Survey result report

Investigation of possibility of improving thermal efficiency and environmental performance at Durgapur Steel Thermal Power Station (DSTPS)
(Implementation of real-time unit performance management using IoT)

May 2018

New Energy and Industrial Technology Development Organization (NEDO)
Tokyo Electric Power Company Holdings, Inc.
Mitsubishi Research Institute, Inc.

Table of Contents

List of Figures

List of Tables

Summary

This project has been executed with the aim of refining the thermal efficiency management of existing coal-fired plants in India, by considering the feasibility of introducing a real-time unit performance-management system using IoT to target plants with target 500 MW subcritical units.

The Government of India announced plans to establish a target of 175 GW in cumulative renewable energy capacity by 2022, including 100 and 60 GW from solar and wind sources respectively. Low-load and load-following operation will be required, even with coal-fired power, which has been positioned as a base load power source, since solar and wind power output are particularly dependent on solar radiation and wind conditions. The background of this project is the need to improve deterioration in thermal efficiency.

After consideration of management methods which would help refine performance management to maintain and improve performance of the target units, the following were found desirable: 1. To determine performance deterioration in real time by recognizing tendencies and age deterioration status on a daily, weekly, monthly and yearly basis, 2. To use highly accurate performance test data and 3. To apply a method which manages deviation from performance reference values using the heat balance model. Using the big data the power plants when applying these management methods allows us to provide a performance-management system service utilizing IoT from Japan as a new business, which is the stand-out feature.

In developing a means of calculating greenhouse-gas emission reductions in this project, we adopted an approach of calculating the theoretical efficiency of measures to be introduced by using the heat balance model, which was then corrected based on performance tests conducted before and after introducing the measures. According to the assumption, annual CO_2 emission reductions at the units were estimated as 21,300 tons. Moreover, when the target unit continues to generate electricity, there is no room for photovoltaic power generation to supply power to the grid under specific electricity demand. However, reducing the amount of electricity generated by the target unit does free up scope for photovoltaic power generation. Given the scope to generate photovoltaic power by changing the target unit operation, it is possible to regard the amount of CO_2 reduction resulting from photovoltaic power generation as a contribution of the target unit. Calculating this contribution, the CO_2 emission reductions were estimated as 35,500 tons (56,800 tons in total). We also discussed the potential of materializing the benefits for each entity, partner country government and companies, Japanese companies and financial institutions, by quantifying the international contribution amount.

Solar and wind power generation are becoming more economically rational in many parts of the world and the introduction of solar and wind power is expanding. Areas where low-load and load-following operations are required for coal-fired power are expected to expand worldwide as well as India and there is a large potential market for this IoT service is large. This service is also expected to expand the scope to contribute in terms of emission reductions. Currently a headwind is blowing against fresh installation of coal-fired plants. However, developing this IoT service would enable the partner country to reduce CO_2 emissions from existing coal-fired power plants, promote the introduction of renewable energy and secure power supply by ensuring the business stability of utilities owning power plants. These can be considered international contribution by Japan to the partner country.

Chapter 1　Present data analysis on the target plant

1.1 The power plant surveyed

On the recommendation of the Ministry of Power (MOP) and the Central Electricity Authority (CEA), the 500MW sub-critical unit at Durgapur Steel Thermal Power Station (hereinafter referred to as "DSTPS") owned by Damodar Valley Corporation (hereinafter, "DVC") were selected as subjects of the study conducted, via analysis of the power plant operational data, to determine causes of the decline in thermal efficiency, improve the operation method and propose measures enabling to thermal efficiency to be maintained/improved by modifying equipment.

Name of Electric Power Company	Damodar Valley Corporation
Name of Power Station	Durgapur Steel Thermal Power Station
Power Station Total Output	1,000MW（500MW　X　2 units）
Performance Testing Target Unit	1
Start of Operations	May 2012
Main Fuel	Coal (Bituminous, Sub-Bituminous varieties）
Standard Output	500MW
Minimum Output (Coal Only)	300MW
Generator	Made by BHEL
Turbine	Made by BHEL
Boiler	Made by BHEL

Table 1-1　DSTPS equipment summary

Figure 1-1　Full view of the power plant and boiler building

(photo taken by the survey team)

1.2 Management conditions of operational data at the power plant

AS a DCS (Distribution Control System) is introduced in DSTPS, almost all operational data necessary for this thermal efficiency survey were conserved. The data storage period is one year or more and even hourly data were available for the units of measure.

The names used in the operational data tag lists are original to DVC and many did not correspond to those in the data list presented by the survey team. Accordingly, considerable effort was spent on analysis to check the correspondence of the data symbols.

Unit 1, the survey target of thermal efficiency analysis, underwent large-scale equipment modification during the period July to August this year and its performance was substantially improved, resulting in an anomaly in data before and after modification. Accordingly, the operational data for one month was used in the analysis, starting from the large-scale modification finish.

Data other than operational data and required for the analysis, such as power plant design data and specifications, documents showing performance curves of principal pumps, performance curves of the unit and records of periodic inspection and large-scale-equipment replacements over the past three years were also conserved. However, some data (such as "Steam condenser exhaust loss curve") were not found in the archive.

Conversely, certain elements emerged after receiving the operational data, such as the existence of operational data not sorted for the database, thus requiring considerable effort to extract and the inappropriateness of the data form for analysis: when extracted data are downloaded in Excel form, lines are inserted between the data, data are cut into parts with only five types of data appearing on a single sheet, etc. Given that it was the first time that the data had been extracted from the database, which was downloaded at the request of the survey team, we inferred that operational data analysis is highly unusual in DSTPS .

It also emerged that performance test data are not gathered with constant output values, indicating that issues remain in terms of how to set performance test conditions and collect information.

	1BFPDTB_LO _TEMP OUT AVERAGE		1HLD01CT103 _XQ03 OUT AVERAGE		1HLD01CT112 _XQ03 OUT AVERAGE		1HLD01CT104 _XQ03 OUT AVERAGE		1HLD01CT105 _XQ03 OUT AVERAGE		1HLD01CT106 _XQ03 OUT AVERAGE
10/25/2017 1:00:00AM	42.002		95.49		114.87		107.87		110.02		111.65
10/25/2017 2:00:00AM	41.996		95.06		114.17		106.73		109.21		110.47
10/25/2017 3:00:00AM	41.993		95.19		114.17		107.20		109.72		111.32
10/25/2017 4:00:00AM	42.001		94.89		113.51		106.95		109.49		111.14
10/25/2017 5:00:00AM	42.004		94.72		113.09		106.87		109.33		110.59
10/25/2017 6:00:00AM	41.995		94.94		112.98		107.08		109.48		110.80
10/25/2017 7:00:00AM	41.997		93.55		112.01		105.95		108.35		109.48
10/25/2017 8:00:00AM	42.005		94.07		112.01		106.38		108.82		110.00
10/25/2017 9:00:00AM	41.998		94.40		112.28		106.47		108.65		109.84
10/25/2017 10:00:00AM	42.003		95.62		113.51		107.98		110.32		111.44
10/25/2017 11:00:00AM	41.999		98.18		115.53		110.85		112.85		113.99
10/25/2017 12:00:00PM	42.003		99.71		116.91		112.09		114.23		115.48
10/25/2017 1:00:00PM	41.985		99.71		117.87		112.51		114.67		115.92
10/25/2017 2:00:00PM	41.987		99.83								115.85
10/25/2017 3:00:00PM	42.000		100.74								6.90
10/25/2017 4:00:00PM	42.000		100.07								6.29
10/25/2017 5:00:00PM	41.995		100.46								6.86
10/25/2017 6:00:00PM	41.998		101.49								8.52
10/25/2017 7:00:00PM	41.997		100.66								7.86
10/25/2017 8:00:00PM	41.994		98.61								5.54

The current data form prevents data analysis due to the lines inserted between the data. The DB should be modified.

Figure 1-2 Example of the operational data DB received from the DSTPS

Table 1-2 List of data necessary to analyze thermal efficiency (Part 1)

NO.	日本語名称	Description	Data collection Period	Data Interval	STATUS	
1	運転開始年と設備ベンダー名	COD year and Equipment Vender Name				
1-a	運転開始年月	COD: Year / Month			Received	
1-b	発電機：ベンダー名、定格出力	Generator: Vender Name, Rated Output			Received	
1-c	ボイラ：ベンダー名	Boiler: Vender Name			Received	
1-d	タービン：ベンダー名	Turbine: Vender Name			Received	
1-e	脱硫設備：ベンダー名	Desulfurization Equipment: Vender Name			Received	
2	設計仕様・仕様書	Design Specification・ Specification				
2-a	設計熱効率 ボイラ効率、タービン効率	Design Thermal Efficiency (Heat Rate), Boiler Efficiency, Turbine Efficiency	When starting operation	Design value	Received	
2-b	設計炭燃料性状 （高位発熱量、真発熱量、全水分、全硫黄、工業分析値、元素分析値、灰の溶融性）	Design Coal Fuel Property (component) （Gross Calorific Value, Net Calorific Value, Total Moisture, Total Sulfur, Proximate Analysis, Ultimate Analysis, Fusibility of Coal Ash)	When starting operation	Design value	Received	
2-c	タービン仕様書	Turbine Specification			Received	
2-d	ボイラ仕様書	Boiler Specification			Received	
2-e	給水加熱器仕様書	Feedwater Heater Specification			Received	Lacking data such as internal data
2-f	蒸気復水器仕様書	Steam Condenser Specification			Received	
2-g	循環水ポンプ仕様書	Circulating Pump Specification			Received	
2-h	グランド蒸気復水器仕様書	Gland Steam Condenser Specification			Received	
2-i	脱硫設備仕様書	Desulfurization Equipment Specification				
2-j	ボイラ伝熱面積、各パネルのチューブの材質・寸法・本数・配置間隔	Material, Measurement, Number of Tubes and Installation Interval of Tube of Boiler Heating Surface Area and Each Panel			Received	
3	性能試験結果及び運転データ、運転計画	Performance Test Result and Operating Data, Operating Plan				
3-a	受入性能試験成績書	Acceptance Performance Test Report (Including Results of Coal Component Analyses)	When starting operation	Design value	Received	
3-b	最新の性能試験成績書	Latest Performance Test Report (Including Results of Coal Component Analyses)	Periodic inspection	Latest value	Received	
3-c	運転データの全タグリスト（有無）	**All PID_Tag List** of Operating Data （Analog Data、Calculated Data）	**See Reference sheet (PID list of coal fired power plant)**		Received	
3-d	弊社からリクエストするタグリストの１ヶ月分データ（１時間間隔）	Actual Data from All PIDTag List (3-c) Data interval: Every hour Data collection period：1month ※a Month with long driving time at rated output	Latest 1 month	Every hour	Received	
4	修繕実績、計画	Repair Record, Repair Plan				
4-a	過去の不具合事象（ユニット停止に至った不具合）	History of Failure (Failures that led to Unit Shutdown)	All data after the start of operation			Hearing should be conducted at site survey
4-b	設備の更新履歴（大物設備を何時取り替えたか）	History of Equipment Upgrade (When main equipment were upgraded)	All data after the start of operation			Hearing should be conducted at site survey
4-c	燃料の使用実績（運開時と現在の石炭成分分析結果）	History of Fuel Component (Results of Coal Component Analyses from COD & the Latest) （Gross Calorific Value, Net Calorific Value, Total Moisture, Total Sulfur, Proximate Analysis, Ultimate Analysis, Fusibility of Coal Ash)				Hearing should be conducted at site survey
4-d	過去５年間、今後の５年間の定期点検の期間、点検範囲	Post 5 Years and Next 5 Years of Periodic Outage and its Scope				Hearing should be conducted at site survey

Table 1-3 List of data necessary to analyze thermal efficiency (Part 2)

NO.	日本語名称	Description	Data collection Period	Data Interval	STATUS	
5	図面	Drawing				
	（1） P & I D	1) P & ID				
5-a	プラント主管系統	Plant Main Tube System			Received	
5-b	蒸気配管系統	Steam Pipe System			Received	
5-c	給水配管系統	Feedwater Pipe System			Received	
5-d	復水・ 補給水配管系統	Condensate・ Makeup Water Pipe System			Received	
5-e	補助蒸気配管系統	Auxiliary Steam Pipe System			Received	
5-f	循環水配管系統	Circulating Water Pipe System			Received	
5-g	ボイラ煙風道（排煙設備含む）系統	Boiler Flue Gas / Air System (Incl. Exhaust (Flue) Gas Equipment)			Received	
5-h	運炭、灰処理、脱硫排水系統	Transporting (Handling) Coal, Ash Treatment, Desulfurization Wastewater (drainage) System			Received	
	（2） 設計ヒートバランス図	2) Design Heat Balance Drawing				
5-i	設計ヒートバランス図 （大気温度や出力別に分類されている設計図面で、発電機出力、蒸気温度・ 圧力、給水圧力・ 温度、復水器真空度など、多くのプロセスデータの運転計画値が記載されている図面）	Design Heat Balance Drawing (Design drawings which are categorized by Atmospheric Temperature or by Output including descriptions of the operating plan value(s) such as generator output, steam temperature / pressure, feedwater pressure/temperature, condenser degree of vacuum etc.)	When starting operation	Design value	Received	
	（3） 性能曲線・ 補正曲線	3) Performance Curve・ Correction Curve				
5-j	熱消費率または発電機出力補正曲線 （タービン側及びボイラ側、あるもの全部）	Heat Rate or Generator Output Correction Curve (Turbine side & Boiler side, Incl. Everything)	When starting operation	Design value	Received	
5-k	復水器性能曲線	Condenser Performance Curve	When starting operation	Design value	Received	
5-l	復水器排気損失曲線	Condenser Wastewater(Drainage) Loss Curve	When starting operation	Design value		
5-m	主要ポンプの特性曲線 （循環水ポンプ、ボイラ給水ポンプ、復水ポンプ、復水ブースターポンプ、給水ブースターポンプなど）	Characteristics Curve for Main Pump (Circulating Water Pump (CWP), Boiler Feedwater Pump), Condensate Pump (CP), Condensate Booster Pump (CBP), Feedwater Booster Pump (BFP-BP) etc.)	When starting operation	Design value	Received	
5-n	発電機損失曲線	Generator Loss Curve	When starting operation	Design value	Received	
5-o	通風機特性曲線 （押込通風機、一次通風機、誘引通風機）	Ventilator Characteristics Curve (Forced Draft Fan (FDF), Primary Air Fan(PAF), Induced Draft Fan (IDF))	When starting operation	Design value	Received	
	（4） 構造図	4) Internal Construction Drawings				
5-p	ボイラ構造図 （パネル配置が分かるもの）	Boiler Construction Drawing (Capable of confirming panel location)			Received	
5-q	タービン構造図	Turbine Construction Drawing				Hearing should be conducted at site survey
5-r	給水加熱器構造図	Feedwater Heater Construction Drawing				Hearing should be conducted at site survey
6-a	タービン仕様書	Turbine Specification document			Received	
6-b	高圧タービンの調速段有効直径 高圧タービンの調速段の有無 （不明の場合、各位置での実圧力データを受領したい）	Governing stage pitch diameter does your plant have a governing stage? If unsure, please specify pressure for each section (before MSV, after valve, before and after HP turbine 1st stage				Hearing should be conducted at site survey
6-c	低圧タービンの最終段面積 低圧タービンの最終段翼長さ 低圧タービンの排気損失カーブ	Annulus flow area of the LP turbine exhaust LP turbine last stage bucket length LP turbine exhaust loss curve				Hearing should be conducted at site survey
6-d	タービン構造図（断面図）	Turbine structure drawing (sectional view)				Hearing should be conducted at site survey
6-e	給水加熱器構造図（高圧／低圧） ・ バッフル板、デスーパー、サブクーリンゾーンに関する情報	Feed water heater construction drawing (HP and LP) (low of baffle plate, desuper and subcooling zone area)				Hearing should be conducted at site survey

1.3 Management method and measures taken to maintain/improve thermal efficiency in the power plant

Thermal efficiency monitoring, data conservation and management organization are managed on a level equivalent to that in Japan.

