ANALYTICAL ENGINEERING — AN APPROACH TO PROBLEM-SOLVING

PTI's letterhead includes the byline . . . Analytical Consultants. Shortly after adopting that letterhead, a PTI client asked what made analytical engineering different from any other kind of engineering. In beginning our 14th year of operation, we thought it worth devoting an issue of the newsletter to clarifying that difference, partly by definition, but mainly by example. PTI's orientation and abilities in Analytical Engineering have, in fact, been the cornerstone of the Company's success in establishing its special role in the utility industry.

The word Analytical really defines an attitude, a problem-solving process, a level of education, skill, and insight to make that process work. The process begins with a test of the problem statement. In engineering, as in medicine, mistaking a symptom for the disease can be disastrous. The Analytical Engineer must also be accustomed to having problems lead him into new technological ground. Some assignments PTI has undertaken simply start in new ground — others find their way there by the engineer's refusal to accept answers to problems without understanding why those answers are in their favor or against their way. And being prepared to place new ground in a technological sense means being prepared to develop new methods of solutions where existing methods are inadequate. In fact, if one looks back through the history of technology it is apparent that most advances in engineering methods have resulted from attempts to solve actual problems not from research into methodology itself. Examples of these problem-oriented advances range from Newton's invention of calculus to explain astronomical observations to Fortescue's development of symmetrical components to analyze imbalances in three-phase systems.

At PTI, the dedication to developing new methods where old ones are inadequate has not only built a successful consulting business, but has produced two by-product businesses. Engineering tools developed by PTI in its own problem-solving pursuits, plus those suggested by our work with clients' problems led PTI into the software business. Furthermore, PTI's engineering analysis often led us to solutions whose implementation required hardware not available through normal commercial channels. As early as 1970, PTI manufactured specialized equipment of this type. This activity has grown to the point where a "Hardware Projects Section" was formed at PTI in November, 1982.

There are no misconceptions at PTI with respect to one fact. The extent to which PTI involves itself in software and hardware project businesses will remain critically dependent on the strength of our core business — analytical consulting. Examples of analytical problem solving are spread through past newsletter issues and illustrated further in this issue dedicated to the fascinating analytical engineering process. A starting point of that development will be with the mainstream of our study activity.

LARGE SCALE SYSTEM EXPANSION PLANNING AND DESIGN

Most of PTI's analytical studies involve dynamic simulation of relatively large and complex systems, either to plan major additions to a system or to address an operating problem in it. The former is more common in developing countries where even in the 1980's, the stage of expansion considered may extend to several times the size of the starting system. Such studies start with postulation of alternatives, then proceed to detailed simulation of those alternatives and their reduction to workable, functionally equivalent solutions. These studies can take many months, sometimes years to complete. They demand that tasks be carefully planned in series and parallel since the results of one task may be necessary as input to another. Figure 1 describes a typical chronology.

As with any analytical study, the sequence of tasks has to be responsive to study results and must provide a timely basis for key decisions. For instance, while special studies such as subsynchronous oscillation analysis are usually undertaken during the optimization phase of a study, there have been cases where these were performed right at the beginning to establish whether a series compensation alternative could be considered at all. In one recent study a completely new equipment application was simulated and shown effective in controlling subsynchronous resonance without requiring any modification to neighboring systems also affected by the problem. This caused a redirection of study emphasis and assumptions.

Many system expansion stages must be considered in the planning and design of a given alternative. Meeting design criteria under normal and contingency conditions, at each stage of expansion, sometimes requires hundreds of load flows, stability, load rejection and other over-voltage cases, including economic and reliability evaluations of each. But in the optimization phase of large-scale studies, PTI has also grown accustomed to addressing first-of-a-kind problems. Figure 2 shows an example from an HVDC transmission project where extensive evaluations had to be made of transformer and filter-shunt harmonics due to faults on the AC side with converter blocking and subsequent fault clearing. The MNT/E program was used to evaluate the instantaneous voltage and current behavior including such details as energy dissipation in arresters, generator field current transients and harmonic content seen by differential relays. The purpose was to find out whether the equipment could be damaged during such faults, whether incorrect relay operation could result leading to cascading outages, and to study remedial measures.

In planning and design of major additions to bulk power systems, PTI has developed logical methods for 1) selection of reliability and disturbance criteria and 2) making reliability comparisons for alternative line and station configurations. Quite often such comparisons offer the only basis for choosing among competing system alternatives.

For example, in one PTI study, criteria were selected to assure that 1) bulk-power transfer objectives would be met during more frequently occurring disturbances and 2) for specified transfers, the system would withstand certain classes of more severe disturbances of less frequent occurrence.

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LARGE SCALE (continued from page 1)

While designing observing the first consideration would yield apparent­ly equivalent alternatives, probing into the second less probable events can reveal vastly different performance among alternatives. This type of analysis often dictates dynamic evaluations of consequences of the more severe contingencies. These consequences could range from simple curtailment of power achievable in an orderly manner to complete shutdown through cascading, voltage collapse or instability. Combining statics and dynamic analysis of performance allowed comparisons between alternatives of not only energy curtailment indices, but also of the probability of complete shut down.

