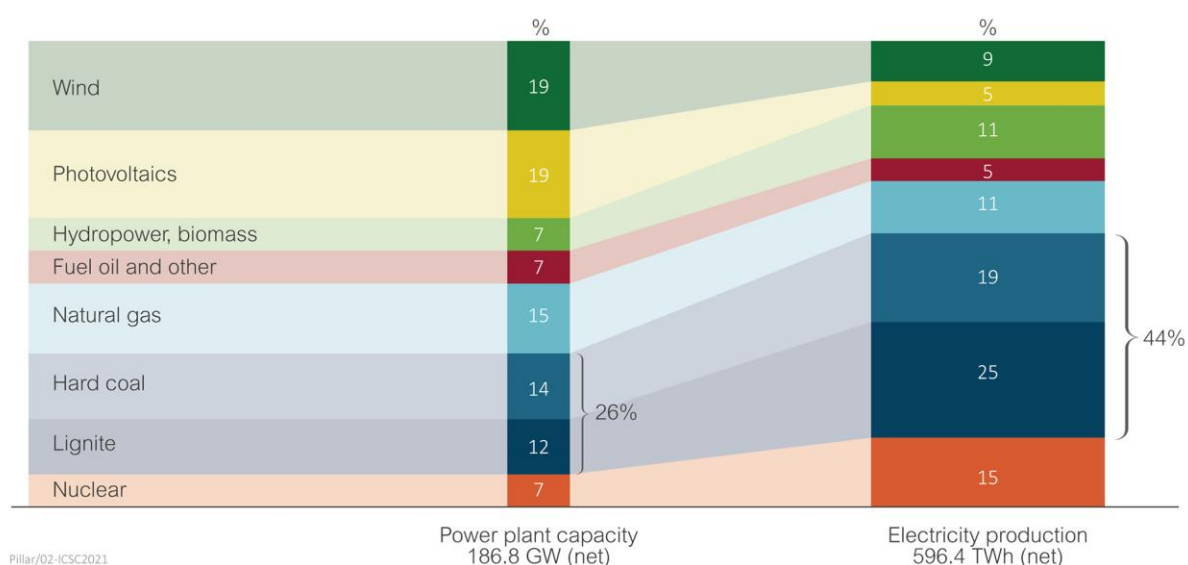


Figure 2 Percentage of capacity and production of various electricity sources in Germany, December 2013 (Schiffer, 2014)

The bar on the left in Figure 2 shows the actual capacity of different energy sources in Germany. In theory, Germany had enough VRE capacity to supply over 45% of its electricity demand. However, in practice, there were days when there was little or no VRE available. On the right of Figure 2 the graph shows how, during December 2013, the VRE input was low (below 25%) and, as a consequence, the hard coal and lignite plants were vital to ensure that power demand was met. And to meet this demand, the coal and lignite plants had to respond by flexing to full load within a very short period. This highlights how important coal plants remain as countries such as India increase their VRE capacity. It also warns that many existing coal plants in India may be called upon to work under conditions for which they were not designed.

Increasing plant flexibility increases plant operating costs (see Section 2.2.3) but can also cause an increase in total system costs. Electricity prices in Germany at the time of the above study were over twice the average for OECD (Organisation for Economic Co-operation and Development) countries and three times as high as in the USA. While wholesale costs of electricity have changed since then, the issue still stands – when the grid relies heavily on VRE sources, flexing baseload plants to meet demand in times of crises can be expensive.

2.2 HOW INCREASED FLEXING AFFECTS COAL PLANTS

In baseload operation, a plant burns coal at a constant rate and produces power at a similarly constant rate. The output of the plant can be increased by loading more coal which can allow the plant to ‘load follow’ – this means it adjusts the power output to meet demand without exceeding demand (thus not wasting coal) and without failing to meet demand (thus risking brown-out or black-out incidents). Conversely, when demand is low, the plant can run below baseload, down to an ‘idling’ or ‘stand-by’ mode. This is where problems may occur. Reduced operation (low coal burn rate) reduces

temperatures and pressures within the plant. If a coal plant cools down significantly, then it cannot simply turn up production by firing more coal. The temperature and burn rate of a cooled coal plant need to be increased carefully if damage is to be avoided. Start-ups from ‘warm’ and ‘cold’ (when the plant has been shut down for an extended period) can be slower and more expensive than ‘hot’ start-ups, by an order of magnitude or more (Sloss, 2016). Figure 3 shows the effect of increased flexing on coal plants.

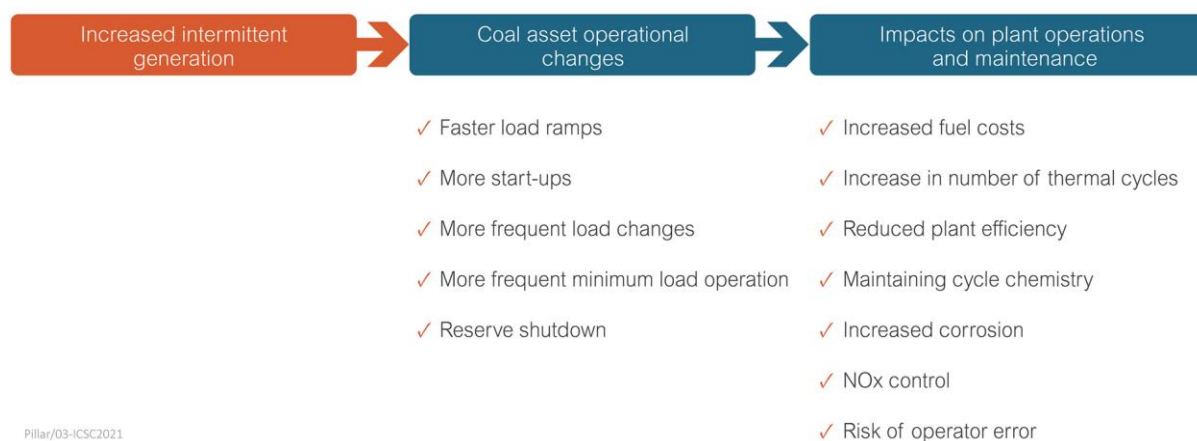


Figure 3 Plant flexibility demands (EPRI, 2020)

As shown in Figure 3, when operation is changed, the plant can incur negative impacts. If the plant slows operation significantly or shuts down completely, then it cools to the point where starting up again becomes challenging and costly. This is where most damage to the plant can occur. Whilst gas turbines can start-up and flex their operation within 10–20 minutes, coal plants can take 1–10 hours to start-up (from complete shut-down), depending on the duration of the shut-down period. Hot start-ups can be initiated within 1 hour of shut-down whereas 10 hours will lead to a cold-start situation. Although many coal plants in Europe have managed to improve their performance at very low load and through deep cycling (see Section 2.4), the following section is relevant for many existing plants in India. Most plants in India are currently operating under one of the following operating modes (EPRI, 2020):

- **Baseload:** running at a high net capacity factor with minimal starts (<10 starts annually);
- **Reserve shutdown:** operating 1000 hours/y or fewer;
- **Load following:** running at over 70% capacity, with fewer than 10 shutdowns annually, but with frequent load changes;
- **Minimum load:** running at minimum design load or reduced minimum load;
- **Two-shifting:** running for fewer than 24 hours with over 50 starts per year.

Each of these modes of operation has different effects on the plants and results in different potential issues and problems.

2.2.1 Plant damage

As discussed above, significant operational changes are expected from a coal plant to meet flexible demand. Figure 4 shows the damage that can be incurred due to such changes. The longer the plant is offline, the colder all the components become. As cooling occurs, there is an increased risk of issues such as condensation, corrosion, and the contraction of metallic components of the plant. If the plant is asked to ramp up again rapidly after becoming cold, there is further risk of damage as components expand with the increased temperatures and pressures.

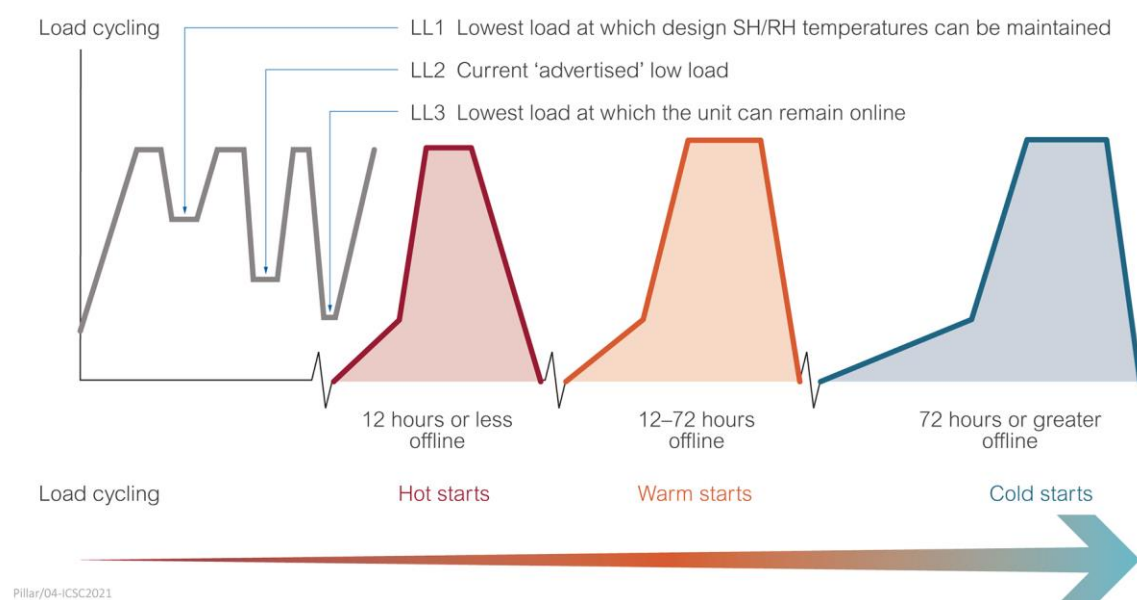


Figure 4 Damage through unit cycling (EPRI, 2020)

This potential damage to the plant requires assessment and monitoring to mitigate potential costly damage to equipment without depleting the plant's operation and maintenance (O&M) budget. Common challenges of 'turn-down' (flexing) operation include:

- fuel loading/heat input management;
- controlling steam temperatures;
- flame stability;
- feedwater control;
- environmental controls;
- excessive cooling of the steam turbine due to control valve throttling;
- feedwater heater cascade drain function;
- fan vibrations; and
- damage to the back end of the turbine.

The increased wear and tear on equipment due to cycling may not be immediately evident and latent damage to a critical power plant component often reveals itself as a failure when the unit is at full load during peak periods. It is at these times, when steam pressures and temperatures are highest, that

stresses on the plant are encountered, causing problems such as cracking due to thermal fatigue. Even if major issues do not occur, increased monitoring by the operator is required to identify issues such as thermal expansion, which can require the replacement of parts. Similarly, increased vigilance is essential to avoid corrosion issues.

According to the review paper by Lefton and others (2010), a 600 MW plant should last for up to 50 years when running under the baseload operation for which it was designed. During this lifetime, it will be closed for maintenance and repair less than 15% of the time. However, if the same plant is moved into cycling mode without being upgraded to do so, outages could put it out of commission far more often. A baseload plant which changes to flexible operation without appropriate upgrades may require significant amounts of capital spending to keep it operational for its full lifetime expectancy of 50 years.

2.2.2 Emissions

Changes in plant operation encountered during ramping up and down can also influence emissions. A report from the ICSC reviewed these issues (Sloss, 2016). For example, changes in flue gas temperature can increase condensation on particles which will affect particulate capture efficiencies in pollution control devices such as electrostatic precipitators (ESP) and baghouses/fabric filters. The performance of these systems is commonly so high (>99.99%) that there is minimal risk of flexing plants exceeding emission limits. However, in older units, there is a risk of increased wear and tear. Similarly, changes in flue gas temperature can affect sulphur dioxide (SO₂) control in flue gas desulphurisation (FGD) systems, especially during start-up and shut-down periods. Again, these changes are unlikely to cause any breaches in compliance with emission limits in well-maintained units but could add to the strain on plant upkeep.

Nitrogen oxides (NO_x) is the pollutant which is most sensitive to variations in plant operation. Changes in flue gas temperatures can lead to ammonium slip in some NO_x control systems which can require the use of additional heaters or baffles to avoid damage and/or reduce operating lifetime in some selective catalytic reduction units (SCR). For plants installed with SNCR (selective non-catalytic reduction) for NO_x control, there may be temperature and injection issues related to changes in load (Wiatros-Motyka, 2019).

The issues discussed here have been identified and studied at plants in Europe and North America and the effects have been minimised through monitoring and adaptation. However, this may be more of a challenge for some units in India where access to advanced real-time monitoring systems is more limited. Case studies in India have indicated that degradation in performance can result causing a significant increase in all emissions. Under flexible operation, thermal efficiency (and reliability) of Indian coal units can degrade. Figure 5 shows the measured effect of efficiency losses on emissions of

pollutants from coal-fired power units in India. Although the numbers are somewhat dated, this information helped form the basis for the EPRI work to develop the flexibility toolkit.

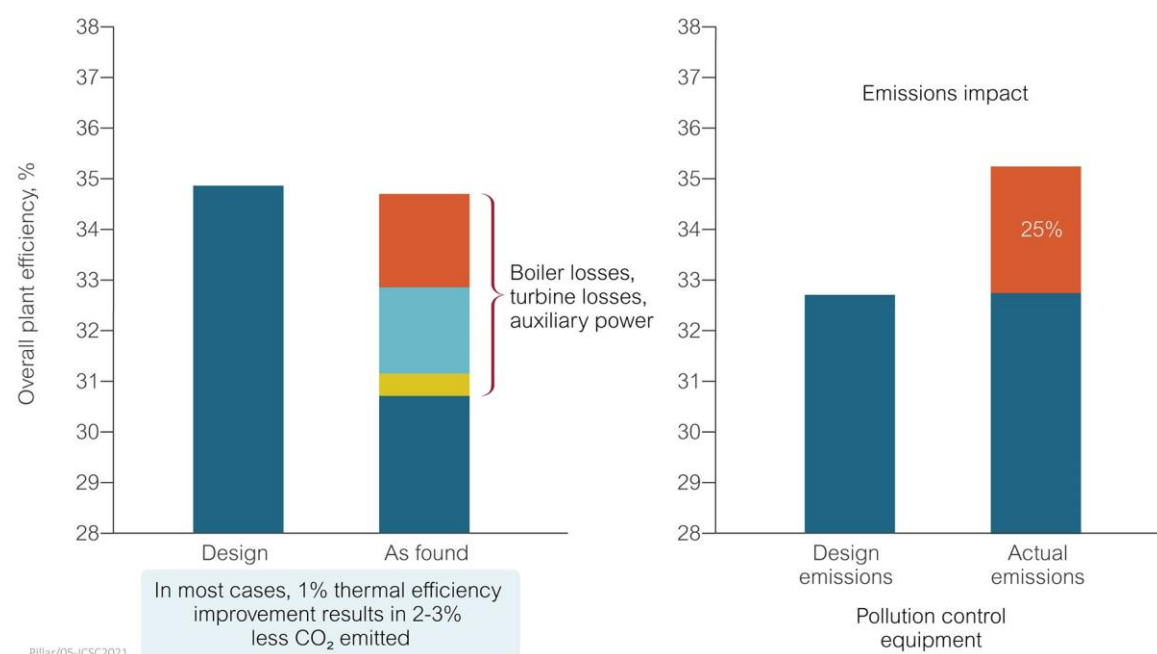


Figure 5 Potential increases in emissions due to changes in plant performance (USAID, 2014)

In the graph on the left in Figure 5, the average design efficiency of subcritical plants is shown as 35-36%. However, the actual efficiency was found to be significantly lower than this and, as shown in the 'as found' column, Indian plants are losing as much as 2% efficiency to boiler losses and a further 2% to turbine and ancillary power losses. A decrease of 4–5% overall plant efficiency means that the plant will require more coal to produce the same plant electrical output which has cost implications including requirements for additional transport and storage of coal coming in and usage/disposal of the increased ash output. As shown in the graph on the right in Figure 5, the reduction in efficiency can increase emissions by over 25% above design values. This could be a major problem for some plants, putting pressure on existing emission control systems and increasing the risk of exceeding emission limits.

2.2.3 Cost

Plants running at below design efficiency require more coal to produce power, which adds to the cost, as does the potential increase in wear and tear and operational issues. Flexible operation increases fixed costs at conventional power plants, many of which are already operating with constrained budgets. Coal plants are therefore being asked to supply energy in a far more challenging and ultimately expensive manner. This increased operational cost could become a significant issue if the energy market does not incentivise flexibility and capacity. Whilst providing electricity during peak demand can be profitable, idling to maintain availability while demand is low can be expensive.

The ICSC review by Sloss (2016) noted that increased penetration of wind and solar into the US energy grid could be increasing coal plant cycling costs by up to 24%, adding hundreds of millions of dollars to expenditure within the remaining coal fleet and impacting costs within some individual plants by orders of magnitude.

A study by Then (2015) showed that coal plants in Germany which ran at baseload for over 8000 hours per year spent over half their fixed costs on fuel, most of the remainder on capital costs and less than 10% on maintenance. When plants switched to flexing mode, plant fixed costs more than trebled with almost all the additional expense coming from capital costs – costs for service failures and unplanned stoppages range from tens of thousands to hundreds of thousands of dollars (Sloss, 2016). Although these extra costs will be mitigated by better grid management, it demonstrates that changes in VRE capacity can disrupt costs significantly.

2.2.4 Staff skillset

As highlighted in the toolkit manual (EPRI, 2020), historically, most utilities in India have been staffed based on baseload operation. Flexible operation requires a larger crew to address the additional support needed for reliable and safe plant start-ups. New procedures for changed operation will be required, along with changes in training. Plants flexing into lower loads will need staff trained in plant preservation measures. All plants changing their usual mode of operation will need to step up performance monitoring, diagnostics, and data assessment to evaluate the performance of the unit, and this may also require investment in new equipment for training in necessary new skillsets. The following list details some of the new requirements for a coal-unit line manager when the unit is called to provide flexible output:

- Design and manage a unit or fleet flexibility programme;
- Perform and align assessments;
- Communicate with staff to coordinate plant improvement projects and address deficiencies;
- Coordinate annual updates to the assessment programme;
- Provide specialised technical support and provide training; and
- Maintain communications between the unit staff and corporate, regional or station management.

2.3 THE SPECIFIC CHALLENGE FOR INDIA

The following information is taken from the ICSC report from Wiatros-Motyka (CCC/295, 2019), available at no charge from www.sustainable-carbon.org.

As with many countries, the energy mix within India is expected to change in the future. Figure 6 shows the predicted change in installed capacity in India between 2017 and 2027, as reported by NTPC in 2017. Coal, shown in orange, is expected to increase until 2022 but then investment in new coal

may be limited. The majority of new grid capacity coming online after 2022 is predicted to be VRE (dark blue).

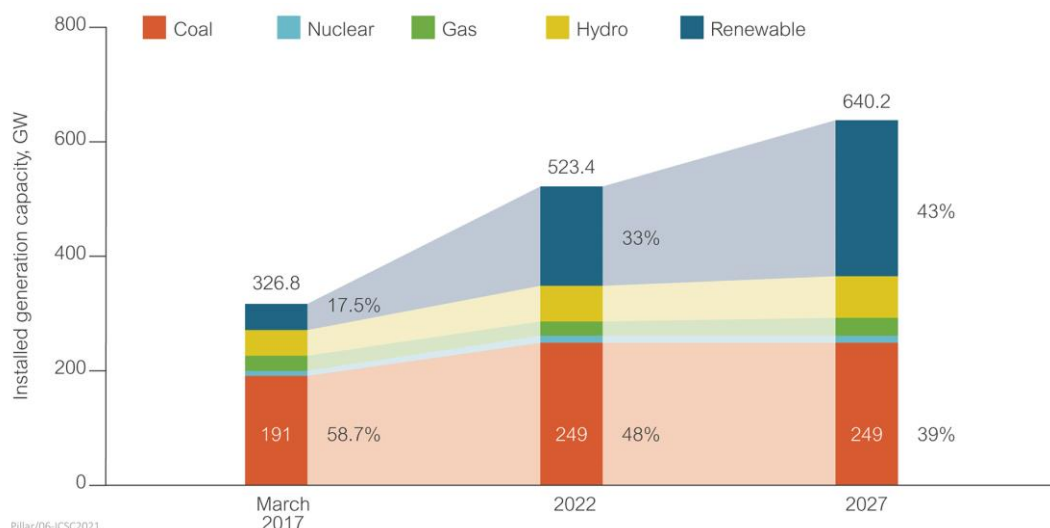


Figure 6 Current installed capacity in India and projections for the future (Mazumder, 2017)

Whilst the increase in VRE capacity will help India achieve its clean energy commitments, it will mean increased pressure on the existing coal fleet to provide flexible and dispatchable power to back up these intermittent energy sources.

Indian coals are high in ash (>30% ash and often as much as 50%) which means that the calorific value of Indian coal is lower than that of hard coal in other countries. To deal with this, Indian coal boilers are relatively large to provide sufficient residence time for complete coal burn-out. High ash coal also causes a temperature decrease in the burner which can lower burner stability. Since burner stability is important for coal units which may have to run at low load, Indian plants will have difficulty lowering the minimum load below 45–50% whereas plants firing coals with a lower ash content can ramp down to 30%. Some of the existing Indian fleet will therefore find it difficult to idle (run at low load) and provide the flexibility required to meet the demands which may be placed on them when VRE capacity increases.

Table 1 summarises the existing coal capacity in India with respect to their predicted flexibility in 2022.

TABLE 1 UNITS AND CAPACITIES IDENTIFIED FOR FLEXIBILITY (SINHA, 2019)		
Operation mode	Capacity, MW	Number of units
Baseload	139,720	299
Flexible with efficiency retrofit*	20,740	80
Flexible – daily start	12,925	83
Flexible – low load	48,385	130
Plant retiring/being replaced with supercritical	9,370	86
Total	231,139	687
* inefficient units with a heat rate >2550 kcal/kWh (10,669 kJ/kWh), can run on flexible operation with efficiency retrofits		

As shown in Table 1, 299 of 687 coal units in India currently run consistently at baseload and do not provide flexing operation. A further 86 units are due to retire and be replaced with supercritical units. The supercritical units will need to be far more flexible than the subcritical ones they replace but may not be online and operational for several years. Of the remaining 302 units, some are flexible but only under certain conditions.

Plants across almost all provinces of India will be affected by the demand for increased flexibility as VRE capacity increases. Figure 7 shows the potential flexibility of the current Indian fleet.

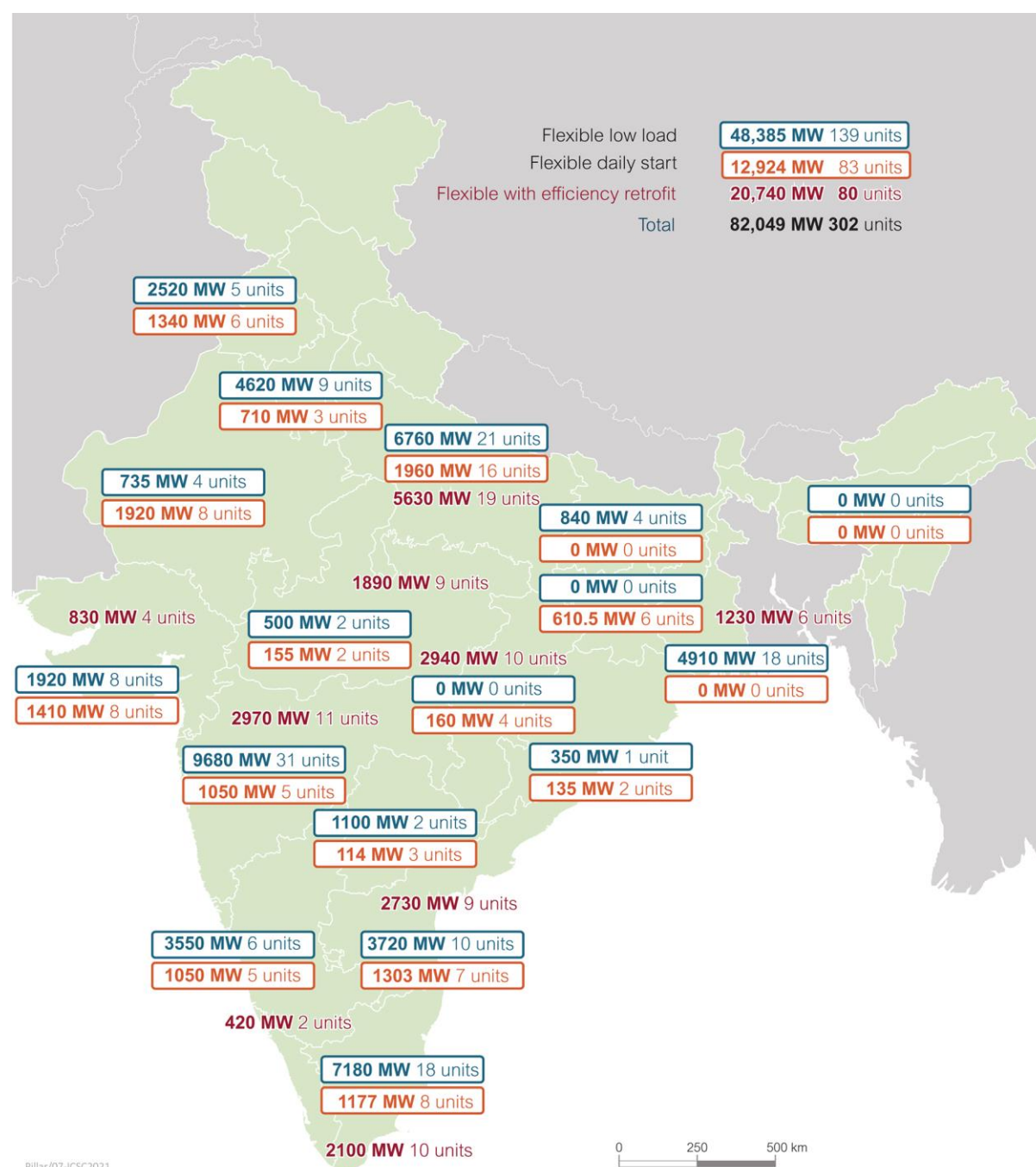


Figure 7 Country-wide flexibility potential based on universal metrics (Sinha, 2019)

The shading in Figure 7 indicates that different plants will have different abilities in terms of flexibility. Plants shown in blue will be able to flex at low load and those shown in orange will be able to provide power based on daily starts. However, over 20 GW of capacity will only be able to operate flexibly if they undergo retrofitting to increase their efficiency. From the map, it is clear that some regions, such as the northeast, have limited or zero flexible coal capacity. It is therefore important that Indian utilities act now to invest in opportunities to increase the flexibility of their coal fleet before the situation becomes critical and there is an increased risk of grid instability. The toolkit and related training will make a valuable contribution to improving the situation.

2.4 COMMENTS

The majority of the existing coal fleet in India are subcritical units which were designed to run most efficiently in baseload operation. As VRE input to the grid increases, coal units are being asked to ramp power output up and down far more frequently, causing issues with plant performance, running costs, and potentially resulting in increased pollutant emissions. It is therefore imperative that the coal fleet monitor and control plant performance as closely as possible. It is also important that flexibility issues are addressed within the next five years, as the intended increase in VRE input to the grid within this time period could place significant stress on the existing coal fleet. The flexibility toolkit is designed specifically to meet this challenge and has been developed by EPRI in conjunction with NTPC to ensure that it meets the real demands of the current Indian coal fleet.

3 THE FLEXIBILITY TOOLKIT

Many existing subcritical and supercritical coal-fired plants in the world are being asked to operate more flexibly to help grids cope with increased input from VRE, as emphasised in Chapter 2. The challenge could be greater for units in India as domestic coals make it more difficult for them to operate in a flexible manner. In order to maximise coal plant flexibility whilst reducing the associated risks and costs, EPRI has developed a toolkit under the Power and Energy Efficiency Pillar of the US India Strategic Energy Partnership (SEP) which was co-chaired by USDOE's Office of Fossil Energy and India's Ministry of Power. The toolkit is intended to assist management and technical personnel at thermal power plants to better understand the complexity of flexible operations and identify areas that need improvement. Guidance is provided for owners and operators of thermal power plants to assess flexible operations. This training is an extension of that work and includes an in-depth overview of how to implement and use the toolkit to meet the specific challenges for India. This chapter summarises the toolkit, explaining its objectives and the areas of plant performance that it covers.

3.1 FORMAT OF THE TOOLKIT

The EPRI High-Level Flexibility Assessment Tool is a user-friendly instrument in the form of tabulated templates. The toolkit comprises numerous pages of templates to be completed by the user to collate specific information on the plant or unit being assessed. The High-Level Assessment Tool guide is available for download by all delegates (before, during and after the training session) and can be accessed here:

<https://www.epri.com/research/products/000000003002019900>

Those wishing to use the toolkit should refer directly to the above document for full details. The following sections give an overview of how the toolkit is implemented and how the results are addressed.

Each template focuses on a different plant system or issue, with areas in which to flag potential problems. There are currently 10 templates for assessment and benchmarking within the toolkit, dealing with the parameters listed below:

1. Equipment operating modes;
2. Pressure part management;
3. Operations;
4. Maintenance;
5. Combustion and boiler performance;
6. Instrumentation, controls, and automation;
7. Environmental controls;

8. Cycle chemistry;
9. Turbine/generator; and
10. Balance of plant.

The simple template approach guides operators of these units on how to conduct complex assessments in a systematic, relevant, and detailed manner in order to reveal unit design and operating gaps, as well as to identify areas that need improvement. The templates apply to both subcritical and supercritical steam generators >100 MW.

The process of using the toolkit for flexibility management is summarised in Figure 8.



Figure 8 High-level flexibility assessment tool application

The flexibility management process starts with the templates which will be completed using data and information directly from each coal-fired unit. A completed template allows an assessment of the current situation in each individual unit but also allows the development of benchmarking. Benchmarking will allow each unit to keep a record of the status of each unit which will help to determine which areas of operation are running as expected and which need attention. If the templates of different plants are shared, this will allow unit operators to determine their performance against other units and promote the sharing of experience and expertise. By providing a ‘living assessment’, which can be updated regularly, the toolkit will allow operators to prioritise the most important maintenance issues. Over a longer period, the information in the toolkit templates will allow plant operators to consider long-term projects specifically suited to each unit. The data from these projects will help to further research into maximising plant flexibility and could feed into digital tools and models, which could facilitate faster responses to emerging issues across the entire Indian coal fleet in the future.

As shown in Figure 9, the toolkit aims to provide both quantitative and qualitative advantages for the user.

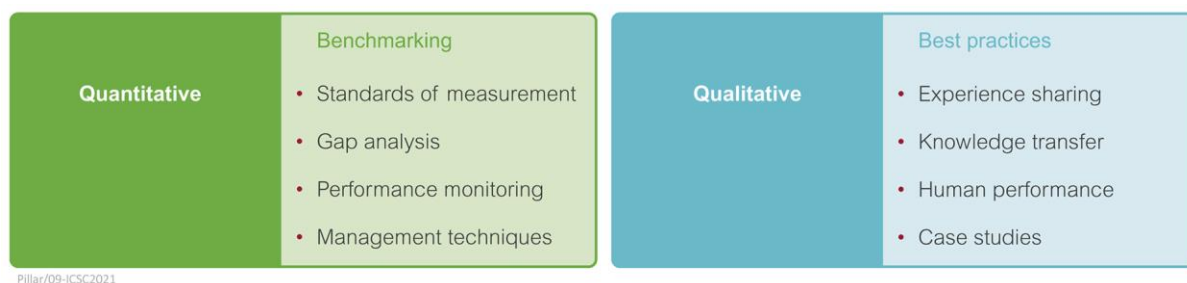


Figure 9 The qualitative and quantitative advantages of the toolkit

In terms of quantitative advantages, the toolkit will ensure that all operators use the same standards of measurement, which will allow easy comparisons across the fleet. If all units within a fleet use this approach then it will be clear where there are gaps in data and analyses. Further, if the toolkit is used regularly and the data are maintained, then it will provide a means of monitoring the performance of each unit over time, allowing management to oversee unit and fleet performance and to make improvements where necessary. For the toolkit to be of long-term benefit, it should be officially recognised as a critical component of the plant's O&M plan and the template data should be updated consistently and regularly. Many of the required modifications, repairs and upgrades should be achievable by the in-house staff, but some may require expert outside contractors.

In terms of qualitative results, use of the toolkit by a growing number of operators will facilitate experience sharing and knowledge transfer, promoting the development of best practice across the fleet. Although some information may be proprietary, it may be possible for equipment manufacturers to facilitate the sharing of experience between plants with similar configurations and specifications. Staff performance and engagement can increase. Case studies can be shared and archived, to avoid repetition of past mistakes and the rapid uptake of successful new approaches.

3.2 COMPLETING THE TEMPLATES

As unit conditions and performance vary, the templates are intended to be used to evaluate an individual unit, allowing an assessment of the current situation whilst facilitating a record to be made in order to highlight when significant changes in operation have occurred. However, by compiling and comparing assessments, multiple units at a given plant can be evaluated simultaneously.

Figure 10 shows a screenshot of a typical toolkit page. Although the toolkit can be implemented in a simple paper format, with printed pages to record assessments, it can also be filled in electronically. By using a Microsoft (MS) Excel spreadsheet, the results can be recorded and shared more easily, and the data can be manipulated into useful figures and charts.

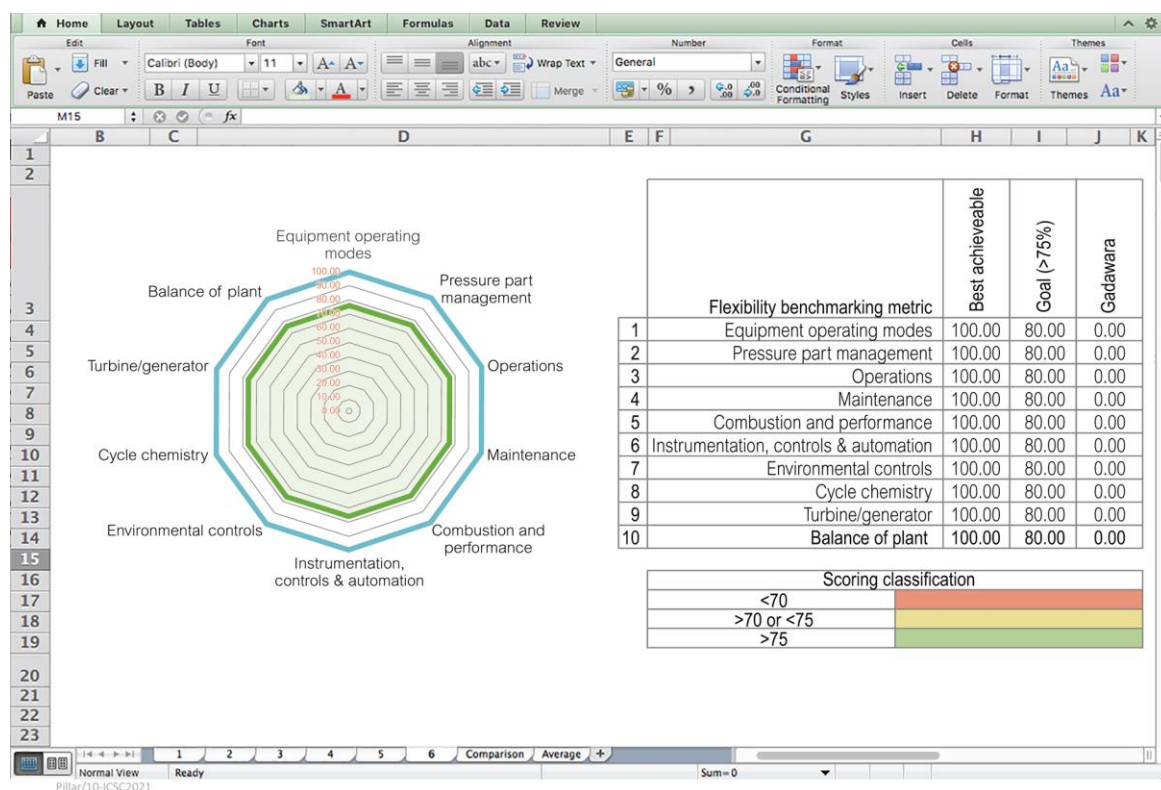


Figure 10 Typical template page within the toolkit

Figure 10 demonstrates that, when data are uploaded directly into an MS Excel version of the template, the results can be immediately expressed in a spider chart. The spider chart is discussed more in Section 3.3 – but first, it is important to understand what data are needed and how they are evaluated. Figure 11 shows how to use the template in more detail.