Checked points	Result of hearing
Daily performance management method of the unit	Performance data are shared daily in the morning meeting. Important performance data (such as High/Low pressure turbine efficiency) are: ・ Compared with design values every two weeks; ・ Reviewed every two to three months in management meetings.
DB system for operation data collection	・ The system always stores six to eight months of data. ・ Only short-term records are available due to hardware constraints. ・ The DB is not in Excel form.
Implementation of performance test before/after periodic inspection	・ Performance tests are conducted after periodic inspections. ・ The data are inaccurate because tests were conducted with loads instructed by the power system and not with constant output.
Installation of team (structure) or specialist for the performance management	A structure is installed in both the power plant and head office. Two specialists are stationed full time in the power plant.
Method to train specialists on performance management	・ A training center is installed in other power plants. ・ Training in the power plant is conducted basically on an OJT basis.
Performance test implementation procedure	・ Records are collected of 500, 450 and 400MW units. ・ Tests are conducted before/after periodic inspection; ・ Measuring equipment is calibrated yearly regardless of periodic inspection.

1.4 Equipment degradation diagnosis method and maintenance policy of the power plant

Level of equipment degradation recognition and remedial action taking was almost the same as that in Japan.

Checked points	Result of hearing
Countermeasure against performance degradation due to scaling in high/low pressure feed water heater	・ No particular measure is taken. ・ Feed water heater piping inner walls not subject to scaling because of the high quality of the boiler feed water and the closed loop system.
Countermeasure against vacuum decrease due to scaling on condenser tube inner walls	・ A ball-type cleaner is installed and operated daily. ・ Jet- or brush cleaning are conducted during periodic inspections.
What kind of check is made when vacuum decrease is observed in "n" condenser?	An air-leak test is conducted.
Performance monitoring (exhaust volume measurement) of condenser vacuum pump	・ There is no permanently installed instrument to measure exhaust volume. In case the condenser vacuum breaks, the exhaust volume is measured by a flowmeter.
Boiler soot blower operations	・ There are three types of soot blower, all of which are operated manually.
Control of clinker deposition on boiler furnace inner wall	・ There is relatively little clinker deposition (No particular monitoring measure is taken)
Method to maintain/control boiler feed water quality	・ The Ph value is controlled with hydrazine and ammonia solution injection.
Countermeasure against air heater differential pressure	・ Soot blowing, plus washing at periodic inspection.
What are the countermeasures taken when increase in air leak from air heater is observed?	・ Sealed part to be repaired after shutdown of the unit.
Management method of cooling tower performance	・ Cleaning of water tank ・ Monthly performance check is carried out.

1.5 Points and situation of KPI management in the power plant

1.5.1 Operation pattern of the power plant

DSTPS was planned and has been operated ever since it was first operated as a base load station but changing circumstances have seen it operated increasingly for load regulation purposes in response to load-dispatching instructions from the power system. Those load regulations mean more oil is consumed at start-up and increase operating costs, constituting a major issue.

The power plant is operated according to dispatching instructions given by the power system. Its recent utilization rate averages between 70 and 80%, while its daily power generation varies from 230 to 500MW depending on instructions dispatched from the system.

What the power plant needs is a set of operations adapting to changing loads rather than a base load power generation with the rated output.

1.5.2 KPI management points

Table 1-4 DSTPS Unit performance records (2017-2018)

Performance in FY 2017-18 (Till Sept'17):

Unit	Gen. (MU)	PLF (%)	DC (%)		SOC (ml/kwh)		APC (%)		Heat Rate (kcal/kwh)	
			CERC bench-mark	Actual	CERC bench-mark	Actual	CERC bench-mark	Actual	CERC bench-mark	Actual
U#1	1155	52.6	85	60.8*	0.5	0.56	5.25	5.71	2443	
U#2	1842	83.9	85	96.0	0.5	0.32	5.25	5.01	2443	2420
Station	2997	68.3	85	78.4	0.5	0.41	5.25	5.28	2443	

*Unit#1- AOH carried out in the month of July-Aug'17

< Glossary >

(1) PLF (Plant load factor) (%): Calendar-day hourly utilization rate

(2) DC (Declared Capacity) (%): Synonym for "availability"

Note: It may decline for various reasons, such as maintenance shutdowns, constraints due to coal storage, etc.

(3) SOC (Specific Oil Consumption) (ml/kWh): Consumption rate of light fuel oil for supplementary firing per generated energy

(4) APC (Auxiliary Power Consumption) (%): Auxiliary power ratio

- Management as KPI of the above four indicators is required for power plants in India by the Government of India.
- CERC, the central government, sets KPI target figures (benchmarks) for India as a whole. Each power plant manages based on benchmarks issued by central government.
- Those four indicators were chosen because of their huge impact on electricity rates.
- As for the benchmark achievement in this FY by DSTPS, PLF and CD were low because of the annual overhaul of the No. 1 Unit carried out in August.

1.5.3 Operation situation of other units

(1) Properties of coals

- Coals are supplied by four coal depots. Given the huge variation in calorific power among the four varieties (2000 to 4000kcal/kg), a mixture is used in the operation.
  - Quality and analytical details of the coals used → Ash content: 40 to 50%. Calorific

power: between 2,500 and 4,500kcal.

Analyses are made daily at each coal delivery (because of the diversity of suppliers such as BCCL, ECL, MCL, CCL) and after blending.

- The properties of coals are analyzed daily in the laboratory within the company. The coals to be analyzed are sampled from the area housing each type of coal and from the blended coal.

(2) Others

- Coal consumption: 480,000 tpy. Water consumption: 2,600m³/hr. Boiler efficiency: 83.23%. Power generation efficiency: 36.81%. Technical minimum PLF: 55% ...

1.6 Site walkthrough

1.6.1 DSTPS power plant walkthrough

In December 2017, the survey team visited the DSTPS to collect operational data and conduct feedback from the plant staff and also carried out a walkthrough of the entire power plant.

DSTPS staff who kindly assisted with the walkthrough.

1.6.2 Walkthrough schedule

Date	Event
11 Dec. (Mon.)	AM: Move (Calcutta → Durgapur) PM: Kickoff meeting
12 Dec. (Tue.)	AM: General visit on equipment PM: Hearing on each technical part, Request for data
13 Dec. (Wed.)	AM: Supplementary survey on equipment PM: Supplementary feedback. Feedback about operation constraints, etc.
14 Dec. (Thu.)	AM: Wrap-up meeting PM: Move (Durgapur → Calcutta)
15 Dec. (Fri.)	Move (Calcutta → Narita)

1.6.3 Summary of the walkthrough result

- The condenser has about a 20% margin against the design performance and shows no performance degradation at present.
- Conversely, only one unit of circulating water pumps was stopped during the high vacuum operation in the winter season, which indicates room for improvement.
- The condenser is cleaned with a ball, brush and acid and actions to maintain efficiency are conducted.
- The boiler has been subject to three tube leaks on the economizer and superheater this year.
- It was explained that while the boiler is cleaned by operating the soot blower manual, relatively little molten ash had accumulated within the boiler at the time of overhaul.
- With regard to the turbine, a temperature difference emerges between the upper and lower casing at low-load (60%) operation and any further increase in this temperature difference is controlled by opening the casing drain valve (connected to the condenser), which is supposed to be open only when the unit starts up, to release the stagnating steam. According to the maker, this might be due to incorrectly positioned heat insulators.
- The purchased coals all had properties with calorific values varying from 2000 to 4000kcal/kg and ash content from 30 to 70％. Domestic coals are supplied from four coal mines and the mine which produces the coal on which the design is based is the most distant and has the lowest purchase quantity, despite being of high quality. This coal seems to be a low-sulfur variety, with a high ash melting point.
- All the coals are transported by train. The capacity of the coal storage area is 280,000 m^3 and the daily coal consumption is 14,000 t.

Full view of the power plant

Underground pit for coal delivery

Coal transportation wagon (rail transportation)

Condenser cooling water and cooling tower

Condenser cooling towers

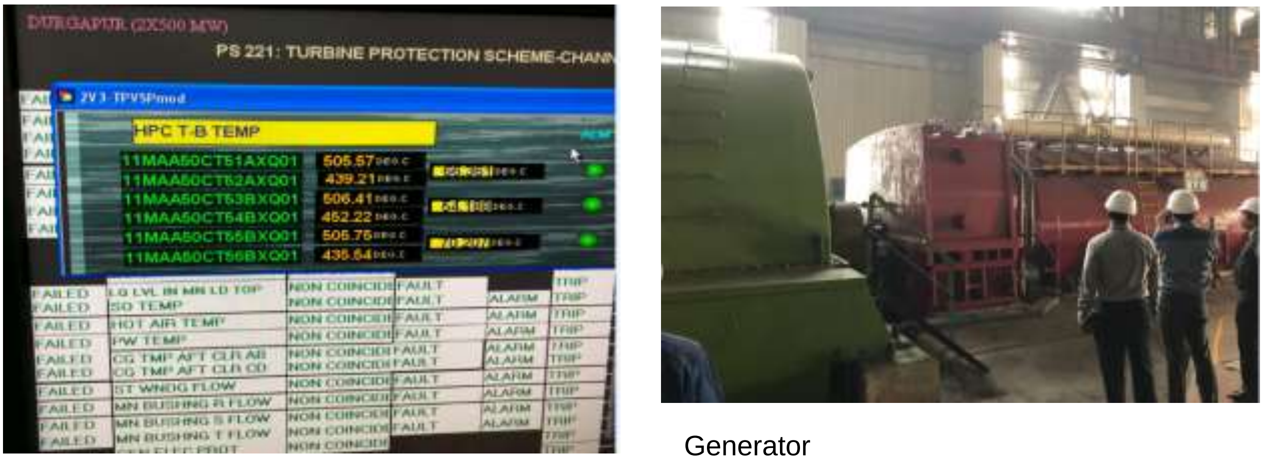
Forced draft fan control drive

Hopper at the bottom of the electric dust collector

Coal pulverizer

Coal storage area

Coal conveyor from the coal storage area



CRT display

Generator

Figure 1-3 DSTPS walkthrough result

1.6.4 Recommendations to improve safety during unit operation

The on-site walkthrough brought up some comments to be noted in terms of safety management of the unit. The walkthrough brought home to use the extent to which the DSTPS prioritizes safety during unit operation above all, through posters posted in many places within the facilities for the purpose, for example, to raise awareness on safety management of the unit operation.

Some recommendations related to safety management are presented here for further improvement on the matter. Conscientious practice of safety management according to those recommendations would lead to decrease unplanned shutdowns and power restrained operations, contributing to improve the unit efficiency.

Figure 1-4 Additional safety-management comments for DSTPS

Chapter 2 Study to improve the thermal efficiency of the target power plant

2.1 Technical summary

2.1.1 Technology enabling the overall thermal efficiency of the thermal power equipment to be improved/maintained

The present project was conducted through the following two approaches, which would lead to the overall thermal efficiency of each unit in the thermal power equipment being maintained/improved:

(1) Thermal efficiency maintenance/improvement of the plant alone

Moves to improve the plant efficiency in the generator unit alone will be implemented to help decrease fuel consumption and reduce CO_2 emissions through the following approaches:

1. Appropriate control of operating condition
   - From the perspective of maintaining plant efficiency, key operating condition values of the equipment will be periodically monitored and if any changes such as a “deviation” from the reference condition or design values are observed, action will be taken immediately. (Example: changes in main steam temperature/pressure, feed water temperature, gas temperature, O_2 content, etc.)
2. Control of premonitory sign of potential decline in performance
   - Premonitory signs of various changes, including measuring instrument malfunctions, will be detected at an early stage by periodically checking all available operational data and determining the tendency indicated. Those early findings would help avoid any decline in thermal efficiency and alleviate equipment deterioration due to malfunction.
   (Example: Leakage from high-pressure heater tubes, increase in differential pressure and performance degradation of AH)
3. Appropriate proposal for each factor hindering thermal efficiency
   - Equipment with performance that declines progressively in the mid- to long term will be subject to long-term monitoring to identify factors hindering thermal efficiency.
   Repairs will be carried out at the right time before shutdown for periodic maintenance and other purposes, based on the tendency for thermal efficiency to decline and other information such as that provided by local engineers.

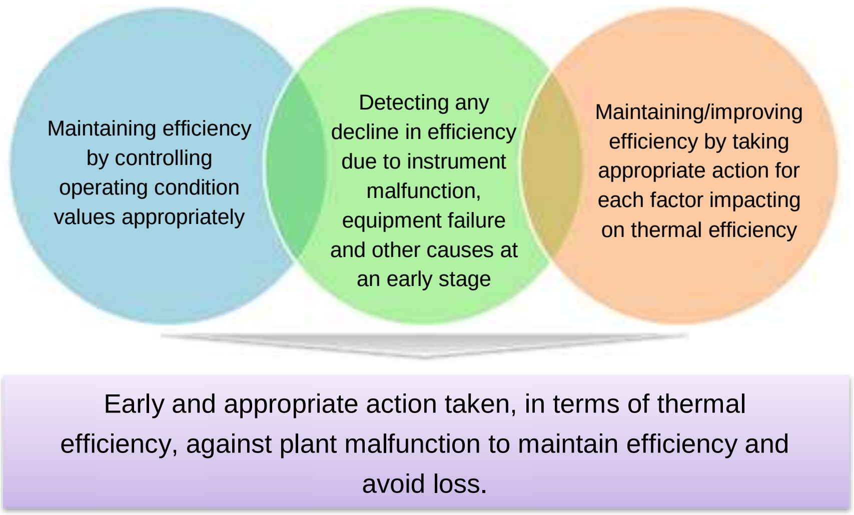


Figure 2-1 Approach to maintain/improve thermal efficiency of the plant alone

(2) Improvement of overall thermal efficiency of the power generation equipment

A decrease in unplanned shutdowns, avoidance of large-scale problems and reduced unit downtime will be attained by implementing a “preventive shutdown”, which consists of stopping the equipment before any problem occurs by appropriately recognizing signs of equipment malfunction, using a premonitory sign control method backed by long-term monitored operational data (big data).

