PERSPECTIVE: POWER GENERATION

The articles in this issue of POWER TECHNOLOGY touch on a number of subjects relevant to the power plant. Generation system efficiency and reliability, long the focus of significant effort by electric utilities, are receiving even more emphasis in today’s environment. Individual machine performance must be accurately characterized to ensure the most cost effective allocation of all units on the system as well as ensure both unit and system reliability. This characterization, in turn, requires accurate knowledge of the detailed dynamic and economic elements that determine the performance of the generating unit.

A generating unit is subject to continuously changing dynamic conditions, both normal and abnormal. The machine must function successfully under these conditions and its complex controls must take the correct actions under all situations. To ensure the proper operation, accurate analyses of power plant operation and performance are required and demand a wide variety of engineering skills. Modern instrumentation technologies, numerical analysis techniques, economic dispatch methods, and dynamic modeling must all be applied — in both mechanical and electrical disciplines. These must be melded with hands-on, practical experience to address the reliable and economic performance of the power plant and the overall generation system.

The articles in this issue of POWER TECHNOLOGY consider several important subject areas of generation performance. Accurate and reliable instrumentation is essential to high quality monitoring, upon which performance analyses depend. The article by Bob de Mello discusses a critical instrumentation device, the flow nozzle. Tim Schmehl and Bernie Fitzgerald describe the PTI Performance Analysis System (PAS) which is software that assists the engineers responsible for obtaining the power plant performance data. The article by Jim Reddington explains the valve loop phenomena in steam plants with partial arc admission valves and discusses the effect of these nonsmooth characteristics on the parameters used for the economic dispatch of power systems in system control centers. In his article, Carmelo Kona discusses a serious control problem occasionally encountered and the dynamic simulation used to analyze and assist in the solution of the problem.

NEW PAS RELEASE INCORPORATES INTERACTIVE PERFORMANCE CALCULATIONS

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PTI recently released version 1.2 of the Performance Analysis System (PAS). PAS is a software package which assists power plant performance engineers in the setup, running, and analysis of a performance test. Since its introduction in the October 1985 issue of POWER TECHNOLOGY, PAS has seen extensive field testing and evaluation. Version 1.2 of PAS incorporates many new features which were based on the results of these field experiences. In addition, the interface to data acquisition equipment has been simplified.

TIME SIMULATION OF FURNACE DRAFT EXCURSIONS

C. Kona, Analytical Engineer

Operation of modern high-draft-loss furnace designs must recognize that plant operating disturbances, particularly a master fuel trip (MFT), can cause serious negative pressure excursions. High draft losses require high-head induced draft fans which greatly increase the potential for these severe pressure excursions and, in some cases, furnace implosions. Therefore, firing and furnace draft controls must be designed with careful consideration of their dynamic behavior during a major disturbance.

Furnace pressure excursions may be caused by uncoordinated manipulation of forced draft (FD) and induced draft (ID) fan controls, such as the accidental tripping of an FD fan, or by rapid changes in furnace gas temperature due to severe changes in fuel input, such as during an MFT. The interplay between the fluid flow and furnace control parameters make it difficult intuitively to determine the net result of a major trip. It becomes essential to use a time simulation computer model to adequately capture the combination of non-linearities involved.

Time simulation studies model the gas flow dynamics and transient heat transfer relationships within the furnace. In addition, a model of the specific furnace controls is constructed to interface with the gas flow calculation. In this way, various control schemes may be devised and their effect on the fluid dynamics can be studied.

Studies of this type are required whenever a boiler modification or control system modification is considered or during the conversion of an older system for new operating conditions, i.e., converting from pressurized furnace to controlled draft by addition of ID fans. The specific details of each installation must be carefully analyzed and an appropriate computer model constructed. The model is usually verified with field test data.

Figure 1

(Continued on Page 2)
CONSIDERATION OF STEAM TURBINE VALVE LOOPS ON UNIT PERFORMANCE

J.R. Reddington, Analytical Engineer

Mathematical models used in the determination of economic operations of electric power systems frequently assume that the input/output characteristics of generating units are continuous strictly convex increasing functions. This assumption implies that the total unit fuel use increases smoothly with unit output. However, it is also widely recognized that losses which violate this assumption are incurred in the control of steam flow by the turbine governing valves. For turbines operated with partial arc admission (valves opened sequentially with increasing load), the effect of throttling and first stage efficiency, if accurately represented, would result in an input/output curve that looks like a series of loops which are concave downward and which join each other at the valve best points shown in Figure 1. Note that the curvatures of the valve loops are more pronounced at the lower loading range of a unit but tend to flatten out at the upper end.

NEW PAS RELEASE INCORPORATES INTERACTIVE PERFORMANCE CALCULATIONS (Continued from Page 1)

PAS is organized to follow the steps necessary to run a typical performance test; namely the set up, the test, and the production of results. The system is specifically designed to shorten the time from the initial planning for a test to the production of test results.

The Set Up function of PAS links the physical process parameter being measured, the specific instrument measuring it, and the data acquisition hardware to which the instrument is connected. The engineer creates a test Set Up by specifying how the instrumentation and data acquisition equipment are linked together. A unique calibration curve or constant for each instrument may be defined. Set Up configurations may be saved and recalled for later use, or may be modified as test requirements change. In this manner, test Set Ups for many different units and unique component tests may be developed and used repeatedly.

Version 1.2 has a new channel calibration procedure and a new type of PAS point, the calculated variable. A calculated variable is a PAS point whose value is a function of other PAS points. For example, a differential pressure could be measured by configuring a calculated variable to be the difference of two measured pressures. Calculated variables, like all PAS points, are calculated and stored in real-time.

During a test, that is while data collection is underway, the test engineer has full use of the built-in statistical and analytical function. This enables the engineer to make informed decisions about the test duration and/or data validity while a test is in progress. Once the engineer is satisfied with the data sample based on the statistical analysis, a library of performance calculations is available to assess component performance. The calculation of results can occur while data is still being collected — at any time during a test, or after the test is complete. There is no waiting to manually average handfuls of numbers, or convert millivolts to temperature, or calculate flows. PAS does this all on-line, following the Set Up configuration which was defined days or even months before the actual test.

New display functions have been added to version 1.2 of PAS. With a single keystroke, the test engineer can view the current value of every pressure, temperature, flow, etc., along with the status and a description of the point, in real-time, while a test is underway.

The PAS Analysis and Reporting functions have been greatly expanded in version 1.2 by the addition of a plot function and the integration of two existing PTI products, Interactive Performance Calculations (IPC) and the Steam Tables Program (STP). These two programs have been implemented on power plant data acquisition and control computers for continuous performance monitoring.

The recent addition of IPC to the menu of PAS analysis and reporting functions has given the system a new dimension in analysis capability. The engineer may select from an extensive list of performance calculation modules. Each module is a rigorous calculation routine to assess component performance. In addition to the standard calculations such as enthalpy-drop efficiency, IPC provides functions to help the engineer evaluate the calculated results. Routines for sizing flow orifices, performing "what if" scenarios, and sensitivity studies to determine the influence of each input on a calculated result are but a few of IPC's features. Among the calculations in the IPC library are:

- Air preheater effectiveness
- Boiler efficiency
- Condenser cleanliness
- Furnace heat transfer coefficients
- Heat balance (HP/LP heater string)
- Feedwater heater performance
- Turbine section efficiencies
- Shaft and packing steam leakage flows
- Turbine-Cycle heat rate
- Unit heat rate
- Deviations and operator controllables

IPC can be used immediately upon initiation of data collection. The engineer determines when the test is completed based upon successful calculation of component performance, not at the end of a clock hour or some other arbitrary parameter. Thermodynamic properties of steam and water are calculated implicitly without the use of approximations.

PTI's Performance Analysis System was designed to assist the performance engineer with all aspects of periodic performance testing. PAS gives the tests engineer powerful tools for the collection and analysis of data. Version 1.2 has incorporated new features which have been developed as a result of continued field experience and user feedback.

Figure 1. Typical Input/Output Curve With Locus of Valve Best Points

Periodic testing of generator units are normally performed at valve best points with the resulting test data fitted into a monotonically increasing function for use in economic dispatch computations. However, a smooth input/output curve passing directly through these points will tend to underestimate the fuel input whenever the unit is operated away from these points, that is, with valves partially open.

In order to quantify this overestimation of unit performance caused by an "idealized" curve, a correction model may be constructed. This model applies a mean-of-valve-loop correction to the turbine efficiency at the middle and upper loading range of the unit above the first valve point. As shown in Figure 2, this correction will, on the average, raise the input/output curve by about 0.2% for reheat units and 0.5% for non-reheat units. Below the first valve point, it is suggested that the unit output be corrected by calculating the change in first stage available energy, based on the pressure after the control valves, assuming that the first stage efficiency will be constant. This results in the type of characteristic shown in Figure 2.

Figure 2. Mean-of-the-Loop Correction

The amount of unit heat rate deviation due to valve loops is highly dependent on the loading levels at which the unit is operated. Generator units that are normally loaded at minimum levels will tend to have a larger deviation than units operated mostly at upper loading levels. In either case, a more accurate representation of actual fuel usage with valves partially open would be best achieved by providing a mean-of-the-loop type of correction to valve point test data.

Figure 2. Mean-of-the-Loop Correction
FLOW NOZZLE QUALITY ASSESSMENT

R.W. de Mello, Manager, Generation

The accurate measurement of condensate flow or final feedwater flow is crucial to the accurate evaluation of turbine-cycle performance. An error of 1% in this primary flow measurement will cause a 1% error in calculated turbine-cycle heat rate. A throat-tap flow nozzle is usually used for the primary flow measurement. Indeed the turbine test code, ASME PTC-6, states:

Excellent results have been obtained using low beta-ratio throat-tap flow nozzles for steam turbine testing and, for this reason, this Code recommends that they be used.

Despite the importance of accurate flow measurement there is no facility able to calibrate nozzles at the flow rates found in modern power plants. This poses a dilemma because a nozzle’s behavior changes with Reynolds Number (which for any nozzle is sensitive to flow rate and fluid temperature). Under ideal conditions a nozzle may be calibrated at a Reynolds Number as high as 7 million, however, 4 to 5 million is common. The nozzle may then be used to measure flow rates with a Reynolds Number as high as 16 million in the condensate line or 30 million at the economizer inlet. Thus the nozzle’s behavior, or flow coefficient, must be extrapolated from the relatively low Reynolds Number of calibration to the higher Reynolds Number actually encountered in a power plant.

To cope with this dilemma, much work² has been done to characterize the flow coefficient of a throat tap flow nozzle as a function of Reynolds Number and PTC-6 has tabulated this characteristic for an “ideal” nozzle. A nozzle, if manufactured carefully, will have a characteristic close to that tabulated in PTC-6 and extrapolation of its flow coefficient can be done with confidence in its accuracy. Presented below is a statistical technique applied to a nozzle’s calibration data that shows how closely the nozzle’s coefficient matches that of the “ideal” nozzle. The technique can be used to verify that a nozzle has indeed been manufactured carefully or to find those nozzles that need remachining.

A nozzle’s flow coefficient can be expressed as a function of Reynolds Number as:

\[ C = A + B \log(R) \]

The region where, with 95% confidence, the true coefficient lies can also be expressed³ as a function of Reynolds Number. For a given Reynolds Number, the confidence intervals lies above and below the curve, Equation above, by the amount:

\[ T^2 \left[ \frac{N-1}{N-2} s_c^2 - (B s_R)^2 \right] \left[ \frac{1}{N} + \frac{(\log(R) - m_R)^2}{(N-1)m_R^2} \right] \]

A, B are coefficients determined by a least squares curve fit of the calibration test points
C is the flow coefficient
m_R is the mean of the log of the throat Reynolds Numbers from the calibration test data
N is the number of calibration test points
R is the throat Reynolds Number
s_c is the standard deviation of the coefficients from the calibration test data
s_R is the standard deviation of the log of the throat Reynolds Numbers from the calibration test data
T is the t statistic at the 95% confidence level with N-1 degrees of freedom

Figure 1 shows calibration results for a carefully manufactured nozzle. Shown are the calibration test points, the curve chosen to best represent the nozzle’s coefficient, the quarter percent band marking the deviation allowed by PTC-6 and the 95% confidence interval of the coefficient’s curve. Note that the coefficient curve (solid line) is constrained to have the same shape as the PTC-6 “ideal.” The width of the confidence interval is a measure of the random error inherent in the calibration. In Figure 1 the entire 95% confidence band lies within the quarter percent band allowed by PTC-6. Further, the 95% confidence interval gives an indication of whether or not the nozzle’s coefficient has the same slope as the “ideal” tabulated in PTC-6. For the nozzle in Figure 1 it is indeed a good assumption that the two have the same, or very nearly the same, slope. Extrapolation of the coefficient to high Reynolds Number can be done with a high degree of confidence.

The analysis, applied to different nozzles, may show that the coefficient curve barely falls within the PTC-6 quarter percent band or that a nozzle’s coefficient actually decreases with Reynolds Number. In these cases, the nozzles may require remachining and recalibration before being installed in order to ensure accurate flow measurements. Considering the importance of accurate flow measurement in the power plant, this relatively simple statistical test should be applied whenever a throat tap flow nozzle is calibrated.

References
1. PTC 6-1976, Performance Test Codes, STEAM TURBINES, ASME, 345 East 47th St., New York, NY 10017.

TIME SIMULATION OF FURNACE DRAFT EXCURSIONS

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Upon verification of the model, control schemes can be applied to various severe transient conditions to study the relative merits of each. For example, the instantaneous application of a large signal to the FD or ID fan vanes upon obtaining a signal to trip fuel could be compared with utilizing a staged fuel shutoff. A full system analysis is necessary to accurately gauge the relative benefit gained by each scheme. Figure 1 illustrates the potential improvement in a furnace draft excursion following a master fuel trip with a modification in control parameters.
A model, such as described here, has an added potential in the area of controls tuning. Typically, a balanced draft furnace will be designed so that the ID fan vanes are controlled by airflow while the FD fan vanes are controlled by furnace draft. Time simulation studies are invaluable in this type of system to determine the tuning parameters which will yield the quickest response while maintaining minimum overshoot and stable operation.

A modern power plant furnace is a complicated array of various systems which must work in harmony under a variety of operating conditions. Severe transients will undoubtedly occur. The results of such transients are usually difficult to predict. For this reason, a computer model capable of combining the effects of the various dynamic parameters is necessary in establishing the integrity of the furnace controls.

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