1984 PERSPECTIVES

PTI's engineering studies business continued strong in 1984, with growing interest among large industrial users of power. Our participation in HVDC application studies also increased, responding to the industry's growing appreciation of DC's functional advantages. PTI's course business flourished too, spurred by the addition of some new subjects and the introduction of a video training course on distribution system operation.

The past year illustrated dramatically the synergism among PTI's three business areas; services, software, and the manufacture of special purpose equipment. As early as 1970, software developed for our system studies was being requested by clients for use in-house. Over the years our success as a software products supplier has been strongly dependent on our leadership position in the studies and analysis of systems and plants.

About 1976 PTI also saw that our mixture of system expertise, software experience, creative people, and close interaction with you, our clients and friends in the industry, led to ideas whose implementation required that we manufacture equipments not yet available commercially. PTI's new stabilizer, the subject of a 1984 patent and described elsewhere in this issue, is a prime example of how the combined strength of three related businesses can be greater than the sum of the parts.

We expect this three way split in PTI's business to continue, but recognize that our unusual strength in the physical and economic understanding of systems, as manifested in engineering services, will remain our primary raison d'être and the foundation on which software and systems businesses must be based.

FIELD TESTS VERIFY PTI'S SS/1 STABILIZER

J.S. Czuba, Senior Engineer

The power system stabilizer described in the PTI Newsletter of January, 1984 was successfully tested last month at the Ludington Pumped Hydro Plant of Consumer's Power Co. The stabilizer had been operated in open loop for several months to verify its reliability and response. After successful open-loop operation, a series of on-line tests were scheduled for November and December. The basic system configuration during the test was as shown in Figure 1, below.

Prior to installing the stabilizer, the system's worst dynamic swings had occurred during the pumping mode. Field tests were made with line switching unit synchronizing and load increases as disturbances. For all conditions, power swings were less severe and better damped with the stabilizer in service. Figure 2 shows an example result.

When Unit 1 was put on-line and synchronized, Unit 4, stabilized by PTI's SS/1 unit, saw a maximum peak to peak power swing of 12.6 MW. Unit 5, without the stabilizer, had a swing of about 16.9 MW and was more poorly damped. Note that the pens on the recorders were offset so the traces do not appear to be serious and better damped with the stabilizer in service. Figure 2 shows an example result.

SHOCK TORQUES DUE TO LINE SWITCHING

F. Paul de Mello, Principal Engineer

A lot of attention has been given to the problem of shock torques in generators due to short circuits, reclosing or load rejection. Not as much has been said about similar phenomena affecting motor loads such as power plant auxiliaries or industrial drives.

An abrupt change in transmission impedance due to line switching (opening or reclosing) can cause a step-like change in voltage phase angle at load buses. The resulting transient torque in rotating equipment can be serious. In the case of large generators the effects of line switching are usually not of concern because of appreciable system impedance relative to machine rating. A given step change in supply voltage angle will produce greater relative effects on motors since the system impedance is usually much lower when expressed on motor base.

Partial loss of transmission will cause an abrupt decrease in voltage phase angle at receiving end load buses. The effect on motors will not be severe since the decrease in supply voltage phase angle will merely cause a temporary decrease in electrical torque. A line reclosing operation on the other hand will cause a positive step change in phase angle and an abrupt transient increase in torque as the motors adjust to the new system supply voltage. The resulting transient torques are additive and can be excessive. The larger the size of the motor, which is synonymous with the more efficient the motor, the more severe are the transient torques due to the longer-lasting flux transients in low resistance rotor designs.

A line switching event can be evaluated from the point of view of a particular motor with the representation of a step change in supply voltage phase angle behind a system equivalent impedance. Both rotor and stator transient effects must be considered for a complete solution such as is done using PTI's MNT/E (machine and network transients program). The torque transient for a typical large motor corresponding to a step change of 40° in supply voltage phase angle is shown in Figure 1. A peak of 3.5 times rated torque is reached.

The severity of the torque transient depends on the composition of the mechanical drive train. The larger the inertia of the driven load relative to the motor, the greater is the proportion of air gap torque that propagates through the shaft. Induced draft fans are an example of high inertia loads.

Transient torque problems due to line switching are not new and in most cases the disturbance is not serious. New situations can arise, however, as transmission systems become loaded with heavy transfers. In some cases the phase angle change due to line switching can indeed impose excessive torques on motor loads.

(Continued on Page 2)
FIELD TESTS VERIFY PTI'S SS/1 STABILIZER  
(Continued from Page 1)

respond simultaneously, although in fact they did. Figure 2 shows that both units 4 and 5 benefit from the SS/1 stabilizer even though it was only applied to unit 4. Damping would have been further enhanced had more than one out of six units been equipped with stabilizers.

Figure 2

While the fundamental principle of supplementary stabilization through excitation controls is simple and straightforward, past implementation has usually required custom-tailored hardware. Many stabilizers use rotor speed to derive the stabilizing signal, a difficult quantity to measure with the adequate resolution. In addition to the measurement problems, speed signals must be adjusted in phase to overcome the lags in the excitation system. Conditioning of signals to eliminate spurious oscillation modes, continual adjustment problems and the need of each utility to maintain a variety of different stabilizer designs often discourages the application of this inherently very effective means of damping. On some utilities more than 50% of presently installed stabilizers are not in service at any given time due to the above stated deficiencies. These problems led PTI and four participating electric utilities — Consumer's Power, Detroit Edison, Georgia Power, and Hydro-Quebec — to develop the SS/1 stabilizer, using a principle developed and patented by PTI.

The SS/1 uses as its stabilizing signal accelerating power as calculated from the generator bus voltages and currents. The block diagram shown below shows the fundamental relationships between mechanical, electrical, and accelerating power and speed of a generating unit. As indicated accelerating power exhibits a 90° lead with respect to speed and is therefore a more effective variable from which to derive the proper stabilizing action.

\[ \begin{align*}
PM' &= PM = (PE + MS\omega) \\
PA' &= PM' - PE \\
\end{align*} \]

Reference 4 presents the analyses leading to the development of the patented microprocessor system which includes a digital algorithm to derive slip frequency from the sampled values of the three phase voltages of the machine.

The hardware system in which the stabilization algorithms are implemented uses reliable, and extensively supported Intel 8086 microprocessor technology.

Figure 3

Several schemes have been published in which accelerating power is derived through measurements of prime mover system variables such as gate positions in the case of hydro units and steam pressures in the case of steam units.\(^1\)\(^2\) However, the simulations and analytical work presented in Reference 3 together with extensive field experience, convinced PTI to base stabilization on electrical power and a synthesized mechanical power \(PM'\) as shown below:

\[ \begin{align*}
PM' &= PM = (PE + MS\omega) \\
PA' &= PM' - PE \\
\end{align*} \]

Reference 4 presents the analyses leading to the development of the patented microprocessor system which includes a digital algorithm to derive slip frequency from the sampled values of the three phase voltages of the machine.

The hardware system in which the stabilization algorithms are implemented uses reliable, and extensively supported Intel 8086 microprocessor technology.

Figure 4

(Continued on Page 6)
NEW COURSES INTRODUCED

M.R. Stambach, Manager, Educational Programs

PTI engineers were quite active in 1984, developing and teaching initial sessions of new courses, which respond to the changing training needs of the industry. These include five engineering "short courses", and a videotaped course for distribution operator training, scheduled for completion later this year.

Most of these courses have been presented this year at PTI offices in Schenectady, NY and at various client locations. Future presentations will be made in New York City and Orlando, FL. Continuing Education Units (CEUs) are awarded for successful completion of each of the short courses. New short courses are:

POWER SYSTEM SCHEDULING AND OPERATION (5 DAYS)
This course offers a description of current methods and techniques used to operate bulk power supply systems in an economic and secure manner. Topics covered include economic dispatch, unit commitment, generation control techniques, daily load forecasting and state estimation. This course is useful for engineers seeking an introduction to the modern techniques used for power system scheduling and control.