The overall thermal efficiency of the thermal power equipment will be improved by reducing downtime and increasing the operation hours of the high-efficiency unit.

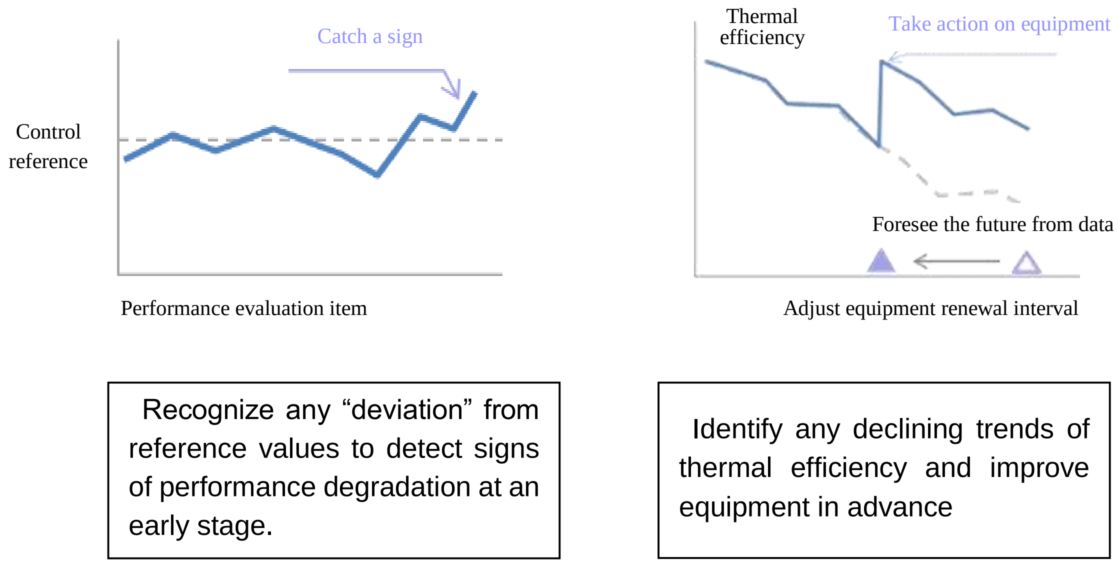
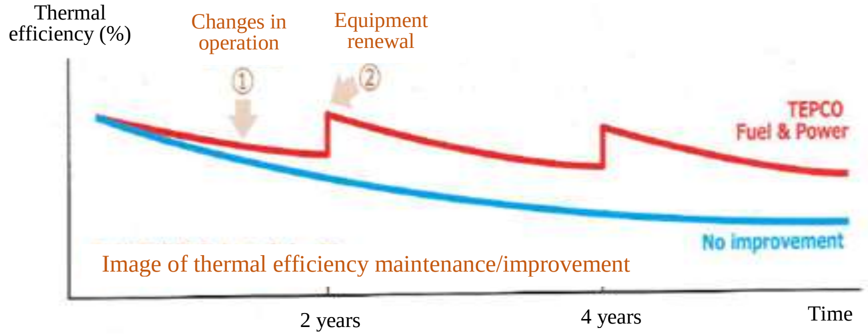


Figure 2-2 Image of early detection of anomalies by comparing operating conditions and reference values



(1) Efficiency improvement by operation changes: The thermal efficiency will be maintained by actions such as changing the operating method of each piece of equipment and reviewing/optimizing their repair interval.
(2) Improving efficiency by renewing equipment: Equipment is renewed during periodic inspections and equipment shutdowns.

Figure 2-3 Image of thermal efficiency maintenance/improvement

2.1.2 Image of thermal efficiency analysis by appropriate performance management

As shown in Figure 2-4, the present study will identify the equipment responsible for any decline in thermal efficiency by making premonitory signs and trends visible through permanent monitoring of about 1,000 operational data, equipment drawings and results of performance tests conducted at periodic inspections as well as real-time heat-balance analysis of the unit using such information.

Furthermore, based on know-how developed to date, recommendations will be made to improve equipment and change operating values to help remedy causes of any decline in thermal efficiency and remedial actions conducted systematically during periodic inspections and unit shutdowns.

Repeating this process on an ongoing basis will help maintain/improve the thermal efficiency of the unit for the long term.

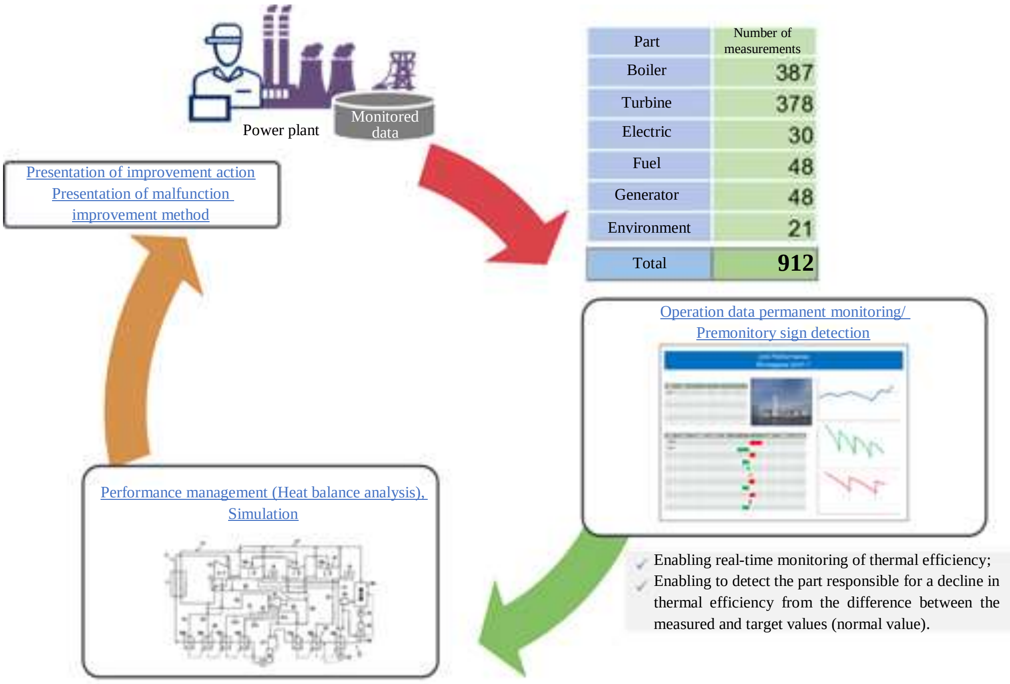


Figure 2-4 Image of the malfunction improvement loop, which starts from operational data monitoring

2.1.3 <Operational data collection – Thermal efficiency analysis – Feedback> cycle

The thermal efficiency improvement loop as shown in 2.1.2 is ensured by a “Remote Supervisory Center” installed in Japan, which collects information and conducts analyses.

(1) Important operating condition values are periodically monitored.
(2) Monitored data are sent from the facility of the relevant country to Japan for remote surveillance.
(3) If premonitory signs such as “deviations” are observed in operational data, contact will be made immediately with the local entity and actions to be taken will be recommended.

Through analysis in order (1)→(2)→(3), a system enabling early detection of signs of various changes, including measuring instrument malfunctions, will be established even with remote supervision, to avoid any decline in thermal efficiency.

Operational data analysis may be conducted by either by offline analysis, which grabs past operational data for a given period in bulk to analyze and extract points that will help improve thermal efficiency and online analysis, which uses real-time operational data of the unit in production to conduct analyses and implement operational changes as required to improve thermal efficiency.

During the exercise of this study, an offline analysis method is used.

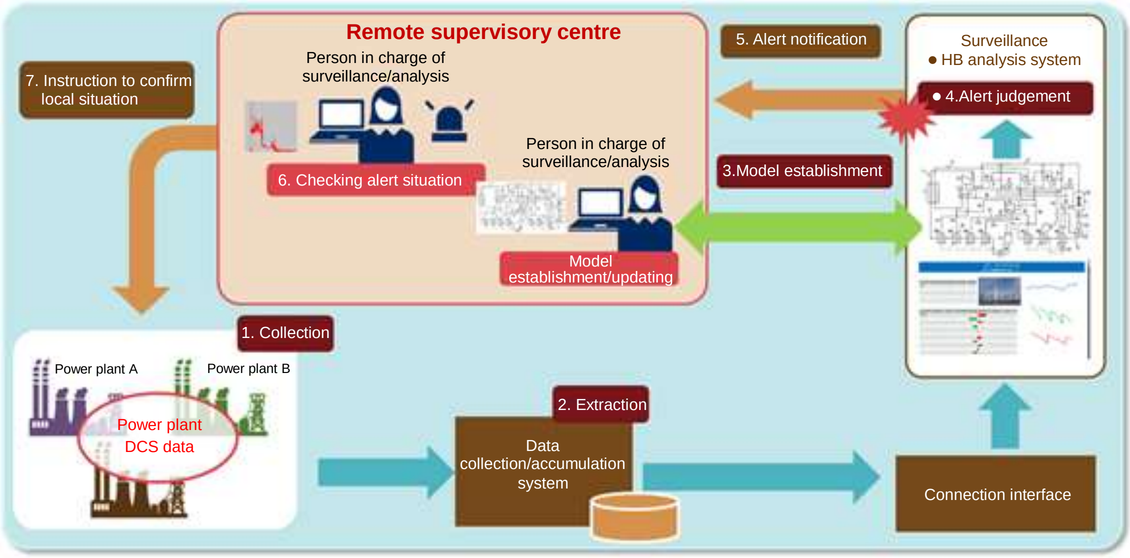


Figure 2-5 Image of Online Analysis

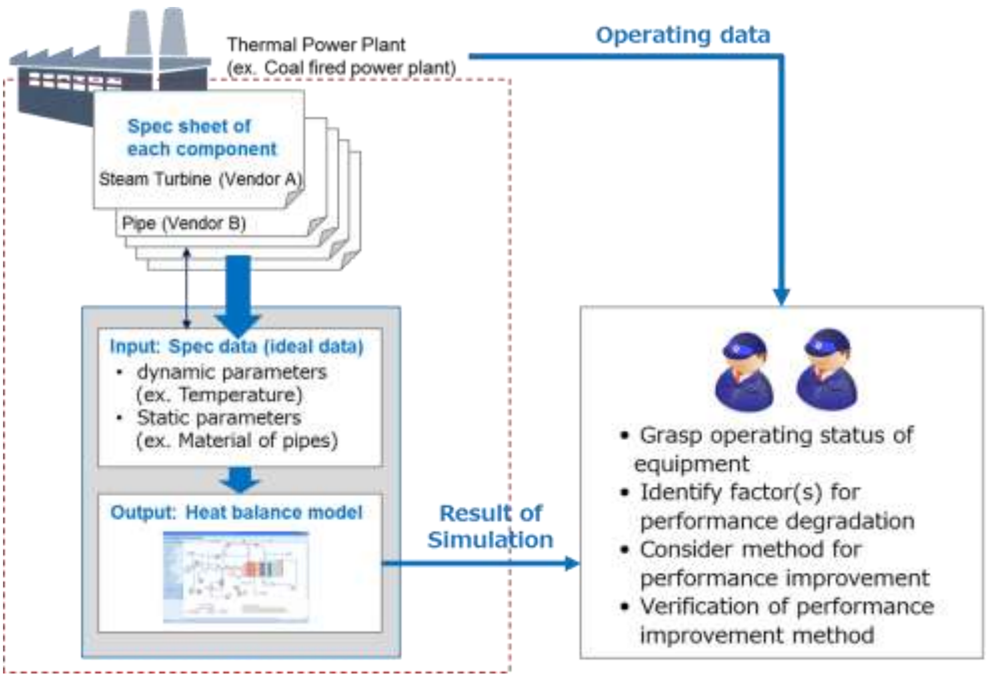


Figure 2-6 Image of Offline Analysis

2.2 Data collection

As stated in 1.2, data are well conserved in DSTPS and almost all operational data (about 1,600 data, hourly data for one month) and documents (test certificates, equipment specifications, repair records and plan, various drawings, design heat balance chart, performance curves, structural drawings, etc.) necessary for analyzing thermal efficiency were available.

The circumstances of data collection were as follows:

2.2.1 Data requested by the Japan side

Data lists as shown in Tables 1-2 and 1-3 were sent to DVC prior to the kickoff meeting with this company, during which the whereabouts and due date for data delivery were also confirmed.

2.2.2 Data delivery from DVC

As far as the operational data of the DSTPS power plant are concerned, the necessary tags were chosen by TEPCO among the data points owned by DCS and the corresponding operational data were delivered as follows:[1]

- Data delivered on 20 Oct.: Portion requested with priority, various drawings and others (about 50 files, 112MB)
- DSTPS operational data: TEPCO requested 1800 places, 25 Oct. to 5 Nov. portion (18MB)
- DSTPS operational data: TEPCO requested 1800 places, 5 to 15 Nov. portion (18MB)
- DSTPS operational data: TEPCO requested 1800 places, 15 to 25 Nov. portion (18MB)

2.3 Data analysis

2.3.1 Operational data analysis

- The operational data period is one month from 25 Oct. to 24 Nov. During this period, the rated output of 500MW was attained for only three days and hovered at around 350MW on other days.

[1] Individual operation data are not attached to this report, since they were delivered in Excel form and shared within the survey team.

(1) Main steam pressure record

Figure 2-7　Record of the No. 1 Unit main steam pressure

(2) Condenser cooling water temperature record

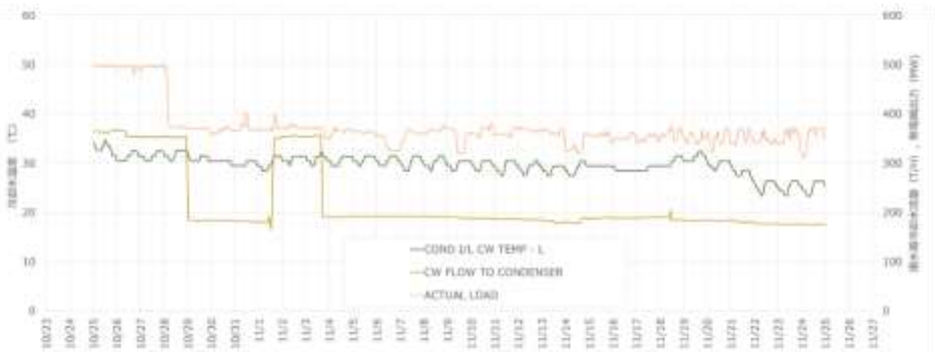


Figure 2-8　Record of the No. 1 Unit condenser cooling water temperature, flow and generator output

2.3.2 DSTPS heat balance model

The heat balance model of the No. 1 Unit at rated output (@500MW) was drawn up based on the delivered operational data.

