Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 2000

Web-based Turbine Cycle Performance Analysis for Nuclear Power Plants

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ABSTRACT

As an approach to improve the economical efficiency of operating nuclear power plants, a thermal performance analysis tool for steam turbine cycle has been developed. For the validation and the prediction of the signals used in thermal performance analysis, a few statistical signal processing techniques are integrated. The developed tool provides predicted performance calculation capability that is steady-state wet steam turbine cycle simulation, and measurement performance calculation capability which determines component- and cycle-level performance indexes. Web-based interface with all performance analysis is implemented, so even remote users can achieve performance analysis. Comparing to ASME PTC6 (Performance Test Code 6), the focusing point of the developed tool is historical performance analysis rather than single accurate performance test. The proposed signal processing techniques are validated using actual plant signals, and turbine cycle models are tested by benchmarking with a commercial thermal analysis tool.

I. INTRODUCTION

Many changes are now under way in the power industrial structure of Korea. One of the most important things among them may be the introduction of deregulation environment, and the most emphasized thing in deregulation environment is economical efficiency improvement. For the improvement of economical efficiency of a nuclear power plant (NPP), there may be many approaches to achieve this. In this study, a thermal performance analysis tool for steam turbine cycle of an NPP has been developed. The objectives and state-of-the-art technical status related to this study were already described [1].

In domestic or foreign power industries, there are many performance analysis tools that have similar functions comparing to the one developed. However the developed tool has unique characteristics as follows;

- All thermal performance analysis for a steam turbine cycle is achieved on web interface. Users do nothing but have a web browser and site access authorization to carry out thermal performance analysis.
- Thermal performance analysis is composed of two sub-calculations. The one is predicted performance calculation and the other is measurement performance calculation. The predicted performance calculation is for steam turbine cycle simulation under hypothesis plant conditions. The measurement performance calculation is for analysis under current operating conditions.
- To implement the predicted performance calculation, a steam turbine-generator predicted performance calculation procedure standard is based [2]. For the measurement performance calculation, field performance test procedures as well as ASME PTCs (Performance Test Codes) are referred to preserve the consistency with site works [3, 4].
- Considering field situation where it is difficult to get enough signals for thermal performance analysis, a few statistical signal processing techniques are introduced for signal validation and prediction.

In the following sections, detailed explanation about (1) system configuration and thermal performance analysis procedures using the developed tool, (2) integrated signal processing technique, (3) steam turbine cycle modeling, (4) interface implementation and demonstration will be described.

II. SYSTEM DESCRIPTION

II.1. System configuration and thermal performance analysis procedures

Conventionally steam turbine cycle thermal performance tests in NPPs are based on the ASME PTC6, PTC6.1 or 6S. The main reason to use the ASME PTCs may be that they are accepted as the worldwide standard test procedures and have been validated for a long time. The ASME PTCs have their own importance from test accuracy point of view. However the rigorous requirements of the ASME PTCs make flexible performance tests difficult [5]. Actually the persons in charge want to watch historical changing of performance indexes through frequent performance tests, and to know what if a turbine cycle is modified in performance analysis of operating NPPs differently from an acceptance tests. Additionally because of popularization of internet and automation of office work, the development of system configuration and interface to reflect them is being strongly requested. So the proposed tool has on-line, server-client structure with web interface like Figure 1. Performance tests are significant to head officers or performance analysis researchers as well as plant field engineers. So the performance test system is organized as server-client structure. The server side is located in a plant field and the client side can be any other offices. In the server side, there are data acquisition facilities and a performance analysis server. The data acquisition facilities take in charge of getting signals by on-line or off-line. The IPMS (In-Plant Monitoring System), the OACS (Operator Aid Computer System) or instrumentation system installed temporarily can be a signal source. Off-line data acquisition is also needed for the input of unmeasured signal or documented data. The performance analysis server consists of a signal processing module, performance analysis module, database supporting performance analysis, and web server engine. To give access-ability into the server to remote users, web-based interface is provided in client terminals.

Turbine cycle thermal performance analysis is carried out by two modes;

- Periodic mode: A user can specify execution period of a performance test. The periodic mode is based on on-line data acquisition.
- Request mode: User can make a request of a performance test non-periodically. In this case, it is necessary to set the interval analyzed. Snapshot data inputted by off-line is also usable.

A performance test may produce three types of heat balance diagrams as follows;

- Dynamic performance index diagram: This is consistent with operating heat balance calculation of the ASME PTC6. Cycle- and component-level performance indexes under operating conditions are calculated. In on-line signal acquisition, the signal processing techniques for validation and prediction are used.
- Dynamic baseline diagram: This diagram is drawn by turbine cycle predicted performance calculation based on performance indexes and turbine cycle boundary conditions taken from a dynamic performance index diagram. It can provide a completed set of operating heat balance diagram on the basis of turbine cycle simulation. Comparing this to a dynamic performance index diagram, a user can recognize 1) unidentified leakage locations, 2) outlier points on measurement, and 3) turbine expansion lines. Suitable maintenance actions can be prepared after identifying leakage locations or outlier measurement points. Turbine expansion lines may be used to evaluate turbine in itself performance.
- Static baseline diagram: A user can input all turbine cycle boundary conditions and performance indexes manually. This module makes turbine cycle 'what-if' analysis possible. This method can be used as feasibility study tool of the replacement of components or the change of operating conditions by comparing between a dynamic baseline diagram and a static baseline diagram.