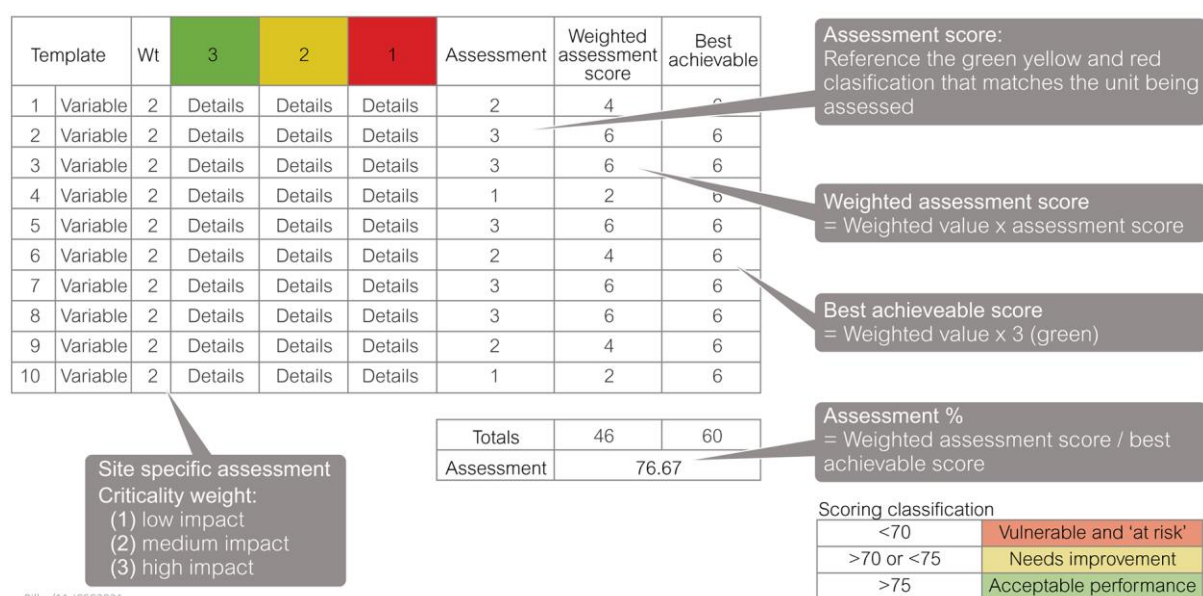


Figure 11 Summary of flexibility toolkit pages

The sample template format shown in Figure 11 includes the fields which will need to be defined and populated by the operator using plant-specific information. In the second column, the variable of concern (such as the condition of a component part or the performance of a piece of equipment) is defined and then, next to that, a value for a weighted assessment is given as either 1 (red), 2 (yellow) or 3 (green), classifying the variable as having a low, medium or high potential impact on plant performance respectively. This weight will be used to ensure that those issues which are more critical to the plant are given significantly higher assessment scores than less critical issues.

Details relevant to the issue can then be noted in the relevantly coded column. For example, if the user finds that a variable being addressed has an acceptable performance then it is assigned 3 points in the assessment column and the details are provided in the green column. If the variable needs improvement, then its score will be 2 points and notes should be made in the yellow column. If there is a significant issue then the score is 1 point and the variable is marked within the red column. The relevant score is then multiplied by the weighted value for the variable to give a weighted assessment score. Figure 12 shows an example page of the template dealing with an assessment of the operation of air and gas systems at an un-named unit.

Operations assessment: air gas systems

		Wt	3	2	1
17	APH ΔP management to avoid gas mal-distribution and/or plugging	2	Low dew point (or design)	Moderate dew point	High dew point
18	APH cleaning system	2	Good performance	Needs improvement	Unacceptable
19	APH, cold-end temperature control	2	Above dew point	Near dew point	Below dew point
20	Impact on furnace exit gas temperature (FEGT)	2	Managed for overheat mitigation	Unrepresentative Some control	Not managed Uncontrolled
21	Minimum airflow	2	Representative and accurate measurement	Some control	Not managed Uncontrolled
22	Boiler O ₂ controlled Minimum to maximum O ₂ set-points	2	Controlled to curve	Needs improvement	Uncontrolled
23	Burner air register and sleeve controls	2	Good condition Good control	Needs improvement	Poor condition Poor control
24	Combustion air - fan performance (PA, FD)	2	Dampers controllable; Acceptable capacity across load range	Needs improvement	Poor control; insufficient capacity control
25	Mill minimum temperature control	2	Good control	Periodic issues (eg wet coal)	Poor control
26	SCR temperature measurement (via representative grid)	2	Good control (no issues)	Periodic issues (eg seasonal)	Poor control
27	SCR minimum inlet gas temperature	2	Good control (no issues)	Periodic issues (eg seasonal)	Poor control
28	Exit gas temperature	2	Good control (no issues)	Periodic issues (eg seasonal)	Poor control
29	Water wall temperature - FW control	2	Good control	Needs improvement	Poor control

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APH = Air preheater
PA = Primary air

FW = Feedwater
SCR = Selective catalytic reduction

FD = Forced draught

Figure 12 Example of template page in action

In Figure 12, each variable is given a number (column on the far left). Each of the variables in this example have been weighted as '2', meaning that they have medium impact on the plant performance.

The following columns give examples of how each variable could be assessed. For example, for row 25, dealing with the minimum temperature in the mill, a good score (green column) would be noted if the mill consistently ran at the required temperature. Alternatively, a note could be recorded in the yellow column if there were issues, such as temperature drops below a minimum when wet coal is introduced. A note would be given in the red column if the temperature control in the mill was generally poor. The written detail in these columns can include an indication of how the issue can be resolved. For example, in this case, ensuring that the coal delivered to the mill is dry could solve the problem.

When completed, the entire template will include information for all relevant instruments and components in the unit. The scores for all items on the template are then added to produce a total weighted assessment value. By comparing this total with the best achievable total (where all variables are in the green column with maximum scores), the toolkit template will produce a score in terms of percentage. If the total is below 70%, then everything in the template (in this example, all instruments, controls, and automation) is deemed acceptable. If, however, the score is 70–75%, then the template will flag parameters as needing improvement. Scores above 75% identify templates representing plant parameters which are ‘vulnerable’ or ‘at risk’. Completion of the template should involve the confirmation of information and evaluation by other members of staff and line managers to ensure that the results are valid and acknowledged.

3.3 APPLYING THE RESULTS FROM THE TOOLKIT

Completion of the templates will result in numerous pages of data in which potential issues are clearly flagged by scoring classifications and associated green, yellow, and red shading, as shown on the right in Figure 13.

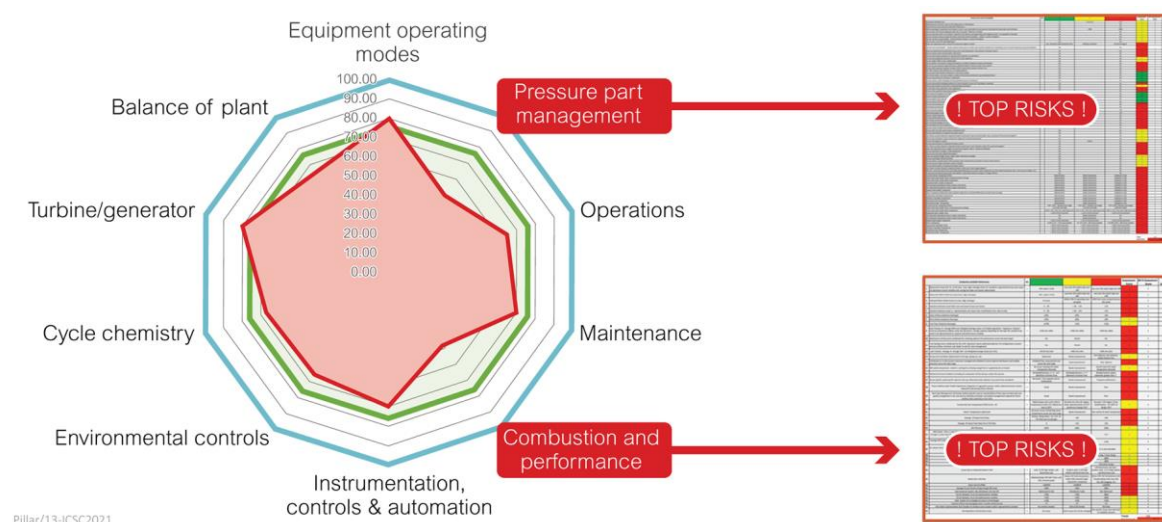


Figure 13 Example of toolkit results

As areas of concern are clearly marked in red in the tables, Figure 13 shows how, even at a glance, numerous issues of concern have been flagged on this example template. If the data are stored in MS

Excel, then the results can be converted into a spider chart (on the left in Figure 13), which will visualise the issues of concern. Ideally, all areas of the star chart should be maximum, and the pink area would reach the outer limits of the area available. Areas inside the green line indicate problems.