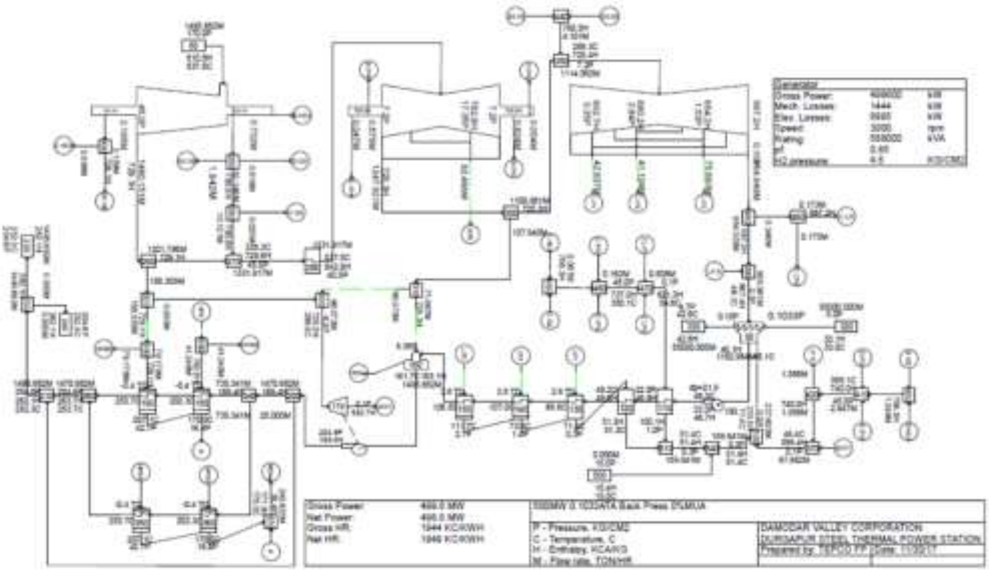


Figure 2-9 No. 1 Unit heat balance model (Turbine@500MW)

2.4 Determination of factors hindering thermal efficiency

2.4.1 Summary of the performance diagnosis

It emerged that the unit loses its efficiency, despite being just less than 5% of the design value at the construction phase. The factors behind the decline were analyzed by individual equipment as follows:

Boiler efficiency was maintained at the design value. However, the air leakage ratio of the air heater (hereinafter, “AH”) was high, causing the AH temperature efficiency ratio to decline and it emerged that such decrease, despite having minimal influence, was responsible for the drop in efficiency.

As for turbine efficiency, a decline in performance from the design value was observed. Following detailed performance diagnosis by individual equipment, a performance decrease due to age-related degradation emerged on the intermediate pressure turbine and the high-pressure heater.

The prime reason behind the decline in efficiency of the unit turned out to be the decline in efficiency of the turbine.

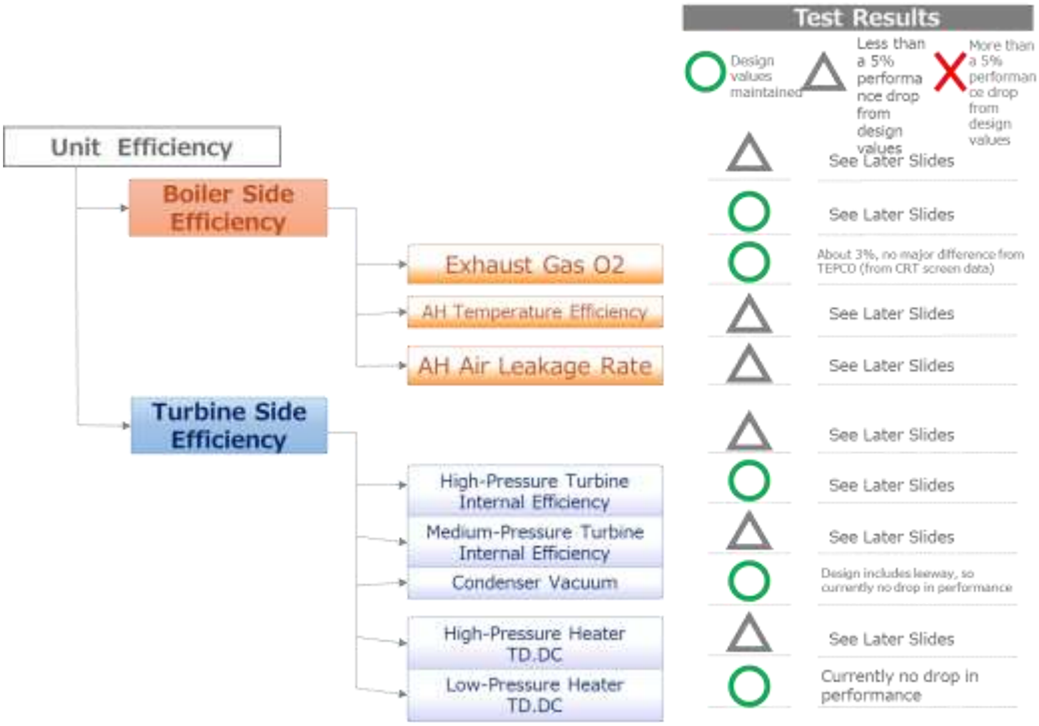


Figure 2-10　Result of performance diagnosis of the entire unit and by piece of equipment

2.4.2 Changes of boiler/turbine performance (Unit Efficiency) (when operating at Rated output@500MW)

Unit efficiency decreases gradually from the operation startup.

To date, it has declined by about 0.7% compared to the design value.

Individually analyzed efficiencies constituting unit efficiency, i.e. turbine and boiler efficiencies, showed that the latter had remained at or exceeded the design value from the operation start while the former had dropped considerably.

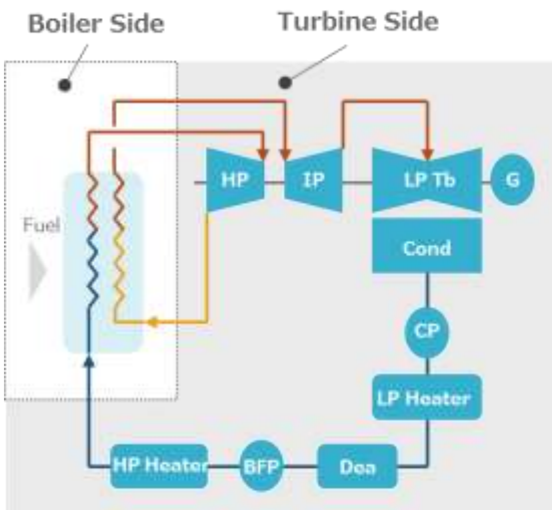


Figure 2-11　Unit components

(Blue indicates turbine equipment)

Table 2-1　Changes in boiler and turbine performance

			Design	Guarantee test	Before 2017Inspection	After 2017Inspection
				2013/10/25	2017/7/7	2017/9/15
Unit Efficiency		%	36.8	37.4	35.6	36.1
	Turbine Side Efficiency	%	44.2	44.3	42.0	42.5
	Boiler Side Efficiency	%	83.2	84.5	84.6	85.1

Figure 2-12　Actual performance and design value of the entire unit, turbine and boiler

2.4.3 Changes in turbine performance (@500MW)

As stated in 2.4.2 above, the turbine is found to be responsible for the actual decline in unit performance. The performance of individual pieces of equipment was analyzed to determine the factors in the turbine equipment impacting on said performance.

Compared to the result of the most recent performance test, the analysis showed that the internal efficiency of the high-pressure turbine remained at the design value while that of the intermediate pressure turbine declined by about 2% of the performance test result.

Based on the above, it is inferred that the factors impacting on turbine performance stem from the intermediate pressure turbine.

Furthermore, the data accuracy of the result and the data-collecting position of the 2013 Performance Guarantee Test should be verified, since some data show extremely low values compared to design values, making the test results themselves problematic.

Table 2-2 Variation in turbine equipment performance

		Design	Guarantee test	Before 2017Inspection	After 2017Inspection
			2013/10/25	2017/7/7	2017/9/15
HP Turbine Efficiency	%	93.9	86.5	91.4	93.9
IP Turbine Efficiency	%	94.0	91.3	91.6	91.9

Note: The performance at the operation start year (2013) was extremely low for both high- and intermediate-pressure turbines. Under normal circumstances, performance as low as this at the start of unit operation is unusual, hence the need to examine the accuracy of the data and the appropriateness of the measuring point choice.

Figure 2-13 Performance of high- and intermediate-pressure turbines compared to the design value at operation start

2.4.4 Transition in high-pressure heater performance - Part 1 (TD: Difference in temperature between feed water outlet and steam) (@500MW)

Considering the TD (Terminal Difference) value, an indicator of high-pressure heater performance, showing increased deviation in both pressure heaters Nos. 5 and 6 from the operation start, it is inferred that performance decreases.

Note: TD value: Difference between saturated steam temperature Ts under extraction steam pressure and feed water temperature at the heater outlet. The smaller this value, the better the performance.

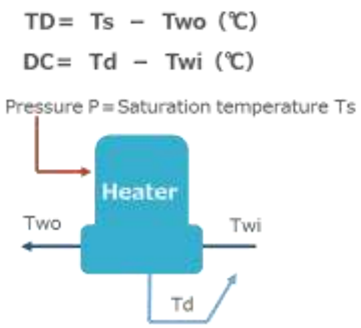


Figure 2-14　TD value

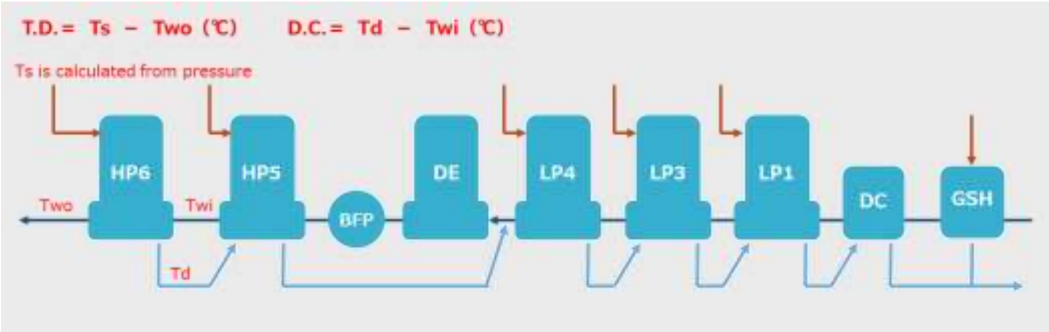


Figure 2-15　DSTPS feed water system components

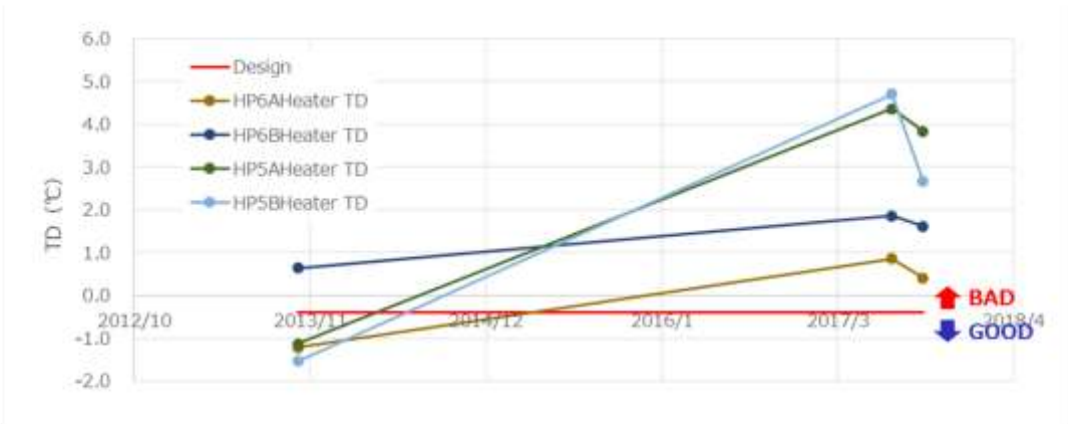


Figure 2-16　TD value transition in high-pressure heaters Nos. 5 and 6

Table 2-3 Performance test result comparison of high-pressure heaters Nos. 5 and 6 in TC value terms

		Design	Guarantee test	Before 2017Inspection	After 2017Inspection
			2013/10/25	2017/7/7	2017/9/15
HP6AHeater TD	℃	-0.4	-1.22	0.86	0.41
HP6BHeater TD	℃	-0.4	0.65	1.86	1.62
HP5AHeater TD	℃	-0.4	-1.13	4.37	3.84
HP5BHeater TD	℃	-0.4	-1.53	4.7	2.67

2.4.5 Transition in high-pressure heater performance - Part 2 (DC: Difference in temperature between feed water inlet and drain) (@500MW)

The DC (Drain Cooling) value, another indicator of high-pressure heater performance shows, as with the TD value, increased deviation from the operation start, based on which a performance drop is presumed.

※ DC value: Difference between the drain temperature of the extracted steam to high-pressure heater and the feed-water temperature at the heater inlet. The smaller this value, the better the performance.

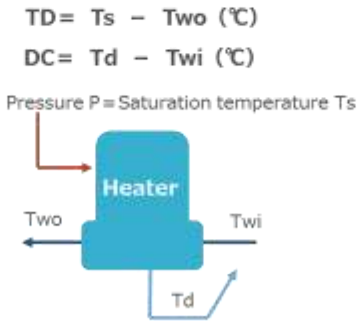


Figure 2-17 DC value

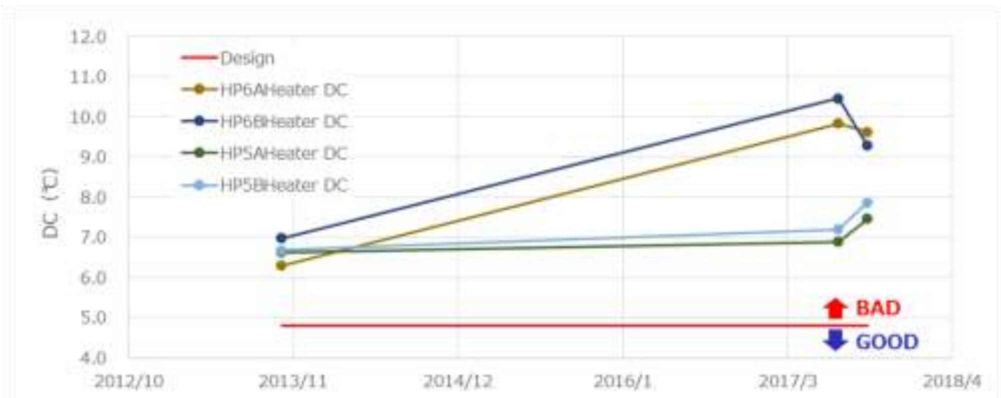


Figure 2-18 DC value transition in high-pressure heaters Nos. 5 and 6

Table 2-4　Performance test result comparison of high-pressure heaters Nos. 5 and 6 in terms of DC value

		Design	Guarantee test	Before 2017Inspection	After 2017Inspection
			2013/10/25	2017/7/7	2017/9/15
HP6AHeater DC	℃	4.8	6.30	9.84	9.63
HP6BHeater DC	℃	4.8	6.98	10.46	9.29
HP5AHeater DC	℃	4.8	6.63	6.89	7.47
HP5BHeater DC	℃	4.8	6.69	7.2	7.87

2.4.6 Transition in high-pressure heater performance - Part 3 (FWPD: Difference in feed-water pressure between inlet and outlet of the heater) (@500MW)

Difference in feed-water pressure between inlet and outlet of high-pressure heater (FWPD: Feed Water Pressure Difference) showed little change since commencing operation.
This indicates little change in the feed-water side temperature of the high-pressure heater, which increases with the heat exchange with steam. This value increases as the high-pressure heater becomes scaled and/or clogged up.

