WORLD ENERGY COUNCIL
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Power Plant Performance: Efficiency & Availability Summary

In the ongoing global efforts to reduce Green House Gas (GHG) emissions, a strong emphasis is placed on improving power plant efficiency. Fossil fuel-fired power plants today supply over 65% of electricity in the world, with coal-fired power plants accounting for about 40% of the total. The efficiency of power generation (amount of fuel to deliver a unit of electricity) varies significantly across the world and it is based on the technology, fuel quality, age of the plant and other variable factors.

The average efficiency of all thermal power plants running on fossil fuels (coal and gas) is around 33%. The most advanced fossil fuel-based generation technologies can achieve efficiencies of 49% using coal and over 60% using gas. There are two main ways to reduce the electricity industry's carbon footprint: improving energy efficiency or availability of the plant.

This is a summary of the main factors which have impact on power plant performance. If all coal and gas-fired power plants in the world used the Best Available Technologies (BAT), it would be possible to save approximately 30% of total global coal consumption each year, thus decreasing the required installed generation capacity of coal-fired power plants by 500GW. In addition, this would also reduce about 30% of the current global natural gas consumption and decrease the demand for power generating capacity by further 300GW of gas-fired power plants. This could help avoid CO_2 emissions by 3Gt per year.

Plant efficiency values from different plants in different regions are often calculated and expressed in different terms, and using different assumptions. Understanding and comparing efficiency across power generation assets is a very challenging task, since it needs a significant number of different input variables, including technology, mode of operation, fuel used, unit size and age. From the perspective of setting improvement targets, even a comparison of a unit to its own historical or design performance is a challenge due to changes in operational regimes, plant modifications made to address environmental regulations, normal degradation, changes in fuel quality/sourcing or equipment upgrades.

The terminology used in the United States and a few other countries is also different from the rest of the world. The primary metric of unit efficiency used in the industry is the heat rate of the unit, which is a ratio of the energy required to produce a unit of electricity – such as how many Btu/h or MJ/s of fossil fuel are required to produce 1kW of electricity at the generator terminal. Within each plant category, actual heat rates may vary by as much as 10-15% due to a number of factors including base or peaking load, load gradients, normal degradation, fuel source, how well the plant is operated and other indicators. While in North America boiler and plant efficiency are reported on a higher heating value or gross calorific value basis, which for a combustion unit means that the latent heat of vaporisation of moisture from the fuel is recovered, most of the world refers to boiler and plant efficiency on a lower heating value or net calorific value basis. Neither metric is "right" or "wrong," but it is important to compare apples to apples.

As an example, the heat rate of a large coal plant may be reduced by 3-4% by switching from bituminous fuel to low sulphur sub-bituminous coal. This efficiency loss, when coupled with the expected increases in unit auxiliary power which are required when using a lower-quality coal, can result in a reduction in the plant efficiency by 5% or more. A combustion turbine based plant burning natural gas may perform 1-3% better than the same plant design burning oil. The use of sea water cooling or cooling towers also makes a significant difference. One of the main hurdles to CO_2 capture and sequestration (CCS) is the huge negative impact on unit performance which can be as much as 10%.

The term “availability” here means the percentage of energy the unit is capable of producing over any given period of time, relative to its design capacity. Availability is the resulting number after all outages and restrictions due to both planned and unplanned events, including outside events caused by e.g. nature, grid operator or lack of fuel have been deducted, given that 100% is the maximum availability.

Although there will always be unique differences between any two power plants that cannot be easily quantified, the statistical evidence clearly points to the quality of management and maintenance strategy as the key factor in determining the plant’s performance. A superior management philosophy, maintenance strategy and personnel will achieve consistently top performance, even with a relatively poor design or difficult operating mode; whereas a weak O&M program will have poor results, even with a superior design. “What you do with what you get is much more important than what you get to begin with”.

There is no simple way to measure overall plant performance, nor is there a single indicator which could be used for this purpose. The process is further complicated by the fact that in addition to high reliability, power plants must at the same time achieve a number of other objectives: economic, environmental, societal and other. These objectives are different for different power plants, and each plant has its own particular aspects to take into account.

As the power industry moves forward to address critical issues such as CO_2 the use of power generating facilities must be managed and operated as efficiently as possible. In addition to the large value of efficiency improvement, public scrutiny dictates the need to adequately address both performance/efficiency but also the means used for evaluating and/or understanding efficiency trends and expectations. The degree of improvements that can be rationally assessed in generation is dependent on asset role, age/condition and the viability of investing additional capital to improve performance/efficiency. As an example, it may be a perfectly valid goal for a simple performance improvement initiative to “maintain plant heat rate at current levels for the next 3 years.” A more aggressive goal may be to “improve heat rate by 1%”. Finally, a goal that would almost always require significant capital improvements and/or major maintenance may be to “improve heat rate by 5%.” Clearly, different circumstances in terms of value of asset, life expectancy, market, and other factors will strongly influence what the rational expectation should be on a facility to facility basis.

With the myriad of challenges in understanding plant efficiency, power generators need a more convenient and transparent way to monitor, track, compare and forecast plant efficiency. They need the ability to compare

Efficiency ranking of coal-fired power plants, December 2015

Country	Value
Russia	23.9%
Slovakia	26.7%
Bulgaria	27.9%
Czech Rep.	29.5%
Romania	29.7%
Estonia	29.9%
Ukraine	30.0%
Kazakhstan	30.3%

Country	Value
Austria	42.9%
Japan	41.9%
Ireland	41.6%
Netherlands	41.1%
Belgium	40.9%
France	40.2%
Denmark	39.5%
Taiwan	39.2%

Power Plant Performance: Efficiency & Availability

In the ongoing international efforts to curb GHG emissions in power generation, which together with heat production today account for over 20% of all anthropogenic GHG emissions, improving efficiency of power plants is often considered a panacea. Higher efficiency would certainly be a win-win outcome but how can it be achieved, at what cost and why is it not happening? The World Energy Council as the leading global multi-energy organisation with members in nearly 100 countries around the world, including the majority of largest utilities, grid operators, research institutions and energy companies provides strategic insight and factual information based on the expertise and experience of its members. This report is a summary of the main factors which have impact on power plant performance.

POWER PLANT PERFORMANCE ASPECTS

Fossil fuel-fired power plants today dominate electricity production worldwide delivering over 65% of the total electricity supply, with coal-fired power plants accounting for about 40% of the total. Their average efficiency (amount of fuel to deliver a unit of electricity) is based on the technology, fuel quality, age of the plant and other variable factors. The average efficiency of all thermal power plants running on fossil fuels (coal and gas) is around 33%.The most advanced fossil fuel-based generation technologies can with today's technology achieve efficiencies of 47-49% using coal and over 60% using gas.

If all coal and gas-fired power plants in the world used the Best Available Technologies (BAT), it would be possible to save approximately 30% of total global coal consumption each year, thus decreasing the required installed generation capacity of coal-fired power plants by 500GW. In addition, this would also save about 30% of the current global natural gas consumption and decrease the demand for power generating capacity by further 300GW of gas-fired power plants.

There are a number of factors affecting the overall performance of power plants, the main being their physical design and technology, on the one hand and operational practices, on the other. Technology and design are basic parameters determining the efficiency, which cannot be easily modified, while availability, i.e. readiness to supply electricity when needed mainly depends on operational practices which plant management can control. WEC has calculated that by improving the availability/performance of existing power generation park around the world to the availability levels currently attained by the top 25% of plant operators, the power industry worldwide could save approximately 80 billion US dollars per year and avoid about one billion tonnes of CO_2 emissions. Moreover, this could be achieved at the cost/benefit ratio of 1 to 4, and would require only some equipment replacements.

Main savings would come from the improvement of operational practices and managerial decision-making. Staff qualifications, maintenance strategy and fuel quality play a major role Analytical studies and documented practical experience demonstrate that technology/mode of operation account for 20-25% of the overall improvement, while human factors/management for 75-80%.

POWER PLANT EFFICIENCY

It is often assumed that the calculation of power plant efficiency is a simple and definitive process. This is not the case, however, particularly for large and complex systems. Plant efficiency values from different plants in different regions are often calculated and expressed in different terms, and using different assumptions.