By making the results clear and visual, it is possible for managers to obtain a quick overview of unit, plant, or fleet operation. Figure 14 shows how the star chart can be applied to a group of plants to provide an overview of a whole fleet of units or plants.

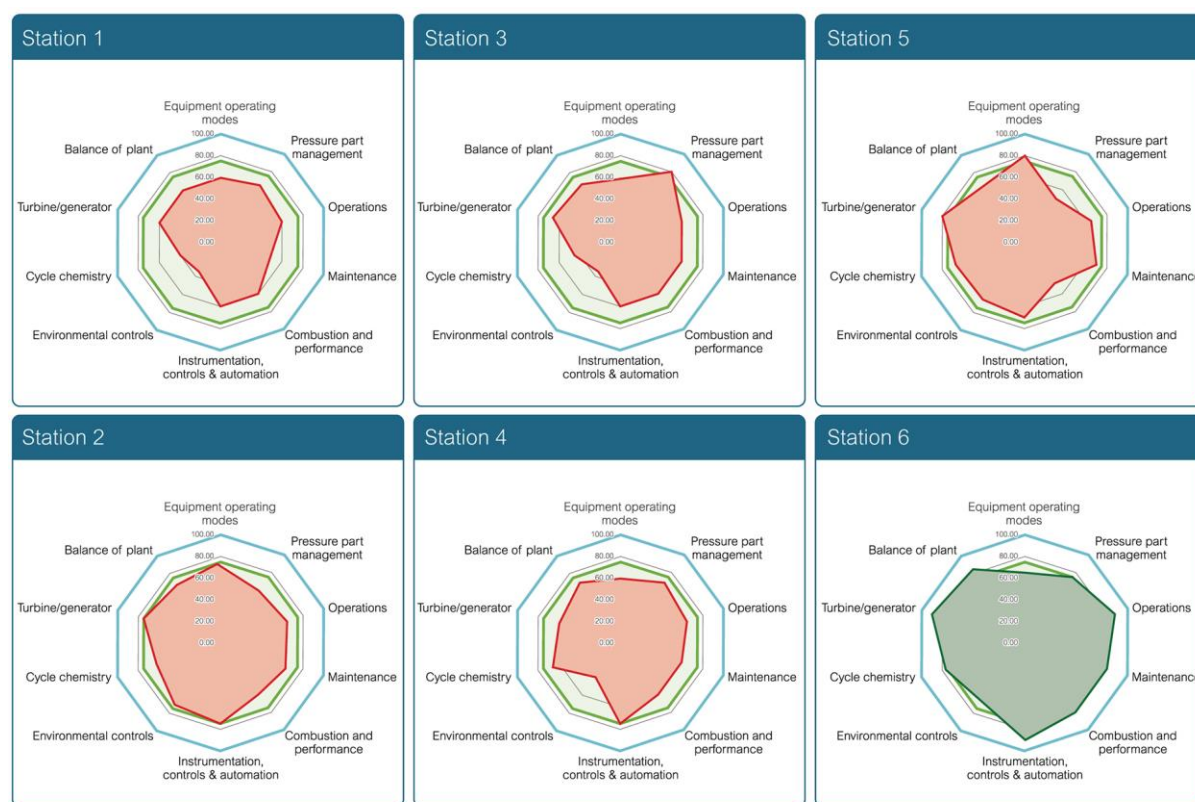


Figure 14 High-level fleet flexibility assessment spider charts

The larger the shaded area within the star chart, the higher the plant scores with respect to flexibility. Those shaded in orange have some issues and, by looking at where the shading is most depleted, the reader can identify the areas of most concern. Station 6 appears in green as none of the templates has identified issues of concern. And so, even a utility manager with limited technical knowledge would be able to look at Figure 14 and appreciate that Station 6 is doing well whilst Station 1 needs significant upgrading.

A summary of the template data, as shown in Figure 15, would then allow the manager to identify exactly the items within the unit that need attention.

		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Average
1	Equipment operating modes	56.16	71.69	58.90	59.36	79.45	66.21	65.30
2	Pressure part management	64.30	63.44	79.57	68.60	47.31	75.27	66.20
3	Operations	58.44	69.14	62.34	65.83	62.62	91.21	68.09
4	Maintenance	47.92	66.67	63.54	61.46	66.67	84.38	65.11
5	Combustion and performance	58.80	58.71	64.35	56.48	47.22	78.87	60.50
6	Instrumentation, controls & automation	60.38	69.96	62.89	68.97	70.23	91.67	70.29
7	Environmental controls	34.62	68.33	34.62	34.62	66.67	71.43	51.35
8	Cycle chemistry	42.33	60.33	46.33	66.67	66.67	84.81	60.10
9	Turbine/generator	56.51	73.65	67.30	59.37	79.68	92.38	71.48
10	Balance of plant	57.14	66.67	64.29	66.67	66.67	86.90	67.86
	Overall score	53.66	66.86	60.41	60.80	65.32	82.31	64.63

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Figure 15 High-level fleet flexibility assessment data

The values in Figure 15 suggest that most plants in this example have issues with their environmental controls, with the average for the plants being 51.35% and two plants having scores as low as 34%. This could empower the operator to decide to implement an informed strategy to improve the condition of the environmental control systems across these units in a coordinated manner.

3.4 EXPERIENCE WITH THE TOOLKIT IN PRACTICE

It is important to stress that the flexibility toolkit has been developed and designed with the specific challenge of Indian coal plants in mind. The largest utility in India, NTPC, provided input and support during the development of the EPRI flexibility toolkit by creating a project team from six coal-fired power plants in India. Each plant conducted multiple assessments with the toolkit on a total of 8 GW of critical generating assets within the NTPC fleet. This hands-on experience validated the applicability of the toolkit and the feedback from Indian stakeholders ensured that the final toolkit addresses adequately all the challenges at Indian coal units.

3.5 COMMENTS

The flexibility toolkit is a relatively simple way of assessing complex information in such a way as to highlight where there are problems. By diving deep into plant-specific data, users can evaluate and compare plant performance either within the same plant (against unit design parameters or to assess changes over time) or against other plants. This will facilitate the benchmarking of unit performance within a plant but also across a fleet. At the same time, by applying the built-in assessment coding and colour shading, all managers can clearly see where there are issues and can compare the relative importance of each. This allows operators to prioritise plant-specific aspects of plant maintenance and repair, not only fixing current problems but addressing issues which have been flagged to suggest future problems. Pre-emptive action on flexing coal units could avoid plant failures and closures and

could also reduce operating costs. Since the toolkit and training are provided at no charge, this is a win-win situation for all Indian utilities.

4 POTENTIAL FOR UPGRADING UNITS

The EPRI flexibility toolkit has been specifically designed for the Indian coal sector, with the aim of ensuring that the existing coal units can maximise their performance to meet the growing demand for flexibility. The toolkit focuses on plant maintenance and optimisation. However, the toolkit does not consider the potential for plant upgrading to increase flexibility and efficiency. Upgrading can improve plant efficiency by several percentage points, can increase plant output and reliability, and can reduce emissions of pollutants while extending the life of an older plant by several years. However, such upgrading can be expensive. This chapter briefly outlines how existing, older units in India could benefit from experience with upgrading in regions such as Europe.

Advances in coal plant performance in recent years mean that some plants can run at extremely low loads (10–15%) and with high ramp rates (10% per minute as compared to 3–5% design ramp rates for subcritical units). However, this has only been demonstrated at a few plants in Europe with specific boiler designs (Henderson, 2014) and following appropriate upgrades. A report from the ICSC (Henderson, 2014) summarised how the flexibility of existing coal plants can be improved. With respect to boiler operation, flexibility can be increased by modifying or upgrading the firing systems to allow lower load operation while maintaining optimum combustion conditions. This could include using pressure-relevant parts which are designed for faster load changes along with changes in mill operation to facilitate changes in fuel delivery. New and modified equipment such as improved firing systems and modern advanced auxiliary motor drive systems can increase plant flexibility if investment in upgrading is warranted. Henderson (2014) provided options to upgrades to improve plant flexibility as follows:

- Boiler firing systems – changing the size and numbers of mills and fitting modern burners will allow lower fuel feed rates and reduce the number of shut-downs. Hoppers and associated pipework can be installed to achieve indirect firing to improve efficiency at part load.
- Boiler pressure parts – improved alloys allow thinner components to be installed, external steam preheating can reduce start-up time, feedwater recirculation can provide greater temperature stability.
- Emission control systems – temperature controls can ensure technologies such as SCR systems can operate at part load and will reduce moisture condensation effects on particulate control systems.
- Turbine and steam systems – bypass and sliding pressure systems can help regulate temperature and pressure fluctuations.
- Control systems – allow command and control of plant performance but can also produce predictive algorithms to continually improve performance.