※ PD value: Difference in feed-water pressure between the inlet and outlet of the high-pressure heater. This value increases as the heater becomes scaled and/or clogged up.

$$PD = Pwi - Pwo \ (kg/cm2)$$

Figure 2-19　PD value

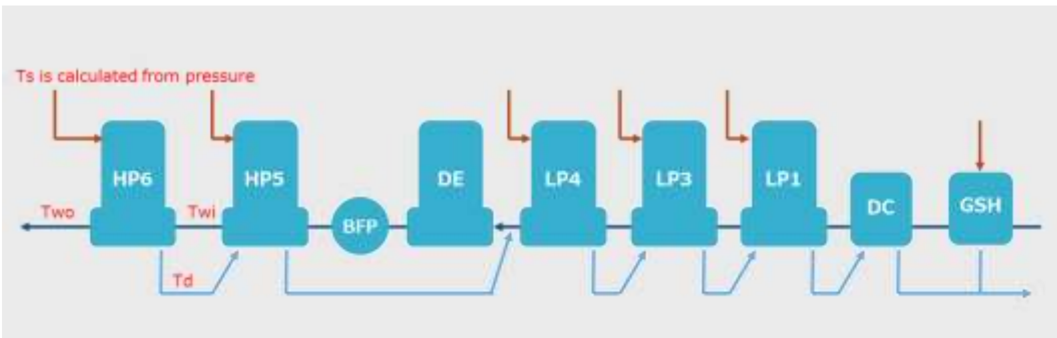


Figure 2-20　DSTPS feed-water heater system components

Figure 2-21　PD value transition in high-pressure heaters Nos. 5 and 6

Table 2-5 Performance test result comparison of high-pressure heaters Nos. 5 and 6 in terms of PD value

		Design	Guarantee test	Before 2017Inspection	After 2017Inspection
			2013/10/25	2017/7/7	2017/9/15
HP Heater PD（5Ain-6Aout)	kg/cm2	-	2.66	2.45	2.28
HP Heater PD（5Bin-6Bout)	kg/cm2	-	2.83	2.92	2.73

2.4.7 Transition in air-heater performance (@500MW)

While the temperature efficiency and the air leakage ratio of air heater had declined since operation commenced, a periodic inspection carried out in 2017 showed that they had regained their design value.

The air heater functions to preheat combustion air via a heat exchange between the combustion exhaust gas generated in boiler and combustion air. Increased leakage from the combustion air side to that of exhaust gas will augment the forced draft fan load and result in loss of exhaust gas and a decline in efficiency.

From the data analysis made within this survey, it is inferred that there have been no leakages resulting in a boiler efficiency decrease and sealing properties were restored by the overhaul and repair carried out in the 2017 periodic inspection.

Figure 2-22 Transition and comparison with the design value of AH temperature efficiency and air leakage ratio

Table 2-6 Transition in deviation from the design value in AH air leakage ratio

		Design	Guarantee test	Before 2017Inspection	After 2017Inspection
			2013/10/25	2017/7/7	2017/9/15
Air Preheater A Gas Side Eff	%	66.2	-	54.4	58.61
Air Preheater B Gas Side Eff	%	66.2	-	56.11	61.24
Air Preheater A Leakage	%	10	8.90	24.69	9.48
Air Preheater B Leakage	%	10	8.57	30.29	9.33

Chapter 3 Proposal for performance management service

3.1 Improvement scheme (Part 1: Improving thermal efficiency by repairing equipment suffering age-related degradation)

3.1.1 Proposal to improve intermediate turbine performance (replacement of first stage nozzle, etc.)

It emerged that the intermediate turbine internal efficiency had decreased by about 2% compared to the design value. The likely cause of this decrease and consequent recommendation proposal for points to be checked and items to be repaired at the next periodic inspection (2019) are described below.

< Points to be checked on the equipment at the next periodic inspection >

(1) Damage examination of the intermediate turbine first stage nozzle
(Measurement and recording of the effective nozzle area)

(2) Ditto for fins: gap and damage examination

(3) Examination of scale adhesion on vanes

(4) Inclination of vanes (Examination of vane inclination toward the direction of steam flow by measuring the vane-wheel gap)

(5) Examination of seal ring damage to verify the presence or absence of loss due to leakage from sealed parts

(6) Examination of diaphragm backside spring to verify the presence or absence of permanent set in fatigue of the spring

<Recommended repair items>

- If any portion of the intermediate turbine is found to be damaged during the equipment check conducted as part of the periodic inspection, the following equipment repair work and/or partial replacements should be carried out. Although specific repair work to be done depends on open examination of the equipment during periodic inspections, taking the need for such repairs and/or replacements into account when establishing future equipment maintenance/renewal plans, will help streamline and expedite equipment management.

A. First stage nozzle replacement
B. Vane gap adjustment
C. Fin refresh
D. Ceramic spraying, Cr pack on nozzles (as a measure to counter erosion)

<Expected value of thermal efficiency recovery after repairs>

By carrying out the above repairs could allow thermal efficiency to be restored up to 93% compared to the actual 91.9% (Performance test result on Sept. 15, 2017)
(Intermediate turbine efficiency would be restored by about 1%pt)
Note: These estimated improvement effects are based on achievements (efficiency recovery by replacing the intermediate turbine first stage nozzle) in Japan.

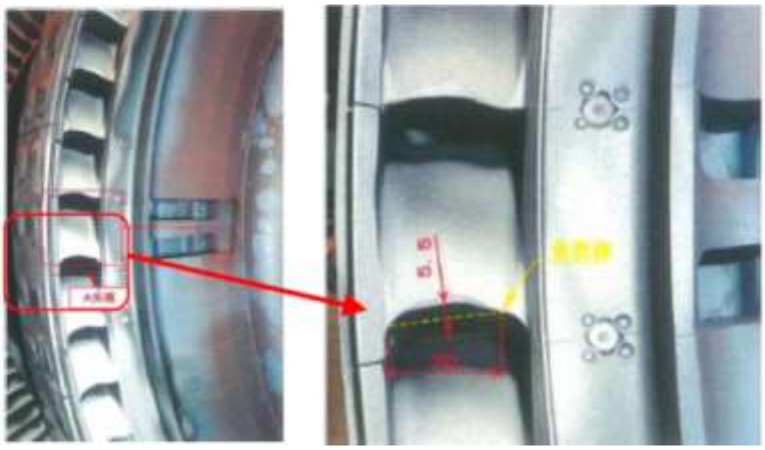


Figure 3-1 Example of turbine first-stage erosion

3.1.2 Proposal to improve air-heater performance (installation of sensor drive)

Although the temperature efficiency and air leakage ratio of air heater showed improvement in the 2017 periodic inspection, the air leakage ratio may increase again over time in future. The leakage observed in this survey did not impact in terms of triggering a decrease in boiler efficiency, but it was thought that a leak may lead to a decrease in boiler efficiency depending on the circumstances of any deterioration in performance. Therefore, it was considered effective to install a sensor which detects an increase in the air leakage ratio.

Moreover, early detection of changes in the air leakage ratio will help reduce risks which involve repairing or replacing the air heater for the following likely causes:

<Likely causes of air leaks>

(1) Seal gap increase due to heat distortion following changes in temperature conditions
(2) Gap increase due to corrosion, heat distortion or wear of the seal plate
(3) Seal plate having dropped off
(4) Atmosphere suction due to outlet duct corrosion, etc.

< Recommended equipment reinforcement >

Installation of sensor drive equipment* (see Note) is recommended to know trends in terms of the air leakage ratio. This equipment will allow identification of the air-leakage ratio in real time, action to be taken at an early stage and, overall, for the air leakage ratio to be reduced.

<Mechanism of sensor drive equipment>

- Non-contact sensor
- This is a system which allows the seal gap at the flange of the sector plate rotor to be controlled by moving the high-temperature-side and gear-driven sector plate outer ring
that is actuated according to the gap measured by this sensor.

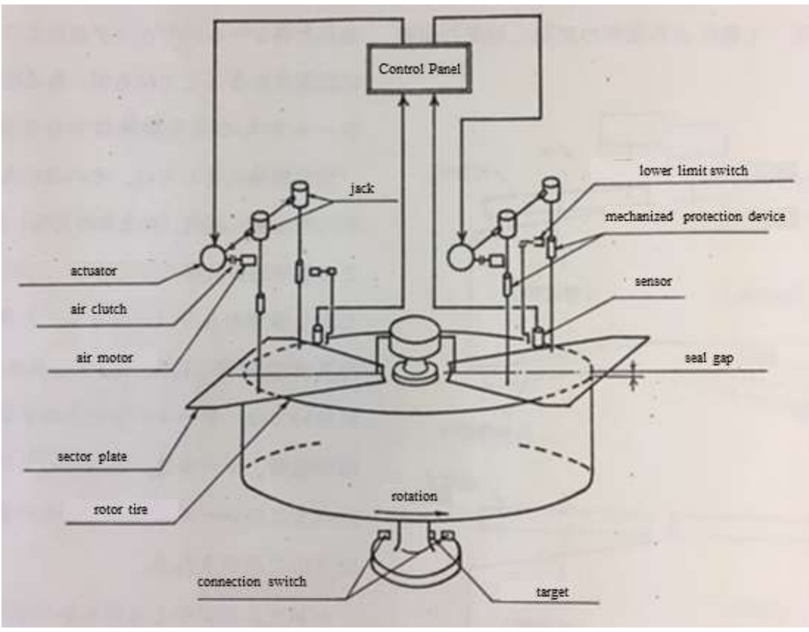


Figure 3-2 Air heater, sector plate, sensor drive equipment

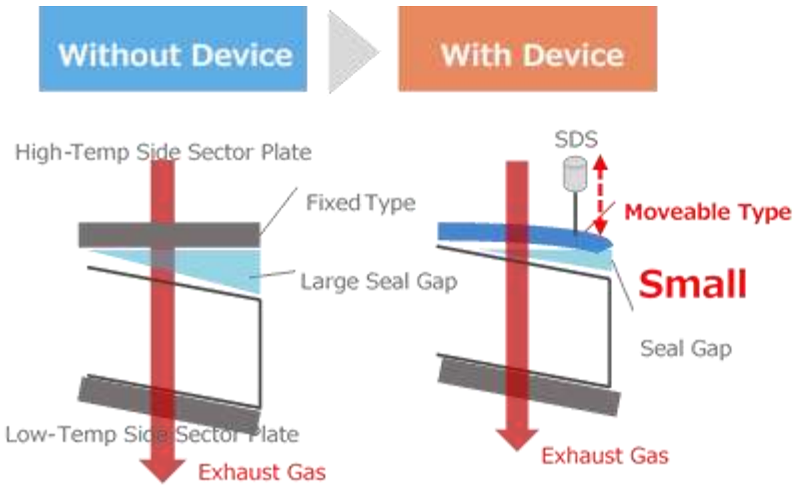


Figure 3-3 Mechanism of sensor drive equipment to reduce the seal gap

3.2 Improvement scheme

(Part 2: Improving thermal efficiency by changing operation and set values)

3.2.1 Proposal to improve high pressure heater performance

(Water-jet washing of No. 6 heater tubes)

Given the increased deviation observed in terms of TD and DC values since operation commenced, which indicate high-pressure heater performance, a decline in performance is likely. A recommendation proposal for points to be checked at the next periodic inspection (planned for 2019), based on the likely causes of this deviation and consequent items to be repaired are described below

<Recommended points to be checked at the next periodic inspection >

(1) Examination of fouling on the inner and outer tube walls (such as adherence of black and firm scaling, called magnetite)

(2) Verification to determine the presence or absence of damage on diaphragms

(3) Verification to determine the presence or absence of damage on tube plate (feed water short path)

<Recommended countermeasures>

If no physical damage is found during the periodic inspection, it is recommended that the Operation & Maintenance management method during periodic inspections be improved on the following points:

A. Keeping N_2 (Nitrogen) in the high-pressure heater while the plant is shut down for periodic inspections, etc.

B. Feed water quality control at plant startup

C. Elimination of fouling on the tube inner walls via water-jet cleaning

<Mechanism of water-jet cleaning of high-pressure heater >

This consists in eliminating elements that obstruct heat exchange (such as scaling) and having adhered to the heat exchange tube inner walls (on the feed-water side) of the high-pressure heater by threading a brush dedicated to the pipe inner wall washing and feeding water to wash them out.

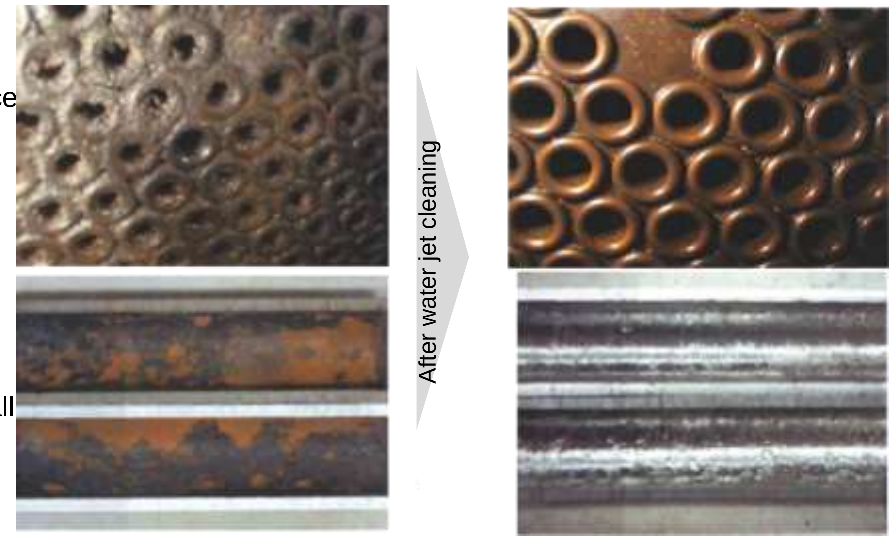
Example of water jet cleaning (brush cleaning) of tubes
(Source: Himeji Eco-tech co., ltd. catalog)

By threading this brush into high pressure heater tubes one by one and washing with water, fouling on tube inner walls are removed. (when high pressure water is used instead of brush, water pressure shall be between about 200 and 300 kg/cm2)

Figure 3-4 Brush dedicated to water-jet cleaning of high-pressure heater

Tube plate face

Tube inner wall



Before cleaning After cleaning

Figure 3-5 Photos showing the heat exchange tube inlet and inner walls of the high-pressure heater tube before and after water-jet cleaning
(In this example, a brush and jig adapted for removing hard scaling having adhered to the tube inner walls are used)

<Expected value of efficiency restored by the water-jet cleaning >

From the actual TD and DC values (Performance test result on Sept. 15, 2017), it is expected that they will be restored by water-jet cleaning up to the values in the performance guarantee test at operation start.