The dynamic performance index diagram and the dynamic baseline diagram are generated in both the periodic mode and the request mode. The static baseline diagram is usable in the only request mode. Also the dynamic performance index diagram is related to the measurement performance calculation, and the others are related to the predicted performance calculation. Overall performance test scheme is shown in Figure 2.

Generally performance tests are carried out before and behind of overhaul. The performance test before overhaul is for the preparing of maintenance programs taken during overhaul, and the other is for the confirmation of the effectiveness of maintenance programs accomplished. The proposed performance test scheme can make up for current condition-based preventive maintenance program, and it is advantageous to save time-, human-, and cost-resource than the previous performance tests.

II.2. Integrated signal processing technique

The purpose of integrated signal processing is to obtain healthy signals needed in performance tests and to provide qualified signals to analysis modules. Because of economic and/or technical limitation, most of plants don't have enough instruments for performance tests. Moreover there is the case when signals are useless because of their low quality even if the signals are acquired. To get the signals with high reliability, we carry out multi-stage signal processing.

In the performance test based on on-line data logging differently from manual logging, all signal processing techniques should be computerized, and suitable signals should be generated through self-diagnosis even if necessary sensors are not installed or unreliable. The overall signal processing consists of the following steps;

- Basic check,
- Identification of necessary but unmeasured signals,
- Classification of temporal or permanent sensor failure,
- Excluding temporally failed signals,
- Estimating both permanently failed signals and unmeasured signals.

<u>II.2.1 Basic check</u>

In this step, signal range and fluid state such as subcooled, saturated, or superheated are checked. Compared with the specified sensor range, each signal would be checked whether it is normal or abnormal. The sensor range is fixed according to manufacturer's sensor manual. Reference fluid state at inlet/outlet of each component is fixed according to thermal power level. Compared with reference fluid state, pressure and temperature at inlet and outlet are checked, and it is classified as normal or abnormal state. In an NPP, most of fluid states are saturated or subcooled and there is no large change in fluid state though thermal power level is varied.

<u>II.2.2 Failure classification</u>

Measured signals are classified into three categories, normal, temporal failure, and permanent failure according to their historical distribution. Momentary noise in short time scale is regarded as temporal failure. On the other hand, permanent failure is defined as the signal completely failed or severely degraded. Other signals would be normal. Because the failure classification is based on probability distribution, sufficient sample signals are necessary. Therefore it is not achieved when a performance test is carried out using snapshot signal set.

Temporal failure can be handled on the basis of sample standard deviation. According to the ASME PTC6R, temporal failure is defined as the value out of 95% confidence level from a sample mean. The proposed system keeps this criterion.

For the identification of permanent sensor failure, the sequential probability ratio test (SPRT) is applied. The general theory and application of the SPRT is known widely. [6~8] Because we are only concerned with mean variation in this step, the following recursive SPRT formula is used for each signal.

$$\Lambda_{k+1} = \Lambda_k + \frac{m_0 - m_1}{s^2}\left(x_{k+1} - \frac{m_0 - m_1}{2}\right) \quad (1)$$

where
L_k: kth log-likelihood value, x_k: kth measured value,
m_0: mean of x_k in normal, m_1: mean of x_k in permanent failure,
s^2: variance of x_k.

A measured signal is considered as a random variable because sampling interval is specified not too shortly even if there is autocorrelation feature. It is assumed that the distribution of a measured signal has normal probability density function, $N(m, s^2)$. m_0 is specified for each signal according to thermal power level and m_1 is set to 5% upper/lower of original mean. s^2 follows sensor manufacturer's data.

When a log-likelihood value is exceeded the following decision boundary, the signal is regarded as permanent failure.

$$A = \ln\left(\frac{1-b}{a}\right) \tag{2}$$

where
α: false determination probability (Type I error),
β: miss determination probability (Type II error).

Considering conservativeness, α is set smaller than β. However, even if a signal is normal, its log-likelihood value may hit the decision boundary after long time in case of on-line signal acquisition from equation (1). Therefore appropriate data range analyzed should be fixed. This range is established by average sampling number (ASN) that is time interval until the identification of permanent failure. An ASN is calculated for each signal according to α, β, m_0, m_1, and s.