Understanding and comparing efficiency across power generation assets is a very challenging task, since it needs a significant number of different input variables, including technology, mode of operation, fuel used, unit size and age. The basic concept seems simple. In practice, however, measuring generating efficiency is a more difficult task than one might think. There are many reasons for this, not the least, asset diversity and normal estimated asset degradation.

From the perspective of setting improvement targets, even a comparison of a unit to its own historical or design performance is a challenge due to changes in operational regimes, plant modifications made to address environmental regulations, normal degradation, changes in fuel quality/sourcing or equipment upgrades. Comparison of a particular unit to its "peers" is further challenged by the large diversity of plant design configurations and the non-standard protocols for plant data, instrumentation and performance calculations. Unit-level performance calculations tend to be highly customised, resource-intensive and not well suited for producing centralised performance metrics.

The terminology used in the United States and a few other countries is also different from the rest of the world. While in North America boiler and plant efficiency are reported on a higher heating value or gross calorific value basis, which for a combustion unit means that the latent heat of vaporisation of moisture from the fuel is recovered, most of the world refers to boiler and plant efficiency on a lower heating value or net calorific value basis. Neither metric is "right" or "wrong," but it is important to compare apples to apples.

The primary metric of unit efficiency used in the industry is the heat rate of the unit, which is a ratio of the energy required to produce a unit of electricity – such as how many Btu/h or MJ/s of fossil fuel are required to produce 1kW of electricity at the generator terminal. Design heat rates vary significantly based on plant type. Within each category, actual heat rates may vary by as much as 10-15% from factors including base or peaking load, load gradients, normal degradation, fuel source, how well the plant is operated and other indicators.

As an example, the heat rate of a large coal plant may be reduced by 3-4% by switching from bituminous fuel to low sulphur sub-bituminous coal. This efficiency loss, when coupled with the expected increases in unit auxiliary power which are required when using a lower-quality coal, can result in a reduction in the plant efficiency by 5% or more. A combustion turbine based plant burning natural gas may perform 1-3% better than the same plant design burning oil. Another factor affecting many coal plants is the addition of emissions control equipment such as SCR systems and flue gas scrubbers which may result in performance penalties of 1-2% for reducing SO_2 emissions. The use of sea water cooling or cooling towers also makes a significant difference. One of the main hurdles to CO_2 capture and sequestration (CCS) is the huge negative impact on unit performance which can be as much as 10%.

Engineers responsible for plant performance are often being haunted by management's question "How does heat rate look today?" In simple terms, measurement of heat rate is as simple as its definition: take the total number of Btu or MJ of fuel the plant has purchased from various suppliers and divide by the total number of MWh of electricity the plant has supplied into its transmission system. This method of calculating heat rate is generally referred to as the "input/output method". Although it looks simple, if measuring heat rate over longer periods of time, measuring it on a daily or hourly or real-time basis is not.

There are two primary challenges to the simple input/output method of determination. One primary challenge is related to the numerator since the solid fuel flow (Btu/h or MJ/s) cannot be measured easily and typically causes a 3-8% uncertainty in the resulting heat rate. Fuel source variability can be very large in some cases, especially when fuels are blended or the unit co-fires waste such as rubber from spent tyres or wood waste from paper mills, which makes the challenge of accurate measurement even greater.

The other primary challenge is related to the denominator since some plants produce more than just electricity, power plants also provide steam or hot water to another facility, process, or municipal heating system. So comparing this plant to others in terms of electricity production heat rate requires correcting for the amount of process heat. Another challenge is that the IO method does not tell you *why* heat rate changed. Was it due to turbine degradation, boiler efficiency or auxiliary power? Since the entire plant is analysed as a unit, it is impossible to determine the root cause of the heat rate differential.

When better than 3-8% uncertainty is required (which is nearly ALWAYS the case when heat rate needs to be understood in shorter timeframe), an indirect method called the "heat loss method" is used. The heat loss method focuses on measuring the efficiency of the major energy conversion blocks of the power plant: the boiler, which converts fuel heat into steam; the turbine, which converts steam into work; and the generator, which converts work into electricity. The fuel flow is calculated from the total Btu/h of steam energy produced by the boiler, divided by the boiler efficiency. Total steam energy produced is calculated from a heat balance of the boiler water/steam flows.

Boiler efficiency is calculated (and this is where the term “loss” comes from in the definition) based on taking 100% and subtracting from it 10-20 different individually calculated heat losses or credits. This method is documented in detail by the American Society of Mechanical Engineers within a series of Performance Test Codes called PTC 4.

Although the heat loss method is an improvement on the input/output method for calculating heat rate, it nonetheless will still result in a 1-2% uncertainty. This sounds insignificant, but for an average 500 MW plant that 1.5% uncertainty in heat rate equates to over US$1 million in annual fuel cost.

POWER PLANT AVAILABILITY

An article published in the Wall Street Journal says: “Business today is awash with data and data crunchers, but only certain companies have transformed this technology from a supporting tool into a strategic weapon. Their ability to collect, analyse and act on data is the essence of their competitive advantage and the source of their superior performance”.

The term “availability” here means the percentage of energy the unit is capable of producing over any given period of time, relative to its design capacity. Availability is the resulting number after all outages and restrictions due to both planned and unplanned events (except for dispatch requirements and depending on definition also outside events caused by e.g. nature, grid operator or lack of fuel) have been removed, given that 100% is the maximum availability.

Although there will always be unique differences between any two power plants that cannot be easily quantified, the statistical evidence clearly points to the quality of management and maintenance strategy as the key factor in determining the plant’s performance. A superior management philosophy, maintenance strategy and personnel will achieve consistently top performance, even with a relatively poor design or difficult operating mode; whereas a weak O&M program will have poor results, even with a superior design. “What you do with what you get is much more important than what you get to begin with”.

Nearly all organisations that need to forecast a plant’s future performance will need to devote much more time and energy to evaluating the quality of the plant’s O&M programme and management methods. And much more analytical research is required in order to identify the characteristic superior management and quantify their impact on plant performance.

There is no simple way to measure overall plant performance, nor is there a single indicator which could be used for this purpose. The process is further complicated by the fact that in addition to high reliability, power plants must at the same time achieve a number of other objectives: economic, environmental, societal and other. These objectives are different for different power plants, and each plant has its own particular aspects to take into account.

BENCHMARKING

What is meant by “benchmarking”? It is one of the most useful analytical tools for improving availability of power plants. The benchmarking process simultaneously evaluates the impact which design and operational variables have on the reliability of an electric generating unit or group of similar units. The process uses the design characteristics and operational factors of the target unit groups as its starting point. The result is a statistically valid group of units with similar design and operational variables. Within the peer unit grouping, the units are not the same, but they are not different enough to be different. Careful selection of design and operational variables is the key in defining an appropriate peer group. The benchmarking process provides a repeatable, statistically valid means of defining the peer group.

Benchmarking and other similar techniques that focus on comparison of unit performance against that of its peers, remain an invaluable aid for discovering and realising performance improvement opportunities. Benchmarking is heavily relying on the availability of operational and historical information and the important components design to forecast the performance. The WEC Performance of Generating Plant Knowledge Network runs a database demonstrating the use of plant availability data.

Different maintenance practices and major overhaul frequencies have significant impact on unit performance and, hence the unit’s heat rate. Different markets will yield different rates of return on heat rate improvement and thus, result in dramatically different perspectives and actions across plants. To illustrate the natural degradation of an asset, for example, a coal power plant heat rate will typically degrade by 100 to 150Btu/kWh over a period of 5 years from normal wear and tear; in some cases this deviation can even approach 400 Btu/kWh. No plant is immune to normal degradation and any performance improvement programme needs to take into account an expectation of degradation. The degree of degradation can also be significantly affected by variations in fuel, fouling, load and frequency of starts. Such data is rarely available for peer units and even if such data were available, it still would be very difficult to estimate the consequences of such impacts.

REGULATION

Regulations for different parts of the energy value chain usually come in groupings which cover or have impact on more than one specific factor. For example, regulations such as Renewable Portfolio Standards (RPS) will also impact energy efficiency of traditional assets by impacting their roles in merit/dispatch order. Some conventional coal or combined-cycle assets may be required to run less, more in terms of intermediate load during certain demand period. Renewables are dispatched before fossil-fired units and energy variations from dynamic nature of the wind/solar assets are currently balanced out by relying on conventional coal/CC generation. These recent changes in roles of power plants impact both the nature of the load as well as the number of hours units run at partial load – both factors have a significant negative impact on heat rate and availability.

SELECTION AND ACTION

The ability to understand the magnitude of opportunity associated with improved plant performance is unquestionably a key challenge for the foreseeable future, given the critical role of existing plant to both produce needed power within the constraints of environmental performance objectives and maintain security of supply and profitability. The ability to evaluate one's performance in the context of its peers will be key. The industry's challenge is to continue to find ways to not only collect and analyse the necessary data but also to provide the framework for which to extend the analysis across markets, technology choices, and across financial realities.

One crucial factor to consider when comparing generating assets is that all metrics of efficiency are compared on an equal footing. As happened in 1999 the loss of the NASA Mars Orbiter, using two different metrics for the same task without being aware of the difference can result in disaster.

AND THE FUTURE

As the power industry moves forward to address critical issues such as CO2, use of power generating facilities must be managed and operated as efficiently as possible. In addition to the large value of efficiency improvement, public scrutiny dictates the need to adequately address both performance/efficiency but also the means used for evaluating and/or understanding efficiency trends and expectations.

The degree of improvements that can be rationally assessed in generation are dependent on asset role, age/condition and the viability of investing additional capital to improve performance/efficiency. As an example, it may be a perfectly valid goal for a simple performance improvement initiative to "maintain plant heat rate at current levels for the next 3 years." A more aggressive goal may be to "improve heat rate by 1%". Finally, a goal that would almost always require significant capital improvements and/or major maintenance may be to "improve heat rate by 5%." Clearly, different circumstances in terms of value of asset, life expectancy, market, and other factors will strongly influence what the rational expectation should be on a facility to facility basis.

With the myriad of challenges in understanding plant efficiency, power generators need a more convenient and transparent way to monitor, track, compare and forecast plant efficiency. They need the ability to compare efficiency of their assets to other assets in their fleet; to similar assets beyond their fleet; to the entire market.

CONCLUSIONS

Key factors influencing plant performance should be identified and analysed to allow a cost/benefit analysis of any activity/programme before its implementation.

Heat rates are important measures of efficiencies and should continue to be measured. However, heat rates should not be used for comparing one generating unit against other. Operating and design factors have a big impact on heat rates.

Heat rates are not constant and are not controlled solely by the unit operators but also by dispatch and operating conditions. The best way to compare your generating unit heat rate is against itself for heat rate changes and efficiencies.

To analyse plant availability performance, the energy losses/outages should be scrutinised to identify the causes of unplanned or forced energy losses and to reduce the planned energy losses. Reducing planned outages increases the number of operating hours, decreases the planned energy losses and therefore, increases the energy availability factor. Planned outages increase the dispatch opportunities, while operating hours must not necessarily increase, as increased dispatch gives more flexibility and possibilities than just operation and is therefore worth more.

Reducing unplanned outages results in safe (security of supply) and reliable operation and also reduces energy losses and increases energy availability factor. At the same time, it reduces costs for replacement electricity.

The industry has transitioned from base-load conventional generation to base-load, mid-merit and peaking generation with a need to include a full range of renewable technologies. The focus areas today cover technologies, management/maintenance practices, regulatory frameworks, environmental compliance, efficiency and lifecycle costs.

With the increased emphasis on renewable energy, retirement/reduction of conventional generation, and most recently, greater focus on greenhouse gas emissions and climate change, most critical performance metrics now revolve around efficiency, renewables contribution and overall “ability” of combined Generation+Transmission+Distribution to deliver cost-effective, increasingly sustainable energy to end users.

The primary reason why many developing countries have poor performance (availability and efficiency) is due to poor O&M practices, often due to severely constrained resources (manpower, money, time). New more efficient technologies usually require more sophisticated O&M practices to achieve their inherent performance potential. Therefore, significant effort should be made to address this problem. Judging from the experience, most generating companies with limited resources spend them on availability projects and let efficiency projects wait.

PGP focus on PERFORMANCE remains an invaluable resource in achieving greater understanding of this issue or other issues in the context of other drivers, technology limitations, economics and other realities. In simple terms, performance must be considered and evaluated holistically (i.e. to be able to see/understand all of the pieces of the puzzle), to be able to evaluate and influence individual performance outcomes.