3.2.2 Proposal to improve condenser performance

(Optimal vacuum control by installing a vacuum-regulating valve)

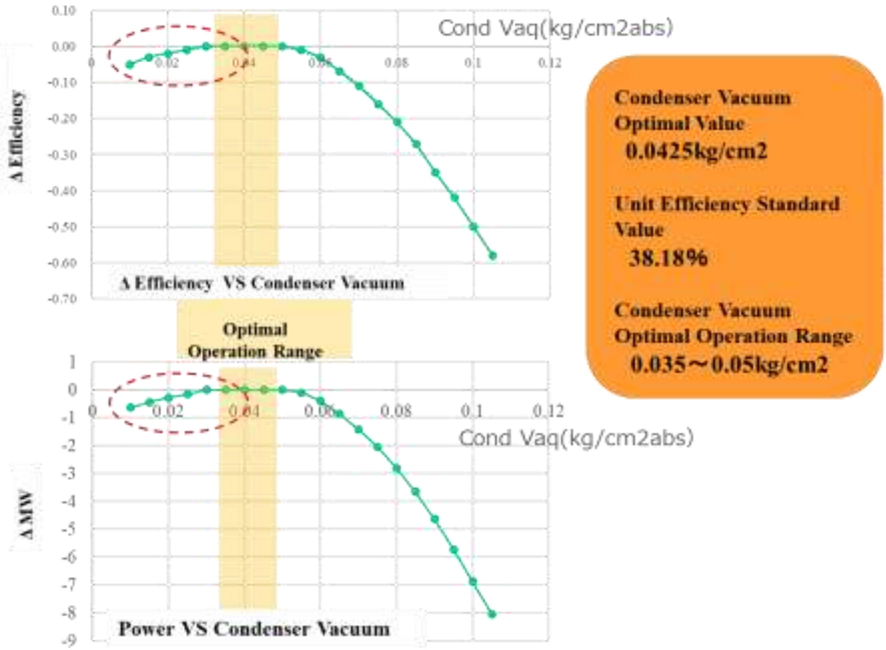
For turbine equipment, one of the key parameters governing whether thermal efficiency declines or remains constant is the condenser vacuum degree, which varies depending on various factors such as turbine steam cooling temperature, atmospheric temperature/humidity, combustion condition of the boiler, etc. Conversely, given the narrow effective range of condenser vacuum allowing optimal unit performance, it is not possible to efficiently control the condenser vacuum by indirect means.

One way to control the condenser vacuum degree directly is proposed below:

<Optimal vacuum degree of the DSTPS No. 1 unit>

The correlation between the condenser vacuum and unit thermal efficiency was calculated using the heat balance model prepared within this survey. The result is presented below.

It was confirmed that the unit operates most efficiently when the vacuum is 0.04kg/cm² abs but loses efficiency when the vacuum exceeds this value due to an exhaust loss caused by the vacuum increase. Naturally, unit efficiency drops rapidly once the vacuum goes below 0.04kg/cm² abs. Therefore, efficient operation depends on controlling the vacuum degree to an optimal value in response to ever-changing external conditions.



Vacuum kg/cm2	Δ Eff %
0.01	-0.05
0.015	-0.03
0.02	-0.02
0.025	-0.01
0.03	0.00
0.035	0.00
0.04	0.00
0.0425	0.00
0.045	0.00
0.05	0.00
0.055	-0.01
0.06	-0.03
0.065	-0.07
0.07	-0.11
0.075	-0.16
0.08	-0.21
0.085	-0.27
0.09	-0.35
0.095	-0.42
0.1	-0.50
0.105	-0.58

Figure 3-6 Correlation between the condenser vacuum degree and unit thermal efficiency

<Current method of condenser vacuum control in the DSTPS >

Feedback from the DSTPS revealed that cooling water flow is currently regulated by modulating the number of condenser water pumps (CWP) in operation. One of the three pumps is shut down in the winter months and all three pumps are operated in other months.

Although not confirmed by operational data examination in the winter season when 2 CWPs are put in operation, it is likely that the condenser vacuum became too low with this configuration and it was inferred that vacuum could hardly be regulated appropriately by modulating the number of CWPs in operation.

<Points in condenser vacuum control>

- Normally, as a margin is allowed for condenser equipment specification compared to basic design, it is rare to see the condenser vacuum decrease and it is normally maintained after operation starts.
- Conversely, if the vacuum is not controlled appropriately, a drop in the cooling water temperature during winter would result in excessive vacuum all at once, which would be likely to see the unit efficiency decline. In response, a way to avoid any excessive increase in condenser vacuum is proposed below.

<Recommended improvement – Part 1>

Maintenance of an optimal vacuum by installing a vacuum-regulating valve

The condenser vacuum will be maintained at an appropriate value by installing a vacuum-regulating valve on the condenser vacuum pump suction side.

Since a vacuum-regulating valve is automatically controlled, the parameter can be changed from the central control center once the valve is installed. It is efficient because it does not require excessive operation and management.

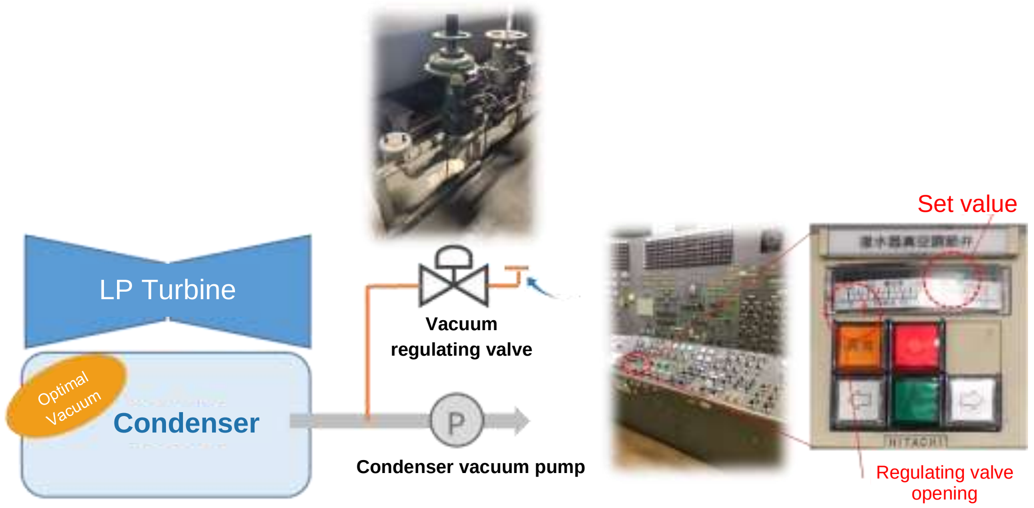


Figure 3-7　Installation site of the vacuum-regulating valve

<Recommended improvement – Part 2> Opening adjustment of condenser cooling water outlet valve

The condenser vacuum will be maintained appropriately by controlling the cooling water flow to the condenser by adjusting the opening of the condenser cooling water outlet valve. In TEPCO, a butterfly valve is used for the corresponding outlet valve for a structure enabling flow regulation.

This solution is cost-effective, since it eliminates the need to invest in equipment, but in practical operation it has the disadvantage of constantly requiring manpower to maneuver the valves and adjust the vacuum. Verification should be made to ascertain whether valve opening adjustment is possible with various parameters, indicating condition changes, in mind.

< Expected value of efficiency restored when the recommended action is adopted >

Although it cannot be asserted due to the lack of actual data on efficiency decrease due to high vacuum during winter, the decline in efficiency due to excessive vacuum during winter is tentatively assumed to be 0.02%pt month/year (potentially avoidable).

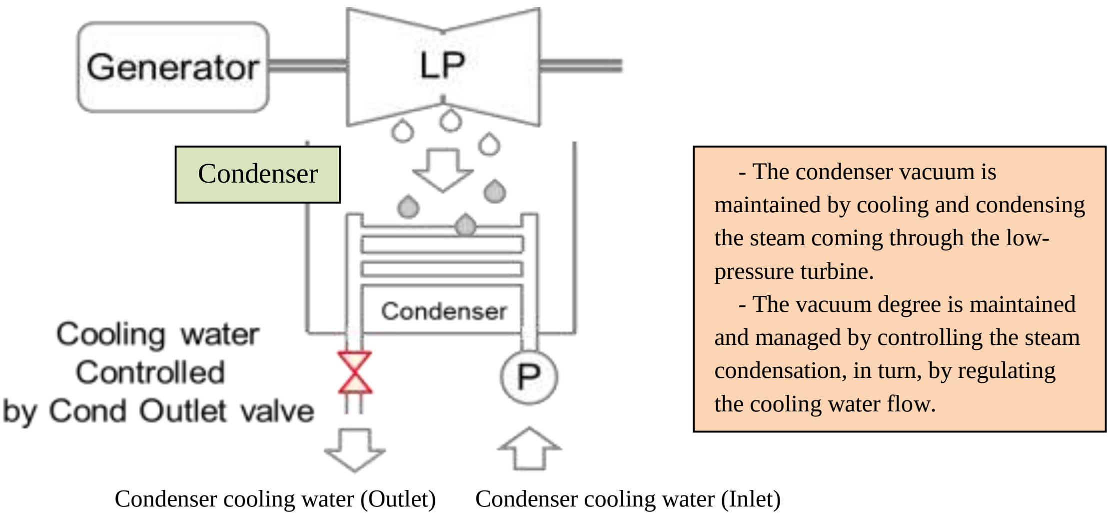


Figure 3-8 Image of opening adjustment of condenser cooling water outlet valve

3.3 CO_2 and cost-reduction effects gained by taking remedial actions

If the remedial actions as proposed in 3.1 and 3.2 above are carried out, the amount of change in thermal efficiency (absolute value), reduction in fuel consumption and annual fuel cost reduction would be estimated as follows:

Table 3-1 Impact in terms of improved thermal efficiency and reduced fuel costs of the unit if remedial actions are taken

Equipment	Recommendation	Expected value of restored performance	Change in thermal efficiency of the unit (%pt)	Reduction in CO_2 emission (t-CO2/year)	Reduction in fuel consumption (t/year)	Fuel cost reduction (103 INR/year)
Intermediate pressure turbine	Efficiency recovery by first stage nozzle replacement, etc.	Recovery of intermediate pressure turbine inner efficiency by 1.0%	0.17	▲13,499	▲10,032	▲30,096
High pressure heater	Heat exchange performance recovery by jet cleaning of tubes	Recovery of TD and DC values up to the values at Performance guarantee test	0.05	▲3,983	▲2,890	▲8,670
Air Preheater	Reduction in air leakage ratio by installing SDS	15% annual average leakage → 10% (design value) will be maintained.	0.03	▲2,391	▲1,960	▲5,881
Condenser	Optimal vacuum maintenance by installing vacuum regulating valve	0.02% pt. efficiency decrease due to excessive vacuum in winter season will be avoided.	0.02	▲1,595	▲90	▲270
Total			0.27	▲21,468	▲14,972	▲44,917

Note 1. The annual utilization ratio of the unit is estimated as 70%.

Note 2. The gross calorific value (GCV) of the design coal, 3300 kcal/kg, was used as the calorific value for the coal fuel.

Note 3. 3000 INR/t (result of hearing) was used as the coal fuel unit price.

Note 4. The above stated CO_2 reduction effect differs slightly from that stated in Chapter 5 because of the difference in the way fractions are treated.

Table 3-2 Impact in terms of ROI of the unit if remedial actions are taken

	①	②	③=①/(②/2)	④			⑤=(③+④)/②
Facility	Fuel Cost Merit	Effective duration	Fuel Cost Merit (per effective duration)	Repair expenses and investment expense	Construction period	Working artificial number	**Total Cost Merit**
	(10^3 INR/year)	(year)	(10^3 INR)	(10^3 INR)	(days)	(Number)	**(10^3 INR/year)**
IP Turbine	▲ 30,096	5	▲75,240	60,000	80		**▲3,048**
HP Heater (4 Unit)	▲ 8,670	5	▲21,675	2,000	5	16 (4 × 4units)	**▲3,935**
Air Preheater	▲ 5,881	20	▲117,620	100,000	50		**▲881**
Condenser	▲ 270	20	▲5,400	5,000	50		**▲21**
Total	**▲ 44,917**		**▲220,117**	**167,000**			**▲7,885**

Note 1. Repair expenses : Convert actual price in Japanese yen to INR (1INR=2yen)

Note 2. Effective duration : It means a period during which the unit performance drops to the performance before recovery

Note 3. For the merit evaluation, we do not consider losses of power sale equipment due to suspension of work

Note 4. HP Heater for 4 units = 5A,5B,6A,6B Heater

3.4 Economic efficiency estimation

The economic efficiency for each of the remedial actions could not be conducted in this survey, given the lack of information on the cost of equipment procurement and construction in India. However, each of the remedial actions proposed in this study was successfully implemented in steam power plants in Japan and their economic efficiency verified.

3.5 Recommendation to maintain/improve unit performance (Part 1)

As suggested before, daily operational data must be managed and analyzed to maintain and improve the unit performance. Where case analyses are ineffective in particular, even if operational data and performance data are collected and known, it would be impossible to ascertain whether the actual performance is maintained at or runs below the predetermined stage level.

In DSTPS, it emerged that although daily operational data and performance values are collected diligently, efforts to make a database from such information to determine age-related changes in unit performance and analyze the causes of changes in performance are not deployed at all.

What we propose below is long-term trend management leading to more advanced performance management and a management method of deviating from the performance reference value.

3.5.1 Points for more advanced performance management

(1) Besides collecting daily performance data, trends in terms of weekly, monthly and yearly age-related changes should be followed to determine real-time performance degradation and the presence or absence of malfunction.

(2) A series of management loops should be established. This loop should comprise setting "reference values", corresponding to the performance values when the equipment is in good condition such as just after the operation start and monitoring deviations from the same to determine whether the unit performance shows a degradation trend and whether such trend is due to malfunction and if so to identify which piece of equipment is responsible for it.

(3) A structure should be established within the company to keep the above-stated performance management permanently in place.

As shown in Figure 3-9, dispersion in performance and deviation from the reference performance values of a unit of equipment (or function) can be determined via graphs (visualization) prepared from operational data and performance data extracted through processing and totalizing those operational data.

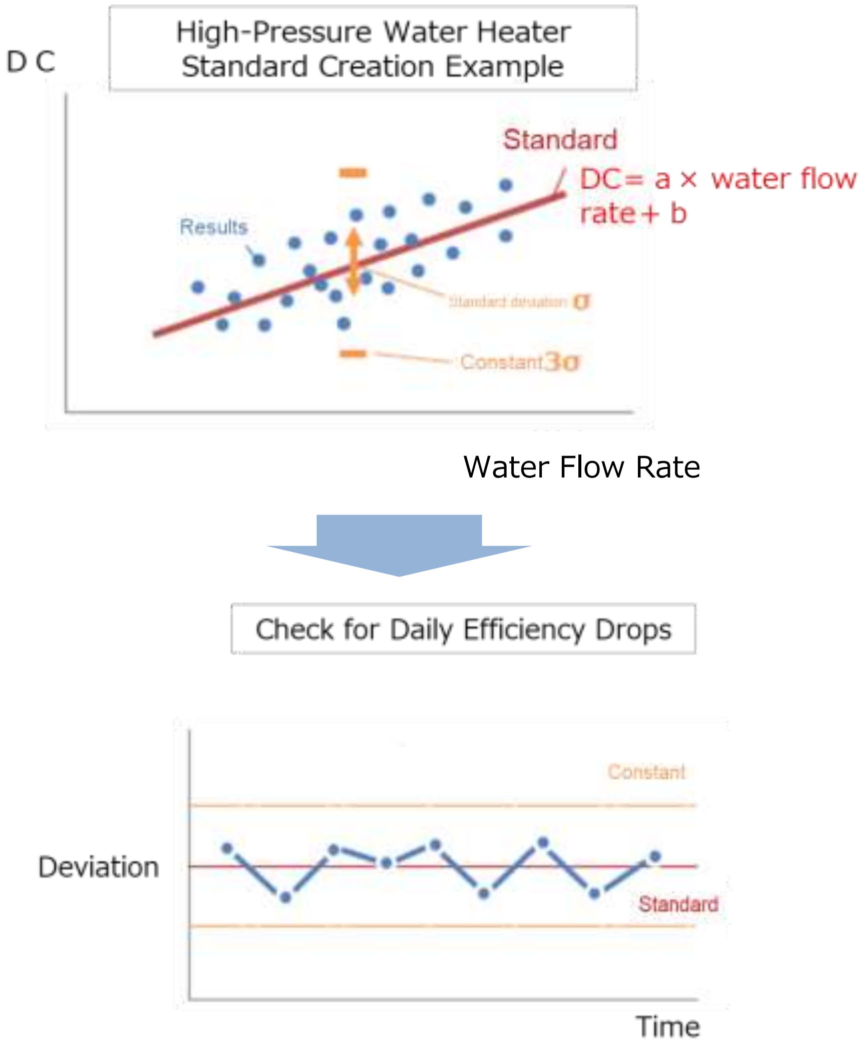


Figure 3-9 Image of more advanced performance management of a high-pressure feed-water heater

3.5.2 Specific case example where a trend of performance decline and its cause were identified

Figure 3-10 shows a concrete case in which the occurrence of a malfunction was detected at an early stage by daily management (visualization) and analyses of performance data on a high-pressure feed-water heater.

Performance management of high-pressure heater consists in collecting data such as feed water temperature and pressure, extraction steam temperature and steam drain temperature in real time and detecting preliminary signs of performance degradation using parameters such as TD value and PD value. This example shows the case which succeeded in early detection of leakage in a high pressure tube by recognizing changes in DC value at an early stage and narrowing down possible causes for it.

(1) Possible occurrence of some performance degradation was detected at an early stage, based on sudden changes in the performance-management parameters of a high-pressure feed-water heater.

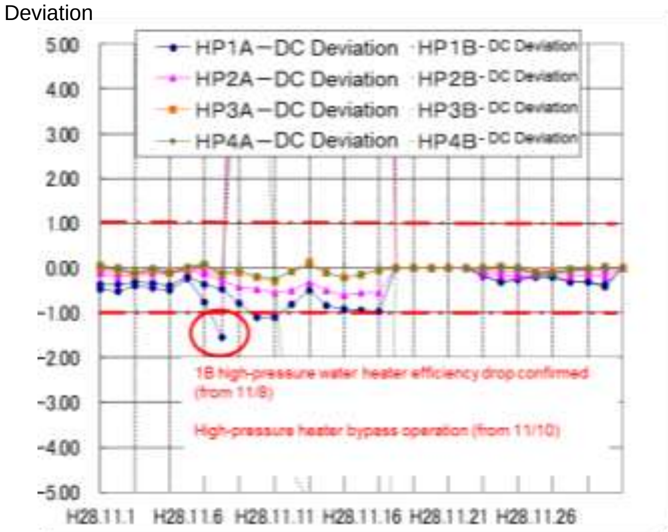


Figure 3-10 Trend of DC value among performance-monitoring parameters of a high-pressure heater

(2) Analysis was made to determine the possible causes of the deviation and a plan to verify the existence or absence of each of those possible causes was established.

(3) During the following periodic inspection, an examination was conducted to verify the existence or absence of tube leaks in a high-pressure heater and leakage having emerged on one tube.

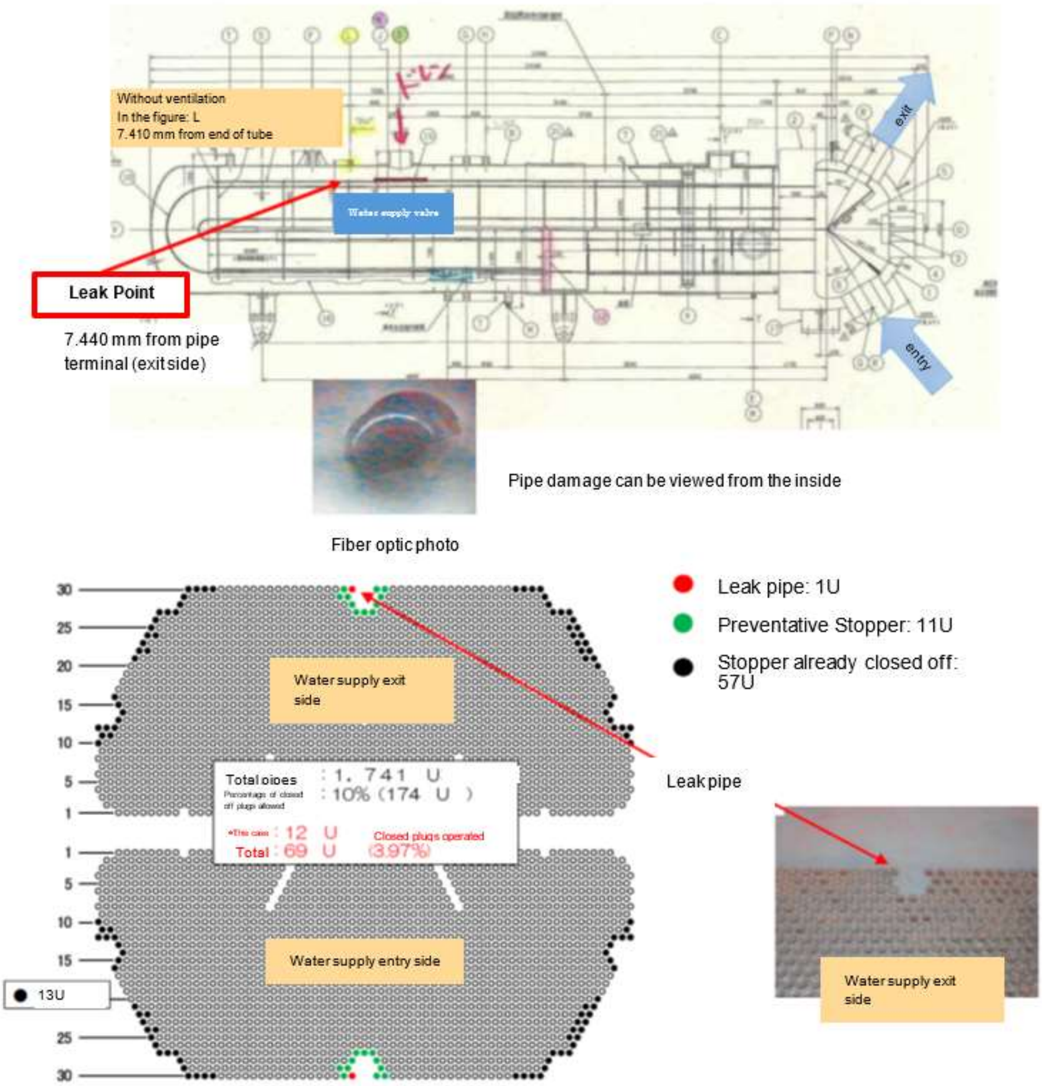


Figure 3-11 Image of tube leak detection in high-pressure heater

3.6 Recommendation to maintain/improve unit performance (Part 2)

In DSTPS, performance tests were diligently carried out after periodic inspections, but some performance test data proved questionable in terms of accuracy.

The feedback revealed that the performance tests conducted to date had been performed without maintaining a constant output of the unit for a certain period. There was also no established standard and interval for calibrating the measuring instruments used for performance tests.

To utilize the performance test results effectively as reference data to evaluate the performance degradation of equipment, the accuracy of performance test itself needs to be improved.

What we propose below is firstly a recapitulation of the performance test objectives, followed by methods which should be used and important points to further improve the performance management quality.

<What are the objectives of the performance test? >

{Things to be done before periodic inspection}

- The performance situation of each piece of equipment needs to be determined before periodic inspection and the information thus acquired should be used to determine the need to carry out complementary examinations at periodic inspection and establish repair plans to be implemented during periodic inspection.
- If equipment performance appears to be declining, such equipment shall undergo an open inspection at periodic intervals to determine its inner condition and search and identify causes of any decline in performance. Furthermore, if work process arrangement and material delivery can be made in time during the shutdown period, urgent repair work shall be carried out.

{Things to be done after periodic inspection}

- The results of the periodic inspection should be utilized as parameters to control the performance recovery situation of the equipment repaired during periodic inspections.
- Data obtained from performance tests conducted after periodic inspection shall be utilized as “reference values” serving as benchmark criteria for the daily performance management after the operation start.

  Note: If a downward deviation trend from the “reference” is observed in performance, it should be interpreted that some problem has occurred, whereupon the cause must be investigated and remedial action taken.

Moreover, the medium- and long-term trend management of performance test results is useful in determining the time schedule for large-scale reparations (i.e. replacement of the turbine nozzle, rotor and steam-generating tubes).

From the above, it is clear that performance test results are key in establishing a long-term maintenance plan for the unit. For this reason, improving the accuracy of performance test data becomes important.

<Important points in conducting performance tests>

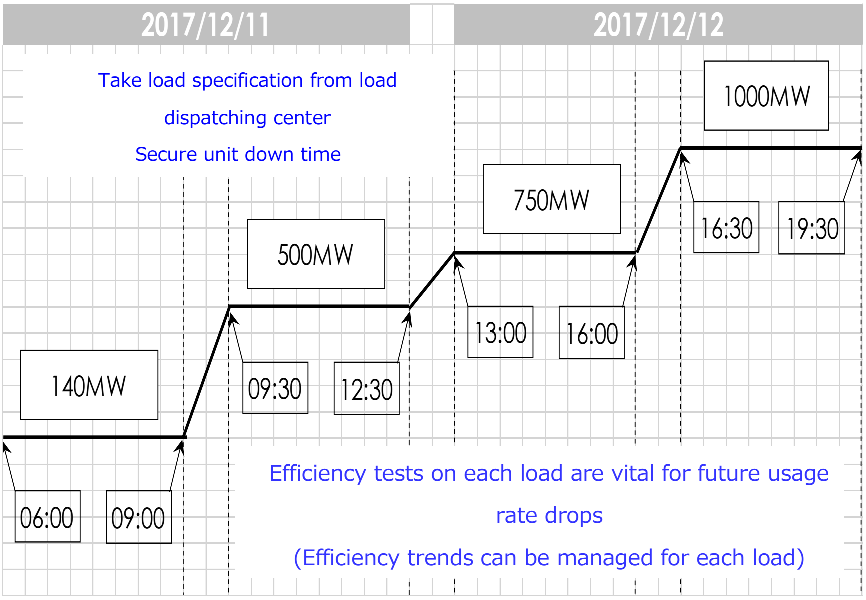
(1) Measuring instruments shall be calibrated before implementing performance tests, therefore before the periodic inspection.

(2) Any maneuver/operation which impacts on unit performance (common auxiliary steam supply, valve test, soot blowing, etc.) should be stopped while conducting a performance test.

(3) The unit’s constant output values, with which performance tests will be conducted, should be determined and observed for all future performance tests.

Note: The DSTPS explained that performance tests are conducted with 500, 400 and 300MW, while operational data shows incoherent output values such as 471 and 367MW. This is likely due to the fact that performance tests were conducted under load dispatching instruction from the power system. In TEPCO, one hour or more of output stabilization time with a constant value is secured before collecting the data.

Note: Equipment performances cannot be measured correctly when the condition is still fluctuating just after any change in output.



(1) Securing an output stabilization time without receiving a load assignment from the load dispatching center.
(2) Loads in performance test should be the same as those instructed during actual operation.

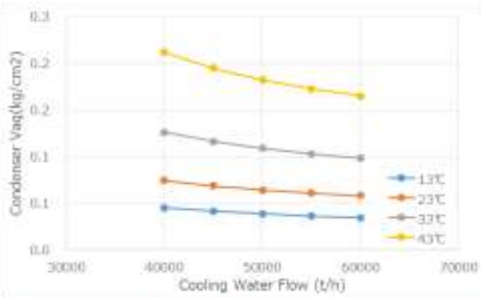
Figure 3-12 Example load assignment curve and output stabilization time for a performance test in TEPCO

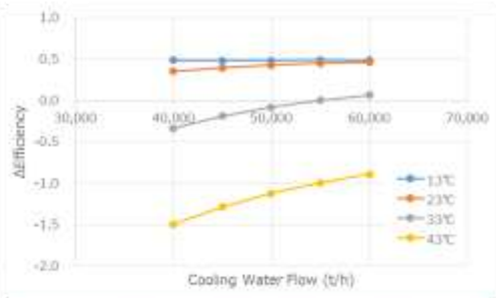
3.7 Recommendation to maintain/improve unit performance (Part 3)

As for the degree of vacuum in the condenser, which has a key impact on any performance change (degradation) of the unit, the higher (nearer to the true vacuum) is not always the better. It should be limited to a slightly lower level.

By using the heat balance model designed within this survey, a correlation between the reference vacuum curve particular to the unit and condenser cooling temperature/pressure will be simulated to establish a “Condenser reference vacuum control table”.

Performance degradation due to condenser scaling and tube leaks will be detected at an early stage by implementing daily control of deviation from such “Reference”.