II.2.3. Signal estimation

If a sensor becomes permanently failed, a suitable value should be generated instead of the measured value. In this step, an unknown signal is estimated by linear combination with reliable signals correlated with the unknown signal. The identification of the correlation is based on the correspondence analysis (CA). The CA is a statistical visualization method for picturing the associations between the levels of a two-way contingency table, and is also a geometric technique for displaying the rows and columns of a two-way contingency table as points in a low-dimensional space. [9] The positions of the row and column points are consistent with their associations in the table.

To show an application example, a portion of the signals of Kori unit 1 was summarized in Table I. Signal values were collected according to power level, and the units of signal value are not necessary in the CA. Let's define Table I as a signal matrix N, a matrix of non-negative numbers. The correspondence matrix P is defined as a matrix of elements N divided by the total sum of N. The vectors of row and column sums of P are denoted by r and c respectively and the diagonal matrices of these sums by D_r and D_c.

The generalized singular value decomposition of $\mathbf{P}-\mathbf{rc}^T$ is

$$\mathbf{P}-\mathbf{rc}^{\mathbf{T}} = \mathbf{ADB}^{\mathbf{T}}, \text{ where } \mathbf{A}^{\mathbf{T}}\mathbf{D}_{\mathbf{r}}^{-1}\mathbf{A} = \mathbf{B}^{\mathbf{T}}\mathbf{D}_{\mathbf{c}}^{-1}\mathbf{B} = \mathbf{I} \tag{3}$$

We can get the **D** from equation (3). The coordinate of the row profiles, **F** is

$$\mathbf{F} = \mathbf{D}_{\mathbf{r}}^{-1}\mathbf{AD} \tag{4}$$

In our application, the coordinate of the points with respect to an optimal two-dimensional subspace is contained in the rows of the first two columns of **F**. Figure 3 is the simple result of this CA analysis. In Figure 3, the original dimension of the signal matrix in Table I is reduced to two-dimension. According to the linearity between two row vectors, the distance between two positions becomes closer. In Figure 3, the point pair of 4, 5 and 10, 11 shows the nearly linear relation. And the point 3, 6 have the almost same positions. So 6th row values are 1.0051 times as large as 3rd row values in all the columns. On the basis of this analysis result, unknown signal and permanent failure can be estimated as follows:

$$\mathbf{R} = \mathbf{D}_r^{-1}\mathbf{P} = \begin{bmatrix} \mathbf{r}_1^T \\ \vdots \\ \mathbf{r}_I^T \end{bmatrix}, \tag{5}$$

where I is the row size of P, $\hat{\mathbf{r}}_i^T = f\left(\mathbf{r}_j^T, g\left(\mathbf{r}_j^T\right)\right)$ for all j ($\neq i$).

The f is an estimation function from the other measured signals. The g is the distance function from the unknown row vector to the other measured row vector and is derived from the two-dimensional plane such as Figure 3.

As the base data for the CA accomplishment, the turbine cycle heat balance diagrams constructed in a plant acceptance test are utilized. Because the highly reliable sensors are used in an acceptance test, its heat balance diagrams are very effective to collect the CA data.

II.3. Steam turbine cycle modeling

Turbine cycle modeling is to develop the modules to draw three heat balance diagrams. In conclusion, turbine cycle modeling is composed of the predicted performance calculation module and the measurement performance calculation module. The predicted performance calculation is related to steady-state turbine cycle simulation, and its objective is to determine fluid conditions at inlet and outlet of each component. The measurement performance calculation is related to performance indexes calculation such as heat rate, thermal efficiency, terminal difference temperature, and so on.

II.3.1. Predicted performance calculation

Steam turbines used in NPPs are operated in wet steam region. The state of working fluid, water, at inlet/outlet of a high pressure (HP) turbine or a low pressure (LP) turbine is wet steam of which quality is about 0.80~1.00. Because of the difficulty of analytical modeling for moisture separation at turbine extraction lines, it is known that the modeling of wet steam turbine cycle is difficult and inaccuracy, if not possible. In case of fossil fuel plants, it is possible to implement high accuracy turbine cycle model since turbine cycle of fossil fuel plants is operated in superheated steam region.

The fundamental principle of component modeling is steady-state mass and energy balance equation. Additionally the correlations of GET-6020 are used for the modeling of wet steam turbine. [2] However the contents of GET-6020 is not enough to implement a specified turbine cycle because it explains General Electric-oriented turbine cycle. Especially it is very doubtful that correction curves, turbine efficiency curves, moisture separation effectiveness curves provided in GET-6020 are suitable to all types of turbines used in Korea. Therefore basic modeling procedure is based on

GET-6020 and minute tuning of the developed model left as further study. There are relatively sufficient materials about the modeling of other components except turbines. The component models implemented are shown in Table II. Considering flexible turbine cycle modeling, all the component models are implemented separately and a user can construct any piping network of a steam turbine cycle. Component models can be classified into logical and physical component. The logical components are necessary to simulate junction among pipes or leakage of working fluid. The physical components are actually the existing ones in a steam turbine cycle.