A more recent ICSC report by Wiatros-Motyka (2019) reviews the options for improving coal-fired power plant design and management to allow increased cycling. Many of these options would significantly reduce or even remove various of the operating and maintenance issues that will arise as Indian coal plants increase their flexible operation. However, there is no ‘one-size fits all’ solution to improve plant flexibility. Some plants may focus on achieving lower minimum loads (so that they may idle more cost-effectively) whilst others may focus on providing faster start-up and ramp-up rates.

Minimum loads (down to 10–15%) are possible when the power plant is modified to maximise stable combustion. This requires investment in parameters such as coal quality, air control, flame monitoring and thermal energy storage for feedwater heating. Start-up, which is commonly the most expensive phase of coal plant operation, can be optimised through improvements in ignition, gas turbine integration, the use and maintenance of advanced seals and turbine hot standby for a cold start. Ramp rates are commonly higher and faster in more advanced coal-fired units and rely heavily on the control of feed rate and turbine operation. Perhaps the most cost-effective way of improving the flexibility of the Indian fleet could be to invest in instrumentation and control and changes to operational practices. Systems behave differently in alternative modes of operation and understanding the effects these changes have on plant components is critical to ensuring safe and reliable plant operation.

The report by Wiatros-Motyka (2019) includes several examples of state-of-the-art upgrades to plants in Germany, Poland and the USA, demonstrating how there are different options available but no common solution. For example, VGB carried out pilot studies on flexibility at NTPC’s 210 MW Dadri and 500 MW Simhandri units. It was found that, although 50% and 40% minimum loads could be possible with ‘moderate’ investment, 25% loads are ‘not an economically viable option under Indian conditions’. This is largely due to the high ash content of Indian coals, as mentioned earlier. A 40% load could be sustained at Dadri Unit 6 with some retrofits, which are currently underway (2021).

NTPC is continuing to work on flexibility with Indo-German cooperation. However, it is generally agreed that staff training is a critical part of improving flexible plant operation. Even with upgrading, the optimisation of O&M strategies is critical to mitigate operating issues. As stated by Wiatros-Motyka (2019), the adoption of new or modified operational practices are recommended especially for older plants that have limited remaining service life where it is not viable to retrofit new systems. This may be the case for a significant number of units in the existing Indian coal fleet.

5 FORMAT AND DELIVERY OF THE TRAINING WORKSHOPS

The overall aim of this part of the USDOS, ICSC/EPRI project is to provide training and capacity building to a range of Indian stakeholders to empower them with the skills to maximise fleet performance under flexible operation as a part of a multi-pollutant emissions reduction strategy.

Training materials included within this scope of work have been developed in MS PowerPoint and will be delivered to stakeholders during interactive workshops within India. The training will raise awareness and provide direction in helping participants realise best practices in flexible operation, standards, processes, and actions required for the sustainability of efficient and reliable operations. It will also provide clear instructional guidance on O&M conditions that damage generation assets and/or impact the sustainability and performance of large steam generators.

5.1 TARGET AUDIENCE

The tool is intended to assist management and technical personnel at thermal power plants to better understand the complexity of flexible operations and identify areas that need improvement. Guidance is provided for owners and operators of thermal power plants to assess flexible operations across various areas of the plant. Support from the executive level (plant owners and board level managers) is essential to ensure that many coal unit operators obtain access to this free toolkit. The course is suitable for most utility staff, but the training will be most suitable when it is integrated into the operating scheme of each plant or utility.

Figure 16 shows the chart of utility staff associated with most coal-fired power plants. The plant operators and senior staff associated with corporate and marketing duties will benefit from the results of the application of the toolkit, but it is the line managers and those staff members who work directly with the plant who will require training.

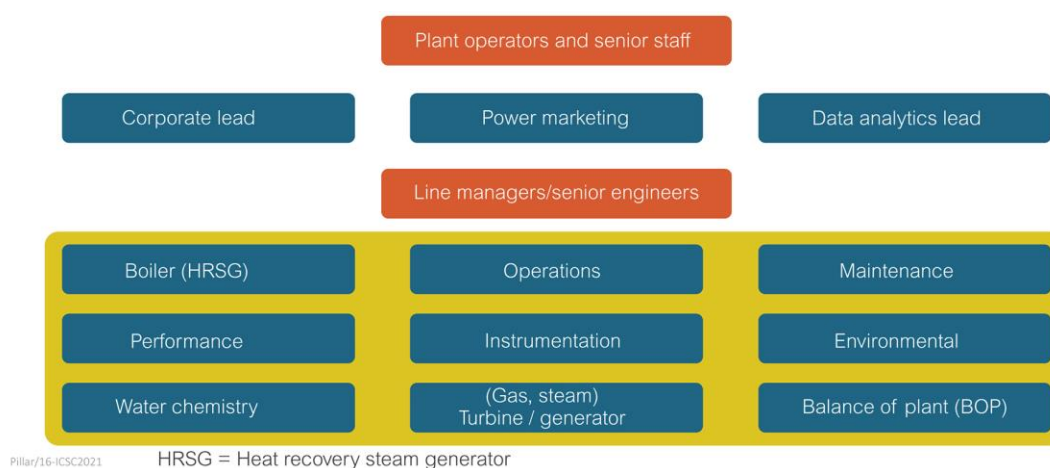


Figure 16 Utility stakeholders

The area in the yellow box in Figure 16 indicates the parts within the plant which are commonly managed by specific staff members. The executive sponsors (board level managers), senior engineers, and line managers should send staff members representing these areas to attend the flexibility training. For maximum benefit, managers and utility operators should:

- Establish a core project team and team leadership for various areas within the toolkit. Ideally, this would comprise 3–5 members of staff. However, if this is not possible, 2–3 staff members could be trained and then required to pass on this training to relevant colleagues;
- Establish a clear and transparent communication path for identifying the best solutions. This will ensure that, when a problem is identified, the issue is raised with someone who will be able to implement a timely and appropriate response;
- Ensure that plant-specific input is available from qualified staff. Plant staff are already aware of issues that could become potential problems, and many will have ideas for improvements. These people should be an important part of the team; and
- Encourage collaboration between staff. The interactions of the different systems are complicated and require input from various sources. The team will need to include all relevant personnel and to facilitate full, open and regular correspondence and cooperation.

The course will be provided free to all, but there are some pre-requisites that must be met to ensure that each delegate will be able to complete the training. These are:

- Proficiency with MS Excel (for template application);
- Proficiency with MS PowerPoint for presentation of findings to their team;
- General knowledge of various power plant systems;
- Leadership capability (to ensure team commitment); and
- Pre-planning and effective communication skills.

Invitations for attendance to the training workshops will be sent to all utilities within India, including details of the course and the requirements for attendance. Utilities will be asked to nominate individuals or teams (depending on availability) to apply to attend the course. If attendance proves to be an issue in terms of the number of delegates, attendance remotely and/or access to a recording of the event will be considered.

5.2 TRAINING CONTENT

The training workshop is designed to take place over 4–5 days, depending on whether on-site case studies can be facilitated (see Section 5.3). The workshop will include at least one day dedicated to desk-based lectures outlining the toolkit in detail. This will include an overview of the tool followed by more detailed presentations relating to each of the template topics, as shown in Figure 17.



Figure 17 Flexibility training content

The training will be delivered with ‘open-book’ access to printed toolkit templates. This will allow delegates to experience hands-on training by working through templates and completing them as they would in practice. Each of the ten templates will be covered in detail, ensuring that delegates have a chance to see all the areas they will need to address when they use the toolkit at their plant. The training will be given live by Stephen Storm of EPRI who will be prepared to answer questions during the training to deal with issues as they arise.

Each delegate will have full access to the online toolkit spreadsheets. If they do not have laptops to work with, printed versions of the templates will be provided to allow them to practice in real-time. Table 2 shows the proposed agenda for Day 1 of the workshop.

TABLE 2 PROPOSED AGENDA FOR DAY 1 OF THE WORKSHOP				
	Day 1,2	Formal workshop activity	Speaker	Duration
1	9:00	Opening comments and logistics	ICSC and/or appointed delegate (TBD)	30 min
2	09:30	Flexibility challenges overview	Stephen Storm	1 hour
	10:30	B R E A K	All	15 min
3	10:45	High-level flexibility assessment tool application – Q&A	Stephen Storm	1.5 hours
	12:15	L U N C H B R E A K	All	1 hour
4	14:00	Detailed overview of high-level assessment templates:	Stephen Storm	
4.1		Template 1: Equipment operating modes	Stephen Storm	Day 1 (PM) Day 2 (AM)
4.2		Template 2: Pressure part management	Stephen Storm	
4.3		Template 3: Operations	Stephen Storm	
4.4		Template 4: Maintenance	Stephen Storm	
4.5		Template 5: Combustion and boiler performance	Stephen Storm	
4.6		Template 6: Instrumentation controls and automation	Stephen Storm	
4.7		Template 7: Environmental controls	Stephen Storm	
4.8		Template 8: Cycle chemistry	Stephen Storm	
4.9		Template 9: Turbine/generator	Stephen Storm	
4.10		Template 10: Balance of plant	Stephen Storm	
		Closing comments and summary	ICSC and/or appointed delegate (TBD)	30 min
ADJOURN				

Day 1 starts with a morning of high-level introduction to the toolkit. This section will be suitable for all utility delegates who wish to complete the training. However, it will also be relevant for high-level stakeholders such as utility managers, regulators and government agencies who would benefit from appreciating the importance of increasing the flexibility of the Indian coal fleet.