Z:CW inlet Temp (℃)	13	23	33	43
X:CW Flow (t/h)	Y1	Y2	Y3	Y4
40000	0.045	0.075	0.126	0.212
45000	0.042	0.069	0.116	0.195
50000	0.039	0.064	0.109	0.183
55000	0.037	0.061	0.103	0.173
60000	0.035	0.058	0.099	0.165

Cond Vaq (kg/cm2) VS
CW Flow(t/h) & CW Inlet Temp (℃)

Z:CW inlet Temp (℃)	13	23	33	43
X:CW Flow(t/h)	Y1	Y2	Y3	Y4
40000	0.484	0.349	-0.338	-1.498
45000	0.48	0.396	-0.191	-1.287
50000	0.481	0.427	-0.082	-1.125
55000	0.488	0.449	0	-0.996
60000	0.487	0.463	0.064	-0.892

Unit Efficiency Deviation (%) VS
CW Flow(t/h) & CW Inlet Temp (℃)

Figure 3-13 Design of temperature, pressure and optimal vacuum degree curve of condensate cooling water

Attached document: Summary of the on-site survey

1. Kickoff meeting at DVC headquarters

The present survey, on the order of the Ministry of Power (hereinafter, “MOP”) and as part of activities under cooperation MOU between Central Electricity Authority (hereinafter, “CEA”) and Japan Coal Energy Center (hereinafter, “JCOAL”), has selected Damodar Valley Corporation (DVC) as the survey target and the MOP has authorized implementation of the survey. The Japanese survey structure comprises Tokyo Electric Power Company Holdings, Inc. (hereinafter, “TEPCO”), Mitsubishi Research Institute, Inc. (hereinafter, “MRI”) and JCOAL.

To start the present survey, a kickoff meeting was held on Oct. 13 at DVC headquarters.

Kickoff meeting at DVC headquarters (Oct. 13, 10:45-15:50)

- Attendees: DVC Presiding Director, Technical director, General manager concerned, DSTPS
- Mr. Kisanuki, Director, NEDO
- Survey team
  TEPCO HD: Messrs. Ueno, Kubota
  TEPCO F&P: Messrs. Ueno, Matsumoto, Murakami
  MRI: Messrs. Yamaguchi, Nomoto
  JCOAL: Messrs. Murakami, Yamada

(By seating order from upper seat) Member (Secretary), Member (Tech.), Member (Financial: absent), Chief Engineer (CE), CEA, ED (Projects: absent), ED (Engg.), ED (Fuel), CE (OS&U) (2 persons), CE, DSTPS (Power plant manager), CE (QC&I) (2 persons)

- At the beginning, chaired by Mr. D. Kar, DVC Operation General Manager, the presiding director of DVC gave an address. DVC expressed gratitude for the opportunity for DVC to take part in the cooperation with CEA and for the selection of the DSTPS for this O&M survey. DVC also added that it expected that the O&M system and process would be improved and technical challenges clarified by this survey.
- Next, the CEA Thermal Power Plant R&M General Manager gave an address. He said that even though DVC considered itself as stepping up various efforts, it has not yet succeeded in closing a technical gap between DVC and international standard. He therefore expected proposals for improvement in many fields such as O&M procedures, planning, operation management skill, etc. by this survey. He also asked TEPCO to examine every piece of equipment which might cause a loss and make countermeasures, which should be divided into short-term and mid- and long-term actions.
- Then, Mr. Kisanuki, Director, NEDO gave an address. He said that he believed that IoT would

contribute significantly to O&M improvement, key for the electric power sector in India and NEDO hoped to support the same. He hoped for the success of this survey and requested cooperation and assistance from DVC for the same.

- The JCOAL member of the survey team explained the cooperation between CEA and JCOAL to date and the position of this survey relative to the overall cooperation. Then, a TEPCO member of the team presented an example in TEPCO on O&M operation improvement and an MRI member presented details of the potential to reduce emissions.
- Finally, DVC presented details of the business summary of DVC and the actual situation of the DSTPS, survey target, followed by a question-and-answer session.

<Main topics of the question-and-answer session>

・DVC → Survey team

- ✓ IGCC efficiency and emission standard→47-48%, (No answer as for the emission standard)
- ✓ In connection with the above, TEPCO stated that Indian ash was unfit for IGCC because of its high ash content. However, considering the need to take policy-making trends of the Indian government, which wishes to keep IGCC as a political option, into account, JCOAL added that IGCC could be an important option if use of the brown coal among Indian coals or imported coals were envisaged.
- ✓ What is the material of condenser tubes? → Titanium or aluminum-copper alloy
- ✓ Is the boiler tube type spiral or vertical? → Vertical
- ✓ What is the ration of fixed coal to volatile matters? → It should be confirmed but is probably about 1.5 (fixed carbon) to 2 (volatile matters).

・Survey team→ DVC

- ✓ Are coal-fired thermal power plants positioned as base-load or middle-load plants? → They were planned and have been operated since operation start as base-load plants but amid changing circumstances, they have to be operated for load regulation purposes in response to load dispatching instructions from the power system. However, such load regulation operations result in increased in oil consumption for start-up, the reduction of which has become a major issue to be addressed.
- ✓ An explanation was given on DSTPS performance, meaning of DC (Declared Capacity), SOC (Specific Oil Consumption) and APC (Auxiliary Power Consumption), relation to CERC benchmarks and other matters. PLF and CD in this financial year were low because of the annual overhaul of the No. 1 Unit carried out in August.
- ✓ How is the quality of coals used and how they are analyzed? → Ash content: 40 to 50%. Calorific power of low quality colas is below 3,000. Analyses are made at each coal

delivery (because of the diversity of suppliers such as BCCL, ECL, MCL, CCL) and every day on coals after blending.

<Schedule of data collection and on-site survey>

- TEPCO explained the overall survey schedule:
  Up to mid-October: Data collection
  Beginning of December: On-site survey
  Until mid-January: Data collection and analysis
  End of January: Result reporting
- A request for site entry authorization was submitted in advance to DVC. However, the DVC person handling this matter did not know that for Japanese nationals to be able to enter electric power plants in India, a business visa as part of an authorization procedure in the order of MOP → Ministry of External Affairs → Ministry of Home Affairs should be observed. For this reason, after consulting CEA R&M Thermal Power General Manager on the spot, it was decided that the request for site entry authorization would be resubmitted through CEA and that DVC would subsequently confirm with authorities. It seems that authorization may be given earlier than the case in NTPC.
- The entry in the power plant is expected to be made by the first week of December.
- Subsequently, based on the list sent by TEPCO in advance, confirmation on the necessary data was made. (See "List of materials for efficiency analysis")
- It was confirmed all data exist except for 5-l "Steam condenser exhaust loss curve". However, data compilation into PDF will take time because of some specification, drawings, acceptance performance test certificates, etc. which are not in electronic form. Given the number of stored DCS data, which amounts to about 4,000 points, it is intended that only necessary points will be produced rather than extracting all the data. Moreover, the names used for data tags differ between DVC and TEPCO. Therefore, DVC will send a tag list, to which TEPCO will respond by letting DVC know the points deemed necessary by TEPCO and data collection will be conducted accordingly. Since Unit 1 is not yet in normal operation, it will take until the latter half of November to acquire data for one month.
- Confirmation of the data collection schedule
  1) DVC→TEPCO: Tag list — The week of Oct. 16
  2) TEPCO→DVC: Reply by extracting the necessary data from the tag list — Immediately after 1)
  3) DVC→TEPCO: Data for model construction (2-a and -b, 3-a, -b and -c, 5-a, -I and -p) — Immediately
  4) DVC→TEPCO: Drawings and operational data list based on 1) — Oct. 26
  5) DVC→TEPCO: One month data — Nov. 24

  Note: 3-a, -b and -c will be scanned data from hard copies.

Note: Given their huge size, data can hardly be transmitted by e-mail.
DVC and JCOAL will discuss how such data should be delivered.

2. On-site survey in DSTPS

An on-site survey was conducted from 11 to 14 Dec. 2017 with full cooperation on the part of the power plant extended to the survey team as for the preliminary data collection. The power plant personnel concerned in this survey were seen asking eagerly questions that came up on a daily basis, even beyond the meeting time, showing their expectations and seriousness. On the first day of the plant overall visit, the TEPCO sub-team noted plant safety management issues, although this subject is not, strictly speaking, within the survey scope. Considering that a headquarters senior manager underlined the need to address this subject previously in the kickoff meeting and that the subject of plant safety management was included in the scope when the CEA made an initial survey request, the survey team dealt with this subject by providing additional advice, despite knowing that this subject was not included in the survey scope.

DVC Durgapur Steel power plant

2-1. Kickoff meeting (Dec. 11, 14:30-17:00)

- CEA: Mr. B. C. Mallick, Thermal Power Plant R&M General Manager
- DVC headquarters: Mr. Tarun Kumar, Equipment Deputy General Manager
- DSTPS: Mr. S. H. Jha, Power Plant Manager; Mr. Debodas, O&M General Manager (equivalent to Deputy Plant Manage); Mr. Sanjoy Gosh, O&M Deputy General Manager; Mr. Ajoy Kesh O&M Senior Engineer; other 40 persons
- Survey team
  TEPCO: Messrs. Kubota, Ueno, Goto; MRI: Mr. Yamaguchi; JCOAL: Mr. Yamada; Interpreter: Mr. Rajeev Taliyan

Kickoff meeting in the power plant

- The meeting began, chaired by Mr. Sanjoy Gosh, O&M Deputy General Manager.
- At the beginning, the CEA Thermal Power Plant R&M General Manager gave an address. He emphasized the importance of improving efficiency and on the capability to be acquired to operate the plant, even with a partial load, without having a major impact on the equipment.
- Then the Plant Manager gave an address and stressed that full cooperation was provided in response to the request from the survey team for providing data and that such cooperation to prove the necessary data would also be extended in this power plant survey. He also stressed that any advice provided would be welcome and would be utilized to the fullest extent to improve O&M.
- JCOAL gave an address. While referencing the bilateral cooperation between CEA and JCOAL as a precondition for the O&M survey, JCOAL thanked DVC and DSTPS for their cooperation in providing data. JCOAL also explained the purpose of this power plant survey.
- TEPCO explained the schedule and survey items during the survey period (Overall situation on O&M and related matters including electricity sales agreement, etc., Daily management systems, Turbine-related equipment, Boiler-related equipment, Fuel-related equipment, Environment-related equipment). TEPCO also explained items to be checked on the delivered data.
- The other party said that they would basically accommodate the schedule as proposed by the Japanese survey team, which allowed for the team to prepare for the survey starting from the following morning without discussing it in further detail in the meeting.
- After the kickoff meeting, the team could anticipate the survey by visiting at least the control room at the proposal of the DSTPS.

2-2. Power plant survey (Dec. 12, 9:00-17:00)

- Attendees: DSTPS: Mr. Sanjoy Gosh, O&M Deputy General Manager; Mr. Ajoy Kesh O&M

Senior Engineer, Responsible persons and engineers concerned

・ Survey team

Site visit and meeting (First day)

・ The team spent more than two hours carefully visiting the power plant, including the control center visited the previous day, followed by an interview survey with the O&M department and the relevant responsible persons and engineers, based on a document prepared for each of the above-mentioned items.

・ The result of the survey is as stated in the wrap-up meeting document.

2-3. Power plant survey (Dec. 13, 9:30-17:00)

Attendees: DSTPS: Mr. Sanjoy Gosh O&M Deputy General Manager, Mr. Ajoy Kesh O&M Senior Engineer, Responsible persons and engineers concerned

・ Survey team

Site visit and meeting (Second day)

・ By agreement between the parties made the previous evening, the team spent the whole morning visiting the ID fan, coal storage areas, coal transportation facilities (including loading equipment) and laboratories. The team also visited the cooling towers and related facilities, in which Japan lacks skills and opportunities to visit such equipment.

・The team spent the afternoon proceeding with the interview survey with the relevant department as the previous day.

2-4. Wrap-up meeting (Dec. 14, 10:45-12:15)

・Attendees: DSTPS: Mr. Debidas O&M General Manager (equivalent to Deputy Plant Manager), Mr. Sanjoy Gosh O&M Deputy General Manager,
Mr. Ajoy Kesh O&M Senior Engineer, Responsible persons and engineers concerned

・Survey team

・ The survey team issued a result reporting in the wrap-up meeting.

・ During the question-and-answer session, an exchange between relevant DSTPS personnel and the survey team ensued on the subject of condenser vacuum control, the black & yellow hazard tapes for safety management, efficiency parameters of intermediate turbine, temperature control of the high-temperature reheater (HRH), etc.

・ Mr. Debodas, General Manager, while giving a closing address, expressed expectations for the final report and the intention to positively adopt advice which could be introduced immediately among that provided by the survey team (e.g. utilization of tapes for safety management).

3. Final reporting session (Jan. 24, 1-16:20)

・Attendees: Mr. Aniruddha Kumar, Joint Secretary (Thermal), MOP
Mr. Harpreet Singh Pruthi, Director (Thermal), MOP
Mr. Suman Majumdar, Under Secretary (State Thermal), MOP
Mr. B.C. Mallick, Chief Engineer (TPRM), CEA
Mr. Rajeev Kumar, Director (TPRM), CEA
Mr. Pulak Datta, Ex. Director (Opn.), HQ/Kolkata, DVC
Mr. Debajyoti Kar, Chief Engineer-I, OS&U, HQ/Kolkata, DVC
Mr. Sanjay Ghosh, Dy. Chief Engineer (O) HQ/ DSTPS andal, DVC
Mr. Ajay Kesh, Supdt. Engineer (M), MPC, DSTPS andal, DVC

・Survey team
TEPCO: Messrs. Ueno, Goto, Ueno, Murakami;
MRI: Yamagushi, Saimura; JCOAL: Murakami, Yamada

・At the beginning of the meeting, Mr. Aniruddha Kumar, Thermal Power Plant Director General, who served as Joint Secretary of the reporting session meeting for the first time in various CEA-JCOAL cooperation projects, expressed his thanks. He attended the first part of the report presented by the survey team, then left to join another meeting. The gist of his comments, including those he made on leaving the meeting, are as follows:

It is delightful that the O&M survey requested by India has reached such a final stage and with such comprehensive contents, for which my most sincere thanks are extended to the Japanese side. For India, with the world's largest coal-fired thermal power production, the recommendations provided by this survey have huge implications, expected to impact not only on efficiency but also all other fields such as cost, reduction of carbon emissions, etc. DVC is expected to take action diligently for each of the recommendations provided.

- At the request of Mr. Aniruddha Kumar, Mr. Pulak Datta, DVC Executive Director of Operation, said that although he would like to implement the recommendations from those that could easily be done, since he would have to consider how best to consult/discuss with OEM, he would appreciate it if detailed information were explicitly presented in terms of duration of equipment shutdown (as required), a payback period, who is to bear/perform the work, preparations and materials necessary to implement the proposed recommendations.
- Mr. Rajeev Kumar, CEA TPRM Director, who proposed the present survey when visiting Japan last year, commented that given that what CEA expects from this survey is to show clearly the situation in comparison with best practice in Japan, he would like to categorize the fields to help remedial actions in each electric power company and hoped that such expectations would be taken into account in the final report.

(See the body of report for discussions on specific technical matters)

- For DVC to determine whether or not to implement the four improvement items proposed by TEPCO, DVC wished to be informed of the investment amount and work scope for each item. No further discussion was made on this request in the meeting because the survey team wished to take it back to discuss within the team. After the meeting, the survey team discussed it internally and decided to prepare a table summarizing the approximate estimation of equipment or material cost (in Yen) as well as the manpower and time necessary for each of the recommendations.
- Since the meeting could not be continued further in the afternoon for reasons attributable to the Indian side, TEPCO explained and pitched its O&M service in the last 10 minutes of the morning session. The parties concerned closed the meeting with a commitment to continuing an ongoing exchange of views.