In predicted performance calculation, a user should input attributes that are composed of geometry data and performance indexes to each component. Attributes work as constraints in calculating mass and energy balance. To adjust these constraints in cycle-level, demand related components are necessary. Mass and energy balance on the constraints is adjusted by the exchange of fluid conditions among demand related components. Three convergence criteria as the standard of adjustment are as follows;

- The flowrate difference between inlet and outlet of a pipe should be less than a specified value.
- In the shell of the component that has inlet ports connected with a downward component, the flowrate difference between previous and current calculation in the shell should be less than a specified value.
- In the mixer, the difference between the sum of inlet flowrate and the sum of outlet flowrate should be less than a specified value.

The calculation sequence for each component follows a pre-defined calculation order. The calculation order is generated automatically after constructing a piping network.

II.3.2. Performance index calculation

It is too difficult to understand overall turbine cycle status with the only predicted performance calculation to determine fluid conditions. To provide indexes that represent component or cycle performance level, performance index calculation module is necessary. The performance index calculation is based on the fluid conditions determined by the predicted performance calculation or actual measurement signals. The performance index calculation is carried out for the only physical components, and cycle-level performance indexes are calculated after component-level performance index calculation. To improve the applicability to field, field performance test procedures are used as main algorithm. The summary of the performance index calculation is shown in Table III and Table IV. Component-level performance indexes in Table III and cycle-level performance indexes in Table IV are described. The detail definitions of each performance index are shown in the related reference [3].

II.3.3. Model validation

For the validation of the developed models, benchmarking tests are accomplished. As a target plant, Kori Unit 1 was selected because it is relatively easy to get performance test data due to the replacement of LP turbine lately. As a reference benchmarking tool, PEPSE (Performance Evaluations of Power System Efficiencies), one of the popular thermal performance analysis tools, was selected. [10] A validation about 100% load case was carried out, and the necessary attributes can be taken from the related references. [11, 12] Figure 4 shows a simplified P&ID of Kori Unit 1 and

Figure 5 is a modeling result using the developed component models on the basis of Figure 4. Because all the attributes are the same in both PEPSE model and the proposed model, the only turbine expansion lines on H-S diagram become grounds to compare benchmarking results. Figure 6 shows turbine expansion lines drawn by the developed model, PEPSE, and reference information.

II.4. Interface implementation

All the functions needed in drawing three heat balance diagrams under on-line or off-line data acquisition are performed in a web browser. It consists of three parts, 1) general engineering tools, 2) heat balance diagram, and 3) input/output verifying tool. The general engineering tools include unit conversion and steam table library.

As a demonstration, the interface for Kori unit 1 was implemented on web for the consistency with modeling modules. There are two operating modes. The one is 'Predictive performance mode' for the static baseline diagram. The other is 'Measurement performance mode' for the dynamic baseline/performance index diagram. According to user authority, accessible functions are different. Figure 7 is the display of the performance test system.

III. CONCLUSIONS AND RECOMMENDATION

In this study the thermal performance analysis tool for steam turbine cycle with web-based interface has been developed. The top principle for the validation and the prediction of the signals used in thermal performance analysis is the adoption of methodologies that can be explained analytically. According to this principle, the only statistical signal processing techniques such as CA or SPRT are introduced in addition to fundamental signal processing techniques on the basis of the characteristics of working fluid and detectors. Both the predicted performance calculation and the performance index calculation can draw three heat balance diagrams to sufficiently analyze plant performance level, so they can be substituted for the previous performance test procedures. All the models to carry out performance analysis were developed independently and validated partly using actual plant signals and a commercial thermal analysis tool. Therefore this study may be meaningful from the viewpoint of localization. The focusing point of the developed system is to do historical performance analysis by low cost. This feature makes it possible to support condition-based maintenance programs and to reduce resource needed in performance tests. To maximize work efficiency and to reduce resources for performance tests, on-line/off-line data acquisition capability, server-client system configuration, and a web-based interface with all performance analysis capability are provided.

However it is yet difficult to adopt the proposed system to actual field because of 1) turbine model inaccuracy, 2) narrow range validation for signal processing techniques, and 3) the incompleteness of interface implementation. These shortcomings will be solved gradually by additional validation using field data and mock performance test experiences.

IV. REFERENCES

[1] G. Heo, S.J. Lee, S.H. Chang, and S.S. Choi, "Thermal Performance Test through On-line Turbine Cycle Performance Monitoring in Nuclear Power Plants", Proceedings of the KNS Autumn Meeting, 1999.
[2] F.G. Baily, J.A. Booth, K.C. Cotton and E.H. Miller, Predicting the Performance of 1800-RPM large Steam Turbine-Generators Operating with Light Water-Cooled Reactors, General Electric Company, GET-6020, 1973.
[3] Standard Performance Management Guidelines for Nuclear Power Plants, KOPEC, April 1993.
[4] W.A. Campbell, Performance Test Code 6 on Steam Turbine, ASME PTC 6-1996, March 1996.
[5] G.H. Yoon, ASME PTC6.0 Code Analysis, '97 Plant Performance Management Seminar, KEPRI, TM.C97GS04.M97.868, pp. 47 ~ 63, 1997.
[6] A. Wald, Sequential Analysis, John Wiley & Sons, New York, 1947.
[7] Tze-Thong Chien and Milton B. Adams, "A Sequential Failure Detection Technique and its Application", IEEE Trans. Automatic Control, vol. 21, 1976, pp. 750-757.
[8] Keith Humenik and Kenny C. Gross, "Sequential Probability Ratio Tests for Reactor Signal Validation and Sensor Surveillance Applications", Nucl. Sci. Eng., Vol. 105, 1990, pp.383-390.
[9] M.J. Greenacre, Theory and Applications of Correspondence Analysis, Academic Press, New York, 1984.
[10] G.C. Alder, B. Blakeley, D.R. Fleming, W.C. Kettenacker, and G.L. Minner, PEPSE and PEPSE-GT User's Guide, ScienTech. Inc., 1998.
[11] G.H. Choi and S.S. Lee, "Turbine Cycle Thermal Performance Analysis According to Replacement of Steam Generator for Kori Unit 1", Proceedings of the KNS Autumn Meeting, 1999.
[12] S.K. Kim, Development of Heat Balance Diagram and Upgrade of NOPAS Program due to Replacement of LP Turbine in Kori unit 1, 4, KEPRI, HRC-98K-M01, June 1999.

Table I. Signal matrix for CA

No	Signal Name	Plant Power Level			
		100%	75%	50%	25%
1	$P_{sg,out}$	60.7	64.3	67.7	71.1
2	$H_{sg,out}$	2777.5	2774.8	2771.7	2768.1
3	$W_{sg,out}$	1027.1	762.6	509.1	268.1
4	$T_{sg,in}$	221.1	206.8	188.6	162.0
5	$H_{sg,in}$	950.3	885.8	805.1	689.8
6	$W_{sg,in}$	1032.3	766.4	511.7	269.5
7	$P_{cond,in}$	0.051	0.045	0.039	0.036
8	$H_{cond,in}$	2274.1	2288.9	2311.7	2368.1
9	$W_{cond,in}$	562.3	433.4	303.8	172.5
10	$T_{cond,out}$	33.2	30.9	28.7	27.1
11	$H_{cond,out}$	138.9	129.5	120.4	113.6
12	$W_{cond,out}$	679.3	514.2	353.0	193.8
…	…	…	…	…	…

P: pressure, H: enthalpy, W: flowrate, T: temperature,
SG: steam generator, COND: condenser
IN: inlet, OUT: outlet.

Table II. Predicted performance calculation summary for a steam turbine cycle

Group	Subgroup	Logical(L) /Physical(P)	Demand related	Etc.
Piping	-	L or P	-	Pressure drop model based
Turbine	Governing stage	P	-	GET-6020 based
	HP turbine stage	P	Yes	
	LP turbine stage	P	Yes	
Heat exchanger	Standard	P	-	-
	Reheater	P	Yes	-
	Drain cooler	P	Yes	-
	Feedwater heater	P	Yes	-
	Condenser	P	Yes	-
Mixer	Standard	L	Yes	Piping union
	Deaerator	P	Yes	-
Splitter	Standard	L	Yes	Piping separation
	Moisture separator	P	-	-
	Drain tank	P	-	Feedwater heater drain tank
	Steam seal regulator	P	Yes	LP turbine packing fluid supplier
	Martins' formula based	`	-	For valve or turbine packing leakage
Pump	Motor driven	P	-	Pump performance curve based
	Turbine driven	P	-	
Valve	-	P	-	For governing valve and stop valve
Boundary Condition	Source	P	Yes	For steam generator, venting or reservoir
	Sink	P	-	

Table III. Component-level performance index calculation summary

Group	Performance index	Etc.
Turbine	Stage efficiency	
	Moisture separation effectiveness	Only for existing extraction lines
	Stage power	
	Pressure ratio	
	Shell flow coefficient	
Heat exchanger	Subcooled margin	Only for condensers
	Heat load	
	Terminal temperature difference	Except standard heat exchangers
	Drain cooler approach	Only for feedwater heaters and drain coolers
	Log mean temperature difference	
	Heat transfer area	
	Heat transfer coefficient	
	Tube cleanliness factor	
	Temperature effectiveness	
Splitter	Moisture separation effectiveness	Only for moisture separators
Pump	Pressure rise	
	Enthalpy rise	
	Developed head	
	Pumping power	
	Pumping efficiency	

Table VI. Cycle-level performance indexes

• HP and LP power	• HP and LP efficiency
• Generator operating capacity	• Thermal efficiency based on reactor output
• Generator mechanical loss	• Thermal efficiency based on SG output
• Generator electrical loss	• Gross heat rate
• Generator output	• Net heat rate
• Reactor output	• Steam rate
• Steam generator (SG) output	

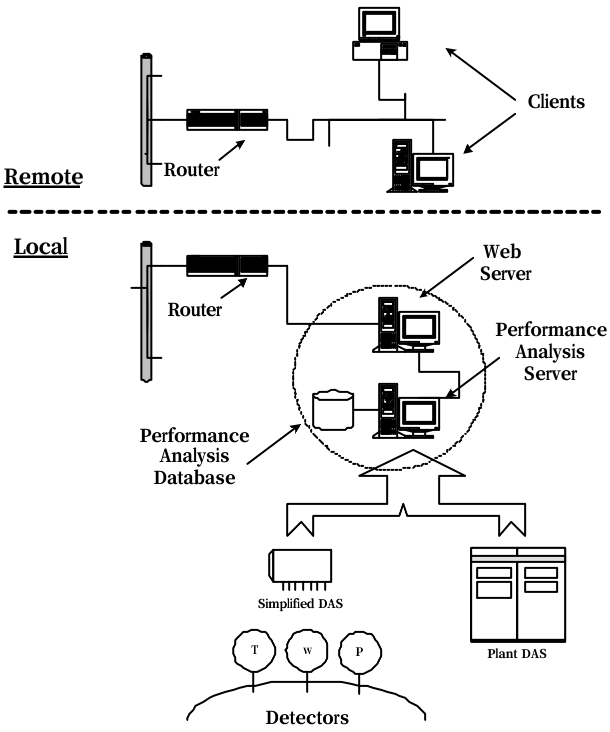

Figure 1. Overall concept of turbine cycle thermal performance analysis system

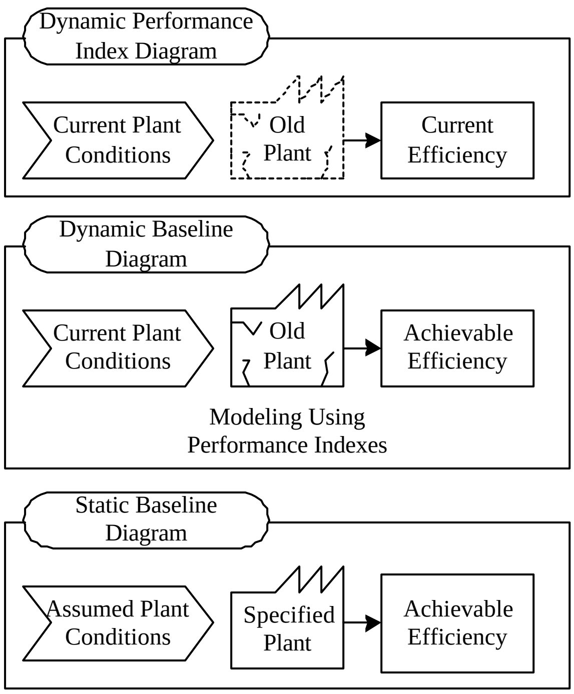

Figure 2. Overall thermal performance test scheme

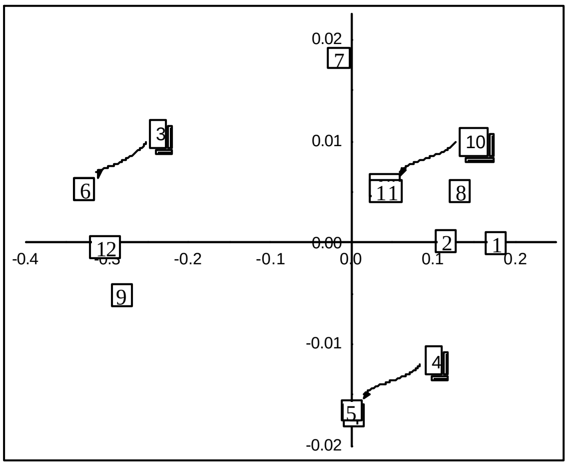

Figure 3. CA results for Kori unit 1 data

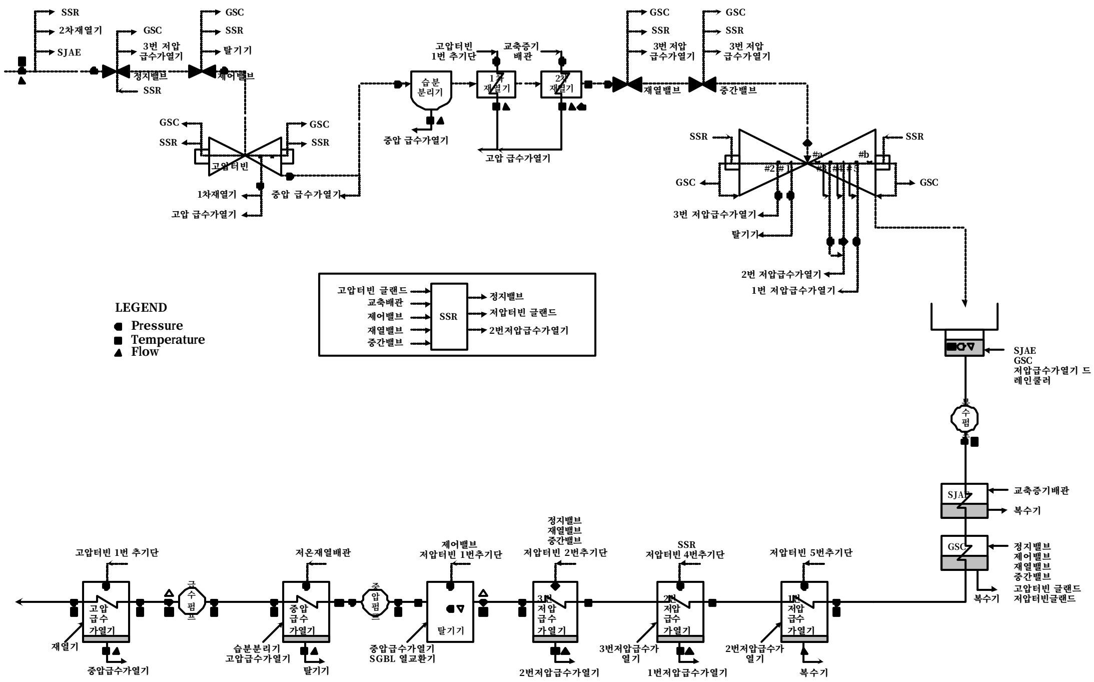

Figure 4. Simplified P&ID and measurement positions of Kori unit 1

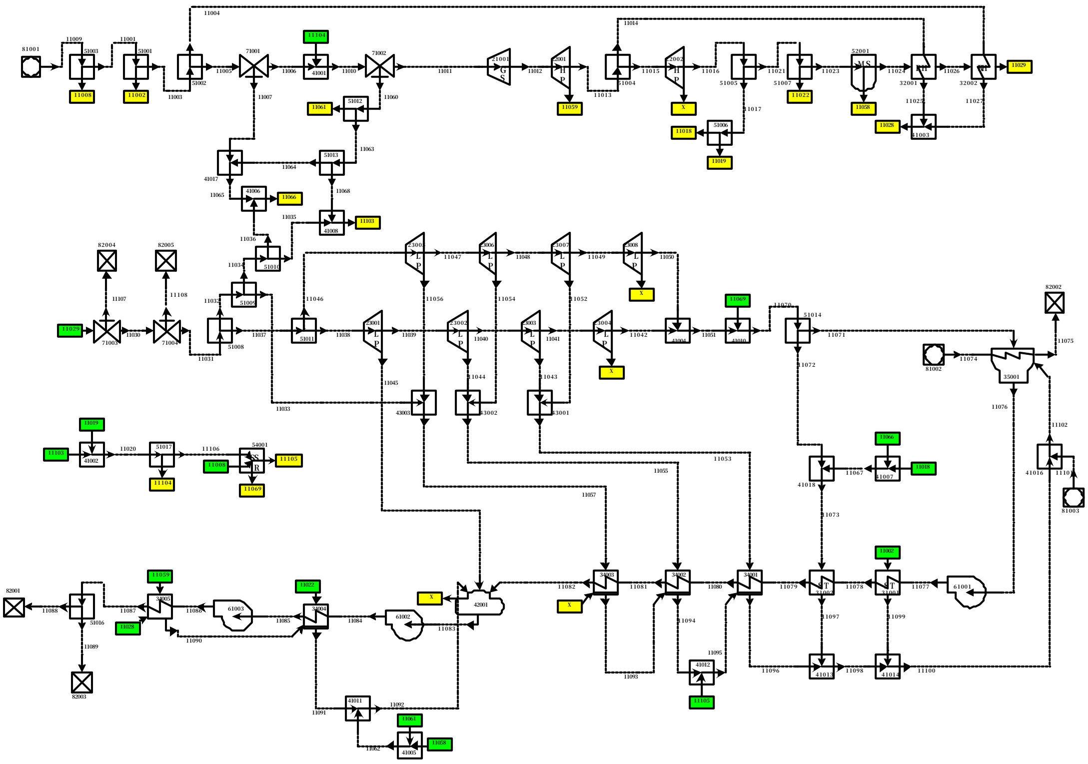

Figure 5. Modeling configuration of Kori unit 1

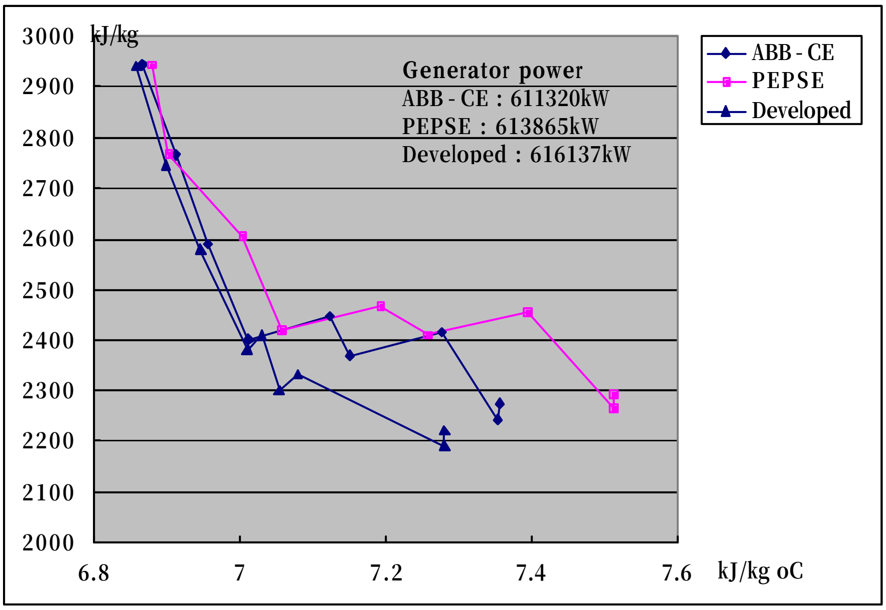

Figure 6. Low pressure turbine expansion lines

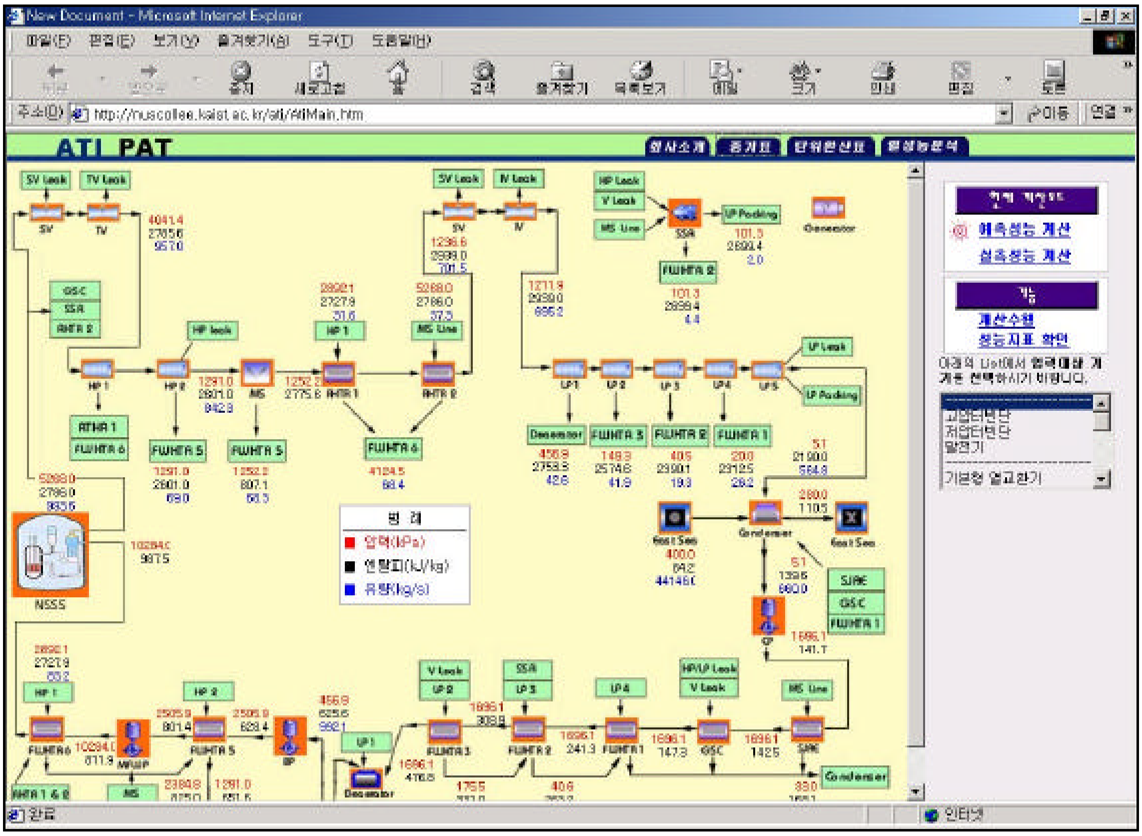

Figure 7. Display of thermal performance analysis tool user interface