The afternoon of Day 1 will take delegates through each of the templates in turn. This will allow delegates to practice with the templates and to discuss any concerns. It is possible that, should discussion periods be significant, training with the templates could continue into Day 2. Days 2, 3 and 4 are intended to focus on using the toolkit under real circumstances. To facilitate the greatest amount of hands-on experience, Days 2, 3 and 4 will include a site visit to a unit to apply the toolkit live. If this is not possible, due to travel or Covid-19 restrictions, then it should be possible to facilitate hands-on training by obtaining live information from plants remotely. This could be through delegates working together to evaluate data from a selected plant or could comprise break-out groups where staff from the same unit or plant work together to address their plant issues.

During Days 2–4, delegates will be able to ask questions of the EPRI trainer but will also be encouraged to talk to their peers, to share problems and challenges, and to develop a culture of sharing and networking. Since the toolkit requires a significant input of plant specific data, some of which will require subjective interpretation with respect to the assignment of weighted assessment values and actual assessment values (see Chapter 3), it is important that delegates have adequate time to become comfortable with using the toolkit. It will also enable them to return to their unit or plant and pass on these skills to colleagues and co-workers, as required.

Day 5 will comprise the completion of the course and the assessment of work carried out. Delegates will be encouraged to share their experiences with the toolkit in practice, reporting their results to the group. At the same time, delegates will be able to raise site-specific challenges and potential roadblocks which all delegates and trainers can discuss with a view to solving as many issues as possible.

Once the course has been completed, delegates who have met the course requirements will be provided with a certificate as a record of their qualification.

5.3 IMPLEMENTATION OF WORKSHOPS

Ideally, training will be provided, in person, on-site in India by EPRI and ICSC. Planning for four regional workshops has commenced, but venue details have not yet been determined. Dates for these workshops will be scheduled later, due to delays caused by the Covid-19 pandemic. Figure 18 shows the proposed locations for the workshops.



Figure 18 Proposed location of workshops in India

The locations have been selected as they are evenly distributed throughout India and represent areas with a relatively high density of coal utilities. This should ensure a good spread of training throughout the country. However, these locations can be changed, if necessary.

In order to reduce travel time for the trainers, it is proposed that four training workshops will be completed within two trips to India. This will mean back-to-back training events held over two 2-week trips.

Due to the ongoing pandemic, it may not be possible to hold all the workshops in India in person within the timeline of the project. In order to ensure that training will be delivered, three options for carrying out training are proposed, as discussed in the following sections.

5.3.1 Option 1 – live, on-site events

Ideally, the workshops will be implemented live, on-site, by EPRI and ICSC staff. If this is possible, the workshops will follow the approach outlined previously and summarised in Table 3.

TABLE 3 OPTION 1 – LIVE, ON-SITE EVENTS	
Day	Activity
1	High-level introduction to flexibility issues followed by hands-on training with the toolkit templates
2, 3, 4	Regional site visits to attendee station(s). Re-introduce the tool to local staff, assist and engage working groups with conducting assessments, with support from EPRI and/or NTPC to demonstrate applicability
5	Complete programme surveys
	Attendee certificate assessment
	Working group report outs (timing will be determined based on number of registrations)
	Attendees provide details of site-specific challenges and roadblocks

Option 1 allows the maximum interaction between the delegates and the trainers and allows real-time experience with the toolkit at a plant.

5.3.2 Option 2 – live virtual training from within India

If travel becomes an option but Covid-19 restrictions remain in place, EPRI and ICSC staff could be on-site at a location in India to provide remote but live training to utility staff around India. The presentations would be shared live on an interactive web channel and would facilitate live interaction between the presenters and the delegates, as shown in Table 4.

TABLE 4 OPTION 2 – LIVE VIRTUAL TRAINING WITHIN INDIA	
Day	Activity
1-2	Formal workshop opening and training provided live to any personnel on-site and remotely to those off-site through a web platform
2,3,4	Breakouts with small groups (size TBD by number of registrations) to conduct assessments with sites. Live data and information can be provided remotely by selected sites to groups working in meeting rooms or staff can work on-site at their own units
5	Complete programme surveys
	Attendee certificate assessment
	Working group report outs (timing will be determined based on number of registrations)
	Attendees provide details of site-specific challenges and roadblocks

This option maximises the live interaction between the trainers and the delegates. The trainers will be in the same time zone and will be able to access the delegates through the web meeting platform but also via other media such as phone, should this be helpful. A virtual platform operated within India will be far more capable of accessing data from coal units within the country in real-time, as opposed to one based elsewhere.

Although one meeting of this format could replace four regional meetings, it will be important to consider the volume of delegates. If the number of delegates is high, then repeating the training several times may allow more dedicated support for delegates.

5.3.3 Virtual workshops

Should travel be impossible, the training could be provided entirely remotely, with EPRI and ICSC staff remaining in their home countries, as shown in Table 5. This will be possible using an appropriate web meeting platform and could still benefit from live interaction between delegates as well as live practice with the toolkit using live plant data.

TABLE 5 OPTION 3 – REMOTE, VIRTUAL WORKSHOPS	
Day	Activity
1-2	Formal workshop opening and training provided through a web platform
2,3,4	Virtual assessment support with stations
5	Complete programme surveys
	Attendee certificate assessment
	Working group report outs (timing will be determined based on number of registrations)
	Attendees provide details of site-specific challenges and roadblocks

Again, the delivery of training over a web platform could mean that only one meeting would suffice for all delegates. However, it may be better to repeat the virtual training workshop several times to smaller groups of delegates to ensure that all delegates are heard, and all individual concerns and questions are addressed.

5.4 ASSESSMENT AND CERTIFICATION PROCESS

Delegates who complete the training course will be eligible to receive a qualification in application of the flexibility toolkit. In order to qualify, delegates must:

- Pass a fundamentals of flexibility test, with score of >80% to validate fundamental understanding of the tool; and
- Demonstrate competent application of the templates and the system process for driving improvements. Ideally, these assessments will be conducted by the participants (with the support of their stations and guided under the project). Engaging the stakeholders to complete assessments and demonstrate utilisation of the tool will validate comprehension and the ability to identify gaps and main areas of risk.

Figure 19 shows an example of the certificate delegates may receive on successful completion of the course. The final certificates will include company stamps from ICSC and EPRI.



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Figure 19 Certificate of qualification

Following the event, Indian stakeholders should be able to apply the toolkit themselves and also to provide training to colleagues and co-workers. Should issues arise with the application of the toolkit, stakeholders should contact EPRI for back-up support.

5.5 COMMENTS

Training to use the flexibility toolkit requires at least one day of working through the templates, to understand why they are needed and how they work. Several days of hands-on practice with the toolkit, accompanied by support from the trainers are then required. Ideally, this practice will be on-site at real plants. However, should travel to and within India be an issue, alternative virtual approaches to training have been proposed.

6 CONCLUSIONS

The rapid move towards renewables in many countries is not reducing coal output as much as would be expected and, in some regions, is actually resulting in the increased use of older, less efficient coal units to provide peak power. While this guarantees electricity supply, the additional stress on some older units may not be sustainable or desirable. Since cycling can have a major impact on plant reliability, grid stability can be negatively affected if the assets are improperly managed.

Plants operating in flexible mode may show wear and tear much earlier than predicted for the same plant running at baseload. In order to avoid equipment forced outages for repair and maintenance, the plant manager must be more aware of the operational conditions of their plant and the potential stresses and damage to individual pieces of equipment. Some of this damage can be monitored and predicted but this often requires increased expenditure in terms of management practices, monitoring protocols and measurement systems. A plant can avoid significant outage and repair costs by being pro-active in terms of management and monitoring. The benefits gained from being pro-active will outweigh any costs for implementing plant improvements.

With USDOE and USDOS funding, EPRI has produced a Flexibility Toolkit that can enable coal utility operators to study and evaluate the performance of their coal-fired units to provide a high-level picture of the plant's current capability for flexible operation. The current USDOS project, led by the ICSC and implemented by EPRI, focuses on delivering training directly to stakeholders in India to empower them with the skills to use the flexibility toolkit.

Plans have been prepared to deliver 4–5 days of free training to Indian utility staff. The exact nature of delivery of this training will be determined by Covid-19 travel restrictions. However, alternative plans have been proposed to ensure that training can be provided within the timeframe of the current project.

If the flexibility toolkit is applied correctly, coal plants in India could improve their efficiency and performance by several percentage points, reducing fuel costs and emissions simultaneously. At the same time, the units will be less prone to stresses and damage which may cause more frequent shutdowns and repair costs. Ultimately, the increased flexibility of the existing coal fleet will help facilitate the uptake of VRE within India, as the country moves towards cleaner sources of energy.

The toolkit and the training materials will be provided, free, to all Indian stakeholders providing long-term capacity building.

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