Performance studies of these kinds depend on advanced simulation software, but depend even more on the experience and analytical capability of the engineer undertaking them. Essential to success is the intuition and efficient study guidance that comes only from experience. Analytical capability is necessary because of the likelihood that studies will lead to ground where there is no “text” and no precedent, requiring invention of new methods and new computer tools. PTI enjoys a number of software byproducts from that inventive process, a process initiated out of a need to get answers and enhance productivity rather than from speculative forays into the frontiers of computer or algorithm theory.

Perhaps the most interesting and certainly the most challenging assignments PTI has undertaken are not the mainstream system development studies, but special ones that arise in the course of those studies or that come to us by virtue of equipment failures or other special circumstances. The balance of this newsletter issue will be devoted to examples of that kind.

MOTOR FAILURE EPIDEMIC — HARMONICS

Several years ago, a small U.S. utility experiencing a rash of complaints on motor and capacitor failures began to suspect their being due to harmonics, particularly when they noted that the problem began soon after a new arc furnace load came on line. PTI was asked to assess the problem and suggest solutions.

A number of approaches were considered. The customer’s initial thought was to instrument the system extensively so as to assess harmonic levels, but was concerned as to the cost of this solution and the time it would take.

PTI engineers suggested that the suspected source be carefully modeled analytically, including a simulation of the system. The harmonic propagation onto the system would then be calculated to see whether the expected levels would be likely to damage motors and capacitors. While this approach appeared to be less time-consuming and less expensive, it required that “load flow” cases be run at harmonics — not a normal load flow program feature. PTI’s MNT/E (Machine-Network Transients) was suggested as the best approach. This program models the system in phase quantities rather than as a positive-sequence network and elements are frequency dependent allowing operation at any frequency specified.

Figure 3 shows an example of the results. Note the voltage amplification in the region of the fifth and seventh harmonics. The amplification was even higher at some buses remote from the harmonic source. Levels at buses close to sites of equipment failures were well in excess of limits normally recommended for motors and capacitors.

Cases for other harmonics showed far less severe results, so PTI staff concluded that a fifth harmonic filter at the furnace bus would solve the problem. The MNT/E program was used to dimension the filter to minimize its cost while still bringing harmonic levels within bounds. The same studies also confirmed that a filter at a lower frequency would be required to avoid parallel resonance between the fifth harmonic filter and the system. The study also showed that a slight reduction in furnace loading would reduce the problem somewhat.

A utility expressed concern as to performance of a diesel engine installed to start emergency cooling pumps in a nuclear plant. The question was whether the diesel set could successfully start and accelerate the motors during an emergency where there was also a loss of supply from the grid. The diesel set had been sized by rule of thumb and apparently had adequate capacity for the load duty criteria initially set. However, with ever-increasing safety requirements dictated by regulatory bodies, additional loads were to be imposed and the question became whether the set could cope with the dynamic stress imposed by the new starting sequence. The initial problem statement expressed fear that the diesel governor could not cope with the duty. But, simulations soon showed that the problem lay not with the governor but with the ability of the excitation system to hold voltage. Sensitivity analysis was carried out to determine the margin by which certain design parameters such as exciter ceiling just missed being adequate, and where these margins were too small the need for validation of

ADEQUACY OF PLANT EMERGENCY SUPPLY

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equipment characteristics by test was indicated. Figure 4 shows test results of diesel generator conditions during start up and run up of an HPSI pump motor. PTI's experience with such calculations and with supporting field tests over the years enables engineers to supply realistic data estimates or parameter ranges where actual data are not available.

ELECTRIC SYSTEM RESPONSE TO HYDRAULIC PROBLEMS

In many system problems, electrical, mechanical, and even hydraulic phenomena are inseparably linked. Some years ago a utility observed rather serious power pulsations in the output of a hydroelectric plant. The manufacturer of the turbine was convinced that the cause was in the electrical system. The owner was not so sure. PTI often gets assigned problems like this, where some form of feedback is involved and where cause and effect are not readily separable. In this case a comprehensive electrical/mechanical/hydraulic simulation was made. Dynamic analysis of the hydraulics, turbine/generator inertial characteristics and electrical system effects as reflected on airgap voltage soon disclosed where the problem lay. The frequency response, shown in Figure 5, predicted electrical power oscillation resulting from draft tube pulsations in the Francis turbine. This involved some amplification due to resonance with the natural frequency of oscillation of the generator rotor. PTI suggested, as a solution later successfully implemented, modifications to a venting system in the turbine draft tube. This example also illustrates the use of frequency response as a powerful analytical tool. Although the problem could also have been analyzed with time-domain simulations, the frequency-response approach was much more efficient in this instance.

SHAFT TORQUE CONTROLLED BY ELECTRIC PARAMETERS

Electric utility systems are not alone in their concern with electrical/mechanical dynamics. Industrial drive systems must also be looked at very carefully to assure satisfactory dynamