Steam Turbine Performance Improvements Through R&M

EEC WORKSHOP
16.09.2013-17.09.2013

PERFORMANCE ENHANCEMENT THROUGH TECHNOLOGY UPGRADATION

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- ✓ On average Coal fired units have a life term of 25-30 years.
- ✓ Units which are older than 30 years are in the capacity range of 60 -110 MW and mostly are being phased out.
- ✓ A good number of 200 MW units would have completed 30 years & operate at efficiency levels less than 30%.
- ✓ Performance of these units can be improved by retrofitting improved technologies.

General Comments

- Utilities must upgrade old plants to improve efficiencies to reduce (O&M) costs.
- Overall efficiency of a Thermal power plant strongly depends on the turbine’s performance.
- For some aging steam-turbine power plants, it may be more cost-effective to upgrade existing steam turbines rather than replace them.

Turbine Cycle Improvements.

- Turbine Performance degrades with time.
- Machines with a higher VWO Capability are operated at nominal loads under degraded conditions.
- Deterioration in efficiency would be known only from specific assessment tests.
- Many a Capital Overhauls scheduled for Turbine refurbishment go unused due to non availability of spares for recovery of Heat rate loss.

Scope of Improvements in Boiler Island

- Coal transport, conveying and grinding
- Boiler operation.
- Overhaul with new heat transfer surface
- Neural network (NN) control system
- Intelligent soot blower (ISB) system
- Air heaters
- Variable-frequency drive (VFD) motors on all major rotating equipment (usually improves efficiencies at lower than full load).

Scope of Improvements Turbine Island

- Turbine
- Feed water heater
- Condenser
- Turbine drive/motor-driven feed pump.
- Water treatment system
- Boiler water treatment
- Cooling tower

Boiler Furnace Modifications

- The furnace of a power plant boiler is the most significant component of a power plant affecting the thermal performance, apart from the steam turbine generator.
- The design of furnace of a boiler typically was based on a specific design fuel for base load operation.
- Replacement of the original design coal with poor fuels is very much prevalent in Indian context and it has affected thermal performance of Steam Turbines .
- Hardly any boiler has undergone major alterations in Boiler Furnace for Indian Power Plants in order to improve performance due to lack of incentives.

Intelligent Soot Blowing System

- The use of Intelligent Soot Blowing systems for improving system efficiency enhances the performance of the furnace and Steam Turbines.
- ISB system functions by monitoring both furnace exhaust gas temperatures and steam temperatures.
- As ash build up on heat transfer tubing, from the super heaters to the economizers, the transfer of heat from flue gas to the tubing is reduced, adversely affecting steam conditions.
- Concept of using ISB on real-time basis to identify affected areas that require soot blowing is some thing which needs to be demonstrated for Indian sub bituminous coals.
- Most of the station practice Soot Blowing in Manual.

R&M must address these operational issues.

- Variation in Steam Temperature & pressures due to load variation.
- Variation in flue gas oxygen content due to changing load and change in coal quality.
- Less than optimum operation of Feed water heaters and Air Pre heaters.
- Off design steam conditions due to normal inaccuracies in commercial instruments.
- Losses during startup and shut down.
- Off design SH & RH sprays.
- High make up water due to passing of drains and leakages.

Pushing Efficiency Goals

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- Computer-optimized turbine design and material improvements have enabled turbine manufacturers to reach goal of 50 percent efficiency.
- Turbine manufacturers have mostly overcome the problem of stationary blade losses, by optimizing the design of the nozzle profiles.
- Using computer-aided tools, a completely new generation of more efficient blades have been developed for retrofitting existing steam turbines, to achieve higher generation efficiencies.

Pushing Efficiency Goals

- Improvement in turbine performance has resulted from developments in modern blading.
- The reduction in wetness of steam conditions in low-pressure turbine sections has resulted in lower erosion.
- Such improvements have increased turbine efficiency up to 10 percent and reduced downtime and maintenance costs

Improving Cycle Efficiency

- Steam turbine manufacturers have developed components such as rotors and casings using advanced materials that have improved resistance to corrosion.
- To cut steam turbine losses, which contribute to decreased power availability, turbine manufacturers now supply improved turbine seals and sealing systems.
- There are a number of measures power producers can take to improve the efficiency of their existing systems,
- including: optimization of auxiliary power requirements and individual component configurations.

Improving Cycle Efficiency

- The four primary causes of losses in steam turbine efficiency and performance are,
- Chemical deposits in the steam path; nozzle and bucket surface erosion; mechanical damage to nozzles and buckets due to foreign objects;
- Steam leakage through the unit's shaft packing, tip seals, and inlet steam pipes – with packing and tip seal losses accounting for more than 50% of a steam turbine's efficiency losses.
- As steam turbines ages, extreme operating temperatures and other conditions gradually cause internal components to deteriorate, resulting in losses.

Evaluating Performance Impacts

- Specific system conditions that a Station must evaluate to improve steam turbine efficiency include:
- Poorly maintained steam seals; eroded/damaged first stage nozzle block; damaged rotating elements and diaphragms;
- Feed water heaters in/out of service; reduced load operation; manual turbine control; valve and horizontal joint leakages;
- Turbine operation at unusually low steam flows; and operating low pressure turbines in condensing mode.

Turbine Upgrades & Improvements

- The typical turbine upgrade depends on the case history of the turbine itself and its overall performance.
- For a Unit of 500-MW which is 30 years old, the typical performance improvements of the high-pressure (HP) and low-pressure (LP) units range from 2-3%pt and the intermediate pressure (IP) units range from 1-2%pt, totaling 2-3% in overall power generation.
- These upgrades take into account the loss in performance over time (degradation).
- If the improvements are compared with the original design basis, they generally range from 1-2%pt for the HP and LP units and 1%pt for the IP units, totaling 1-2%pt in overall power generation.

Turbine Upgrades & Improvements

- Significant increases in performance can be gained from turbine upgrades when plants experience problems such as steam leakage and blade erosion.
- In such cases, except for the outer casing, the entire turbine might have to be. replaced, which would yield improvements in turbine efficiency above 5% pt and, in extreme cases, can be over 10%pt.
- Such large improvements (>10%pt) in efficiencies are not the norm .

Feed Water Heaters

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- Feed water heaters are used within a power plant's thermal cycle to improve overall efficiency.
- The number and placement of feed water heaters are determined during the original plant design and are highly integrated with the overall performance of the steam turbine.
- Feed water heaters preheat the boiler feed water prior to it entering the boiler for steam generation.
- The heat used to increase the feed water temperature comes directly from the thermal cycle, as steam extracted from various turbine sections.

Feed Water Heaters

- The feed water heaters in a power plant are either LP or HP shell and tube heat exchangers.
- The primary means of improving the operation of such heat exchangers is to maintain their operational effectiveness.
- Feed water heating surface could be added to improve efficiency.
- The costs associated with either increasing the heat transfer surfaces of existing heaters, or adding additional heaters for efficiency , is prohibitive due to the small incremental reductions in heat rate that would be obtained

Surface Condensers

- Effective operation of the steam surface condenser in a power plant can significantly improve the heat rate of a unit.
- It can pose the most significant hindrance to a plant trying to maintain its original design heat rate.
- Since the primary function of the condenser is to condense steam flowing from the last stage of the steam turbine to liquid form.
- It is most desirable from a thermodynamic standpoint that this occurs at the lowest temperature .
- By lowering the condensing temperature, the backpressure on the turbine is lowered, which improves turbine performance. A condenser degrades primarily due to fouling of the tubes and air in-leakage.

Surface Condensers

- Tube fouling leads to reduced heat transfer rates, while air in-leakage directly increases the backpressure of the condenser and degrades the quality of the water.
- If once-through cooling is used, fouling of condenser tubing can be substantial.
- But if a closed cooling system is used, cooling water quality can be controlled to a much higher degree.
- Condenser tube cleaning can be performed while the unit is on line or off line.
- Generally, the historical standard method of online cleaning has been to use circulating rubber sponge balls that flow through the condenser tubes with the coolant.

Variable Frequency Drives

- Due to current electricity market conditions, many units no longer operate at base-load capacity and, therefore, VFDs, also known as variable-speed drives (VSDs) can greatly enhance plant performance at off-peak loads.
- VFDs can significantly improve the unit heat rate.
- VFDs as motor controllers offer many substantial Improvements to electric motor power requirements.
- The drives provide benefits such as *soft starts, which reduce initial electrical load, excessive torque.*
- Wear during startups; provide precise speed control; and enable high-efficiency operation of motors at less than the maximum efficiency point.

Variable Frequency Drives

- During load turndown, plant auxiliary power can be reduced by 30-60% if all large motors in a plant were to be controlled by VFD.
- With unit loads varying throughout the year, the benefits of using VFDs on large-size equipment, such as FD or ID fans, boiler feed water and condenser circulation water pumps, can have significant impacts.
- Because plants today usually use either new booster ID fans or new ID fans, the option of investing in VFDs generally appeals to plant operators since they are incurring long outages to install the either new or additional air emission controls equipment.
- Depending on plant configuration, the improvement in heat rate can range from 20-100 Btu/kWh.

Variable Frequency Drives

- There are circumstances in which the heat rate improvement has been estimated to be much higher, depending on the operation of the unit.
- Cycling units realize the greatest gains representative of the upper range of heat rate improvement, whereas units which were designed with excess fan capacity will exhibit the lower range.
- Heat rate improvements will vary when the VFD is compared to a single- or dual-speed motor with VIVs.
- The costs associated with the O&M portion of the VFDs account for partial electronics replacement and can vary significantly due to a vendor's commercial offering

Variable Frequency Drives

- The use of VFDs are also applicable with boiler feed water pumps.
- Generally, if a unit with an older steam turbine is rated below 350 MW the use of motor-driven boiler feed water pumps as the main drivers may be considered practical from an efficiency standpoint.
- If a unit cycles frequently then operation of the pumps with VFDs will offer the best results on heat rate reductions, followed by fluid couplings.
- The use of VFDs for boiler feed pumps is becoming more common in the industry for larger units. And with the advancements in LP steam turbines, a motor-driven feed pump can actually improve the thermal performance of a system up to the 600-MW range versus turbine drive pumps.
- As for smaller and older units, an upgrade to a VFD boiler feed pump drive generally does not occur due to high capital costs.

Boiler Water Treatment System

- Reduction of power plant heat rate as related to cooling systems and water treatment primarily involves
- Maintaining the proper water chemistry to reduce boiler scale and the amount of boiler water blow down needed to control solids and impurities.
- Boiler scale lowers heat transfer due to low thermal conductivity. Heat transfer may be reduced as much as 5-10% by the presence of scale.
- A scale approximately 1/8-inch-thick may cause an overall loss in boiler efficiency of about 2-3% in fire tube boilers, as well as in the convective sections of water-tube boilers.
- More important than the heat loss is that scale can cause overheating of the boiler tube metal and can result in subsequent tube failures, leading to costly repairs and boiler outages.

Boiler Water Treatment System

- Iron and copper content in condensate can corrode condensate systems. This reduces heat transfer efficiency and could cause tube failure.
- Condensate corrosion control is required to protect process equipment, lines, tanks, as well as to maintain the condensate as a quality feed water source.
- Condensate system corrosion can result in increased maintenance and equipment costs, energy loss through steam leaks, and loss of process heat transfer efficiency.
- To prevent condensate corrosion, volatile neutralizing amines, such as cyclohexylamine, morpholine, and diethylamino ethanol, typically are used to neutralize carbonic acid and raise the condensate pH.

Boiler Water Treatment System

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- A blend of several amines will ensure that corrosion protection is distributed throughout the entire steam/condensate system.
- The use of filming amines present an alternative or additional condensate treatment process in which the compounds protect the metal components by adhering to the surface and providing a protective layer.
- High-purity water provides for greater boiler cycle concentration, thus reducing water and energy losses to blow down. Savings will be realized in reduced use of water treatment chemicals and water. High-quality water for the thermal cycle can somewhat reduce the blow down required.

Boiler Water Treatment System

- By reducing the blow down amounts, more steam is available in the thermal cycle, thereby improving overall power plant efficiency and reducing heat rate.
- The majority of utilities are aware of boiler chemistry and its associated issues.
- Most power plants already have the most advanced water treatment systems installed, leaving minimal opportunity for further improvements regarding new technology.
- The primary means of improvement relate to careful monitoring and maintenance of the water treatment systems for optimal water quality

Boiler Water Treatment System

- Cooling tower water quality not only affects O&M costs of the cooling tower, it enables up gradation of advanced cooling tower packing.
- Advanced packing increases the overall thermal efficiency of the tower by increasing mass transfer efficiency.
- The high efficiency fills are more susceptible to fouling than are older style splash fill towers.
- Water quality factors affecting cooling towers are those that lead to deposition on the cooling tower packing, such as suspended solids.
- Those leading to cooling tower surface scaling include water hardness and biological fouling.

Boiler Water Treatment System

- All three contaminants - deposition, scaling, and biological fouling - contribute to plugging of CT fill.
- Suspended solids in the cooling tower makeup water may be treated by a clarifier. The 10-15 ppm of suspended solids that is commonly the guaranteed effluent quality from a clarifier is more than sufficient for cooling tower makeup water.
- The scaling tendency of water can be estimated based on the pH, alkalinity, calcium concentration, and temperature of the water using scaling indices, such as the Langelier saturation index (LSI).
- The LSI indicates the number of pH units the solution must be lowered in order to prevent scaling. The change in pH typically is affected by injection of an acid, such as sulfuric acid.

Cooling Water Treatment

- Care must be taken to prevent over-injection of acid as that may corrode the internals of the cooling tower and circulating water heat exchange surfaces.
- Due to the recent increase in the cost of sulfuric acid, specialty chemical suppliers offer alternatives to straight acid injection to prevent cooling tower scaling.
- These chemical blends are tailored to the makeup water chemistry specific to the plant. Currently, there is no single chemical blend that would be applicable to all plants for scaling control.
- Sodium hypochlorite (bleach) is the industry-standard chemical for biological fouling control. Bleach is injected either continuously at 1-2 ppm or injected at a *shock dose of 5 ppm for 90 minutes 3 times per week.*
- *Bleach is* effective in preventing biological fouling due to microscopic organisms, such as the bacteria that lead to Legionnaires’ disease, and macroscopic fouling, such as Asiatic clams and zebra mussels

Cooling Water Treatment

- It is important to note that when selecting more efficient fills, fouling degrades the effectiveness of the fill.
- So any increase in efficiency gained by the use of high-efficiency film fill can be forfeited through the mismanagement of cooling tower chemistry.
- In general, by properly maintaining the quality of a power plant cooling water system, adequate efficiencies may be obtained for the thermal cycle.
- Because the proper maintenance of water quality in the cooling system is not always rigorously monitored, many plants have relied on condenser fouling as the primary means of measuring performance decreases indirectly due to water quality.
- Additionally, advanced cooling tower packing cannot be used unless the water quality meets a certain standard.
- This also renders water quality itself an indirect factor in heat rate improvement, and one that is difficult to quantify.

ADVANCED COOLING TOWER PACKING

- Wet cooling towers function by utilizing the cooling effect of evaporation and to a lesser extent, the transfer of heat from the water to the ambient air through direct contact.
- The mass transfer from the liquid phase into the vapor phase, and therefore the decrease in temperature, due to evaporation, is strongly dependent on the contact surface area between the ambient air and the water.
- Cooling tower manufacturers increased the mass transfer area by spraying the cooling water onto planks of redwood to break the water droplets into smaller droplets and coat the surface of the planks with water.
- The planks were arranged such that ambient air was drawn across the planks and then up trough the cooling tower fan.

ADVANCED COOLING TOWER PACKING

- This is known as a *cross-flow cooling tower since the air primarily* contacts the water in a horizontal cross flow arrangement.

- Cooling tower manufacturers have, within the last 20 years, altered the configuration of new cooling towers to a counter-flow design, where air and cooling water flow counter-currently through the tower, air flowing up and water flowing down.

- The counter-flow configuration provides an increase in the cooling tower thermal efficiency. Cross-flow and counter-flow cooling tower designs enable the implementation of more advanced film fill packing material.

- The film fill packing configuration, which provides increased heat and mass transfer between the air and water, can reduce the height (total amount) of packing required .
- It lowers the fan power requirements due to a lower total air flow friction and water pumping requirements .
- The reduced pressure drop is probably the most significant form of heat rate reduction to be achieved from such a project due to the lower power requirements of the fans.
- Increasing the total amount of packing and thereby lowering the temperature of the water through the condenser can also have a significant impact on the heat rate of the unit.

- An optimization study between fan power reductions and cooling water temperatures should be conducted to investigate the most effective use of upgrading a cooling tower fill .
- The implementation of VFDs for cooling tower fan control can also enable power reductions if the older fans were not replaced during a packing upgrade and there is significant margin in fan capacity.
- The reduced pressure drop due to the new packing would enable the use of VFDs to efficiently control the speed of the fans and reduce power consumption.
- The application of VFDs on cooling tower fans can also be capitalized upon during seasonal operation when ambient temperatures are significantly cooler.
- A cycling unit with a wet cooling tower will also benefit from VFDs being used with the cooling tower due to the lower thermal demand on the tower and subsequent reduced fan loads

Turbine Cycle Improvements

- Turbine Performance degrades with time.
- Machines with a higher VWO Capability are operated at nominal loads under degraded conditions.
- Deterioration in efficiency would be known only from specific assessment tests.
- Many a Capital Overhauls scheduled for Turbine refurbishment go unused due to non availability of spares for recovery of Heat rate loss.

Auxiliary Power Consumption

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- Auxiliary power consumption is a process requirement to convert fossil fuel into Electricity- a most efficient form of Energy
- Aux. Power consumption as a %age of Generation Capability decreases with increase in Unit size.
- In a 600 MW unit, with Turbo driven feed pumps – auxiliary power consumption is around 6.0% .

The breakdown of auxiliary power loads for a large coal-fired power plant is presented in the Table . The feed water system loads are determined by operating parameters of the Rankine cycle (where boiler feedwater pump power depends on the main steam pressure), and there is little opportunity for reducing these auxiliary power loads except in the selection of drives. The feed water system loads include the main feedwater pumps and condensate booster pumps. Auxiliary power use in coal-fired power plants by technology.

Component	Technology			
	Subcritical	Supercritical	Ultra-supercritical	Future ultra-supercritical
Feedwater system	32.2	40.9	42.2	48.3
Cooling water system	17.1	14.9	14.6	13.0
Pollution control system	13.3	11.6	11.4	10.2
Combustion air and flue gas	18.8	16.4	16.0	14.3
Fuel handling	5.0	4.3	4.2	3.8
Other loads	13.6	11.9	11.6	10.4
Total	100.0	100.0	100.0	100.0

BOILER FEED PUMP

Boiler feed pump is not a boiler auxiliary and its power consumption varies in response to turbine mode of working and its degradation

BFP Power consumption can be optimized using variable pressure operation; reduction of spray rates would also help.

BOILER FEED PUMP

BFP Power consumption constitute a major chunk of power consumed by unit auxiliaries.

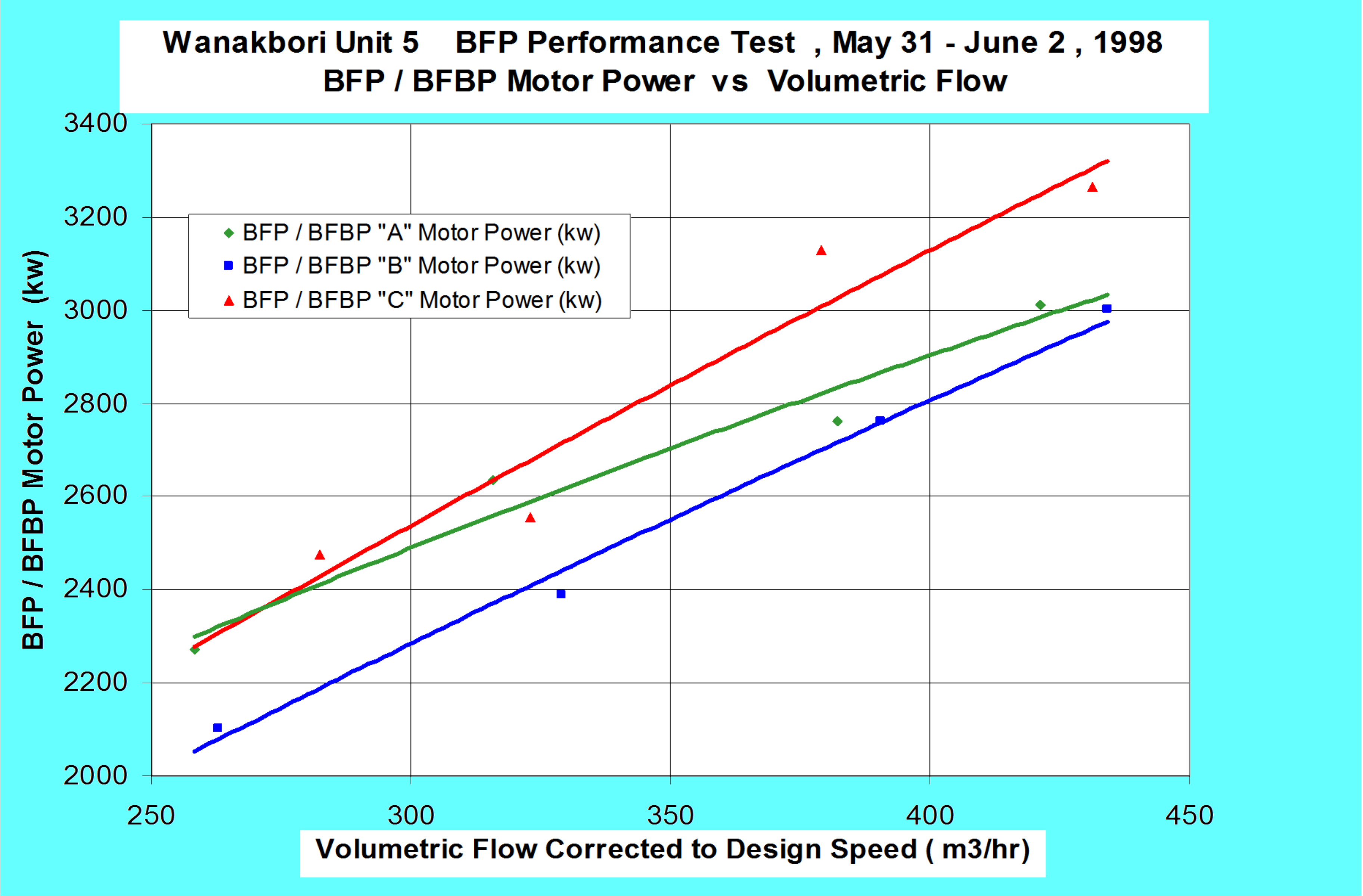
Usage of steam driven feed pump results in reduction of apc %.

Usage of turbo driven feedpump improves cycle efficiency .

Any feedback on tdbfp performance due to condenser degradation !

Boiler Feed Pump Performance Testing

BFP	Flow t/hr	Train Efficiency %	Power Consumption kw	BDLO flow t/hr
A	327	61	2761	29.4
B	337	62	2760.8	28
C	319	51.4	3128	42.2



Wanakbori Unit 5 BFP Performance Test , May 31 - June 2 , 1998
BFP / BFBP Motor Power vs Volumetric Flow
BFP / BFBP "A" Motor Power (kw)
BFP / BFBP "B" Motor Power (kw)
BFP / BFBP "C" Motor Power (kw)
BFP / BFBP Motor Power (kw)
3400
3200
3000
2800
2600
2400
2200
2000
250
300
350
400
450
Volumetric Flow Corrected to Design Speed (m3/hr)

Performance Enhancement Through Technology Upgradation – NTPC Example

- R& M route is being adopted in units taken over from Orissa & UP.
- 200 MW units commissioned by NTPC during 1980-87 are being subjected to Performance improvement through technology up gradation.
- Improved Performance Monitoring system & Controls systems have been installed.
- Capitalization of expenditures towards improvement is a necessary incentive for utility to make that kind of investment.

Conclusions

- Mega projects with super critical conditions would enhance Thermal Efficiency of New Capacity being set.
- Sustaining Optimum Efficiency of existing capacity would come through regular investment in quality Overhauls.
- Regular equipment up gradation through technology interventions would help extend unit life and mitigate CO_2 emissions as well.