POWER SYSTEM PLANNING TECHNIQUES (5 DAYS)
The Planning course helps engineers address challenges presented by today's utility planning environments. Economic analysis, production costing, transmission and generation reliability analysis and planning techniques, as well as strategic planning concepts are among the subject areas covered. Engineers desiring an introduction to the analytical techniques and procedures used in system planning will find this course useful.

POWER DISTRIBUTION SYSTEMS COURSE (5 DAYS)
This course comprehensively describes the design and operation of electric power distribution systems and equipment. Subjects covered include overcurrent and overvoltage protection, voltage control, emergency conditions, distribution system economics and automation and load management trends. The course will benefit distribution engineers involved in system planning, design and equipment specification.

STEAM TURBINE PERFORMANCE AND OPTIMIZATION (3 DAYS)
This course will help engineers achieve higher sustained levels of efficiency and capacity of large steam turbine units. A variety of proven techniques are discussed for measuring and analyzing performance problems of steam turbines. The course is useful to engineers responsible for maintaining, measuring and attaining high levels of power plant performance.

CORPORATE MODELING USING A PERSONAL COMPUTER (3 DAYS)
This course will enable participants to perform strategic analyses using mathematical corporate models developed on a personal computer. Each participant develops a basic corporate model of his utility, during daily workshop sessions using the computer. Managers and technical personnel charged with corporate modeling and strategic planning will benefit from this course.

DISTRIBUTION SYSTEM OPERATION VIDEOPROGRAM:
(23 Videotapes with Student Workbooks and Instructor Guides)
The videoprogram is designed primarily to train those responsible for the day-to-day operation of electric power distribution systems. The production of the tapes and written materials has passed the half-way mark in 1984, and is scheduled for completion in mid-1985. Several prominent utilities have already committed to purchase the Iowa Power & Light, Metropolitan Edison Company, Pennsylvania Electric Company, Puget Sound Power & Light, Jordan Electricity Authority, Kansas Gas & Electric, South Carolina Electric & Gas, Central Vermont Public Service, Omaha Public Power District, and Nova Scotia Power Corporation.

ACCURACY OF MODELING GENERATING UNIT INPUT/OUTPUT

D.J. Lawrence, Senior Engineer
R.J. Ringlee, Principal Engineer

INTRODUCTION
Economic Dispatch concepts have been applied in loading generating units for more than four decades, first manually, then by analog controllers, and, for the last twenty years, by digital Economic Dispatch and Automatic Generation Control programs. It also has been at least twenty years since the first models for the recognition of transmission losses were developed and installed in economic dispatch controllers and more than ten years since models for handling network limitations were introduced.

Today's attention has turned to on-line determination of unit performance and to assessment of the accuracy with which that performance can be established. As the influence of inaccuracies and uncertainties on production cost is better understood, incentives for more accurate instrumentation, more frequent updating of incremental heat rate and capability models, and alternative economic dispatch algorithms may be demonstrated.

This article provides a brief overview of input/output curve fitting techniques used at PTI, and looks at how the effects of modeling and measurement errors can be reflected in both input/output and incremental heat rate curves used for economic dispatch. Much of the work cited here was performed for Potomac Electric Power Company (PEPCo) as part of Research Projects RP1681-1/2153-1 and RP1681-2/2153-2, Power Plant Performance Instrumentation Systems, sponsored by the Electric Power Research Institute.

CONSTRAINTS IMPOSED BY ECONOMIC DISPATCH ALGORITHMS
Most economic dispatch algorithms currently in use require incremental heat rate curves that increase with unit output. This requirement is equivalent to forcing the unit heat input to be a convex function of unit net output.

All would be well except for the fact that input/output data exhibits distinctly non-convex trends, due to effects of partial arc admission and variations in auxiliary loads. A comparison between measured I/O data and the constrained curve fit I/O curve can be seen in Figure 1. Consequently, any attempt to fit input/output data will introduce inaccuracy into the input/output curve due to modeling error. To compound the problem, measurement of unit performance carries with it a certain amount of error that is a function of the accuracy of the measuring equipment and the variability of the process being measured.

Figure 1
At this point, it is important to distinguish between systematic error, or bias, and random, or precision error. Bias error can occur due to improper calibration of measuring devices or any similar systematic error in observing fuel input, boiler, turbine, or generator performance. Bias error can be reduced by using different measurement systems, using additional instrumentation, and by equipment recalibration. Correction of measured input/output to standard temperature and pressure conditions reduces bias error, or bias, and random, or precision error. Bias error can be expected to fall, recognizing the effects of various levels of measurement random error. As would be expected, the envelope of confidence limits will tend to widen about the fitted curve as the level of measurement error increases, and tighten as the number of test points is increased.

One way to reduce the uncertainty in incremental heat rate models is to increase the number of performance measurements taken. Such a procedure tends to reduce the uncertainty by the square root of the number of measurements taken. Figure 2 illustrates the confidence limits about an incremental heat rate curve, determined from actual performance measurements. The limits are based on a measurement error with 3% standard deviation. The Figure also shows how doubling the number of measurements will improve the confidence limits on the incremental heat rate curve. Repeat measurement will do nothing, however, to reduce the bias error introduced by the modeling requirements.

Table 1

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<tr>
<th>Test No.</th>
<th>HHV (BTU/lb)</th>
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<tr>
<td>3</td>
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</tr>
<tr>
<td>4</td>
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<td>7</td>
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Average = 12607.5
Standard deviation = 243.2 BTU/lb (1.9%)

RECOGNIZING UNCERTAINTY IN INPUT/OUTPUT MODELING

Performance measurement and modeling error statistics can be used to develop confidence limits for input/output and incremental heat rate models. PTI has developed a computer program, QUAD, to perform constrained least-squares curve fits for input/output models. The program is written in FORTRAN 77 for use on both the PRIME minicomputer and the IBM PC. Sample output from the IBM PC version is shown in Table 2. As part of the PEPco work described above, QUAD was modified to calculate confidence limits about both the input/output and incremental heat rate models, given various levels of measurement random error.

Table 2

<table>
<thead>
<tr>
<th>Sample Output from QUAD</th>
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<tbody>
<tr>
<td>TESTING AVERAGE HEAT RATE CONFIDENCE LIMITS</td>
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<tr>
<td></td>
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<td>-------------</td>
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Figure 2

IMPACT OF INCREMENTAL HEAT RATE UNCERTAINTY ON OPERATING COST

Having knowledge of the uncertainty limits about the incremental heat rate allows one to perform parametric tests to determine the impact of heat rate uncertainty on system operating cost. To perform these studies, it is necessary to develop an economic dispatch simulation program in order to simulate system operation over a period of several weeks. Incremental heat rate errors, represented by curve displacements within the calculated envelope of uncertainty, may be used in conjunction with the dispatch simulation program to test the sensitivity of system and unit operating costs to various levels of measurement uncertainty. Results obtained during the PEPco study indicate that performance measurement precision error could have a significant impact on system operating costs for levels of uncertainty above 4% of rated unit output (2 standard deviations). At 4% measurement uncertainty, system production cost increased between 0.1 and 0.2 percent for the 30-day study period investigated. The effects on operating cost are quite dependent upon the system generation mix and unit loading characteristics, with the effects on marginal units being most pronounced.

(Continued on Page 6)
LIGHTNING SURGES ON DISTRIBUTION LINES
J.G. Anderson, Senior Consultant

Lightning is a major cause of electric service interruptions on distribution systems, particularly in southeastern areas of the United States where thunderstorms are frequent and severe. Flashovers, fuse blowing, breaker operations, and damaged transformer and pole line hardware are common aftermaths of summer thunderstorms. It is important that distribution systems be designed to be resistant to the lightning overvoltages that occur.

There are three different causes of distribution line lightning damage. First, a direct hit to the weakened by previous adverse service conditions a distribution pole line can be regarded as a subject to a strongly-changing electromagnetic field created by surge currents in the lightning channels. The voltage induced on the conductors by these changing fields can reach 200 kV or more, even if lightning does not actually hit the line. These induced overvoltages must also be considered in selecting the insulation levels of the various line components.

Although lightning surges have plagued distribution systems since the first lines were built in the last century, there is still inadequate understanding of magnitudes and waveshapes. They are hard to “catch,” and very sophisticated instrumentation is necessary to collect statistical distribution of all the important waveshape parameters such as magnitudes, rates-of-rise, and total charge.

In 1983, EPRI funded the redevelopment of a lightning transient surge recorder which can record the waveshapes of up to 20 lightning events, and catch the statistical data that the utility industry needs. This development is essentially completed and the recorder can now be built in large quantities for the job of collecting field data. EPRI recently awarded PTI a three year contract (RP2542) to install these recorders on distribution lines and to collect and analyze distribution transformer and arrester surge voltage data, as well as arrester surge currents and energies. CH2M Hill of Gainesville, Florida will be the principal subcontractor responsible for any utility communications, utility-related design work (such as layout of the pole top equipment), project planning with the operating utilities, and the actual data collection from the recorders.

Figure 1 shows a conceptual pole-top arrangement including the lightning transient surge recorder. In addition, event recorders, such as those used in a previous study addressing the problems of distribution fault recording (See PTI Newsletter of July 1979), will be employed to record fault activity on the monitored distribution feeders. CIGRE-type flash counters and lightning detection data will be utilized to provide additional information.

Arrester surge current statistics are of great interest. Better knowledge is needed of the peak surge current an arrester is likely to see during its service life, as well as more about arrester energy requirements. The latter information can be gained by simultaneous measurement of voltages and currents during numerous lightning events. In such cases, the EPRI surge recorder will have dual wave processing and data capabilities.

In order to extract the maximum quantity of lightning surge data from American distribution lines at the lowest possible cost, PTI is also evaluating several new inexpensive devices to record surge voltage and surge current magnitudes, rates of rise, and areas under the waveshapes. If these devices can be built in large numbers at low cost, they could augment the complete waveshape data collected by the EPRI recorders.

The first group of recorders and supporting instrumentation will probably be installed in the Florida area in 1985, with a larger installation to follow in 1986. At least one additional group of recorders will be installed in another location. The option also exists to install some in New York State, and in the mid-west at a later time. By 1987, the state of the art on lightning surge voltages and currents on distribution lines should be considerably advanced. Benefits will include better distribution equipment, better design of distribution feeders, and improved supply reliability.

SHOCK TORQUES DUE TO LINE SWITCHING (Continued from Page 1)

Figure 1

A credible occurrence that can impose similar effects is a full load rejection through opening of a generating unit circuit breaker while auxiliaries are supplied from that unit. Another scenario would be the blocking of a d.c. converter, particularly where the converter capacity is essentially equal to that of the generating station that supplies it.

While there is not much evidence from field data that damage to motors has occurred, neither is there similar evidence of shaft damage due to shock torques in turbine generators. The fatigue problem is cumulative, however, and the industry should be cautious about the phenomena it applies to motor loads just as it has been in the case of generators.
CONCLUSIONS

The procedures described above can be used to:

- estimate the confidence limits about performance and incremental heat rate curves, and
- develop a relationship between the level of measurement uncertainty and the sensitivity of system operating cost.

Further work is being done to identify the sources of process and measurement fixed and random error, and quantify the levels associated with typical generating units. Knowledge of actual uncertainty levels, coupled with the resulting changes in system operating costs, will permit evaluation of the cost/benefit of improved instrumentation and process monitoring accuracy. It will also allow evaluation of more frequent updating of incremental heat rate and capability information, recognizing current operating conditions.

Any implementation of either improved instrumentation or dispatch models must be judged on the basis of the cost of not only the monitoring equipment and/or performance model update, but also the cost of improved control systems. Changes would be justifiable only if the present worth of future operating and maintenance savings offset the costs of acquiring the installing improved control and data acquisition systems.

References


SPRING 1985 SHORT COURSE SCHEDULE

Courses to be presented at PTI offices in Schenectady, N.Y.

<table>
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<tr>
<th>Course Name</th>
<th>Dates</th>
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<td>Power Plant Performance</td>
<td>March 4-8, 1985</td>
<td>$900</td>
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<td>Steam Generation Control</td>
<td>March 11-15, 1985</td>
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<td>Power System Planning Techniques</td>
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<td>Utility Economics &amp; Finance</td>
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For further information and registration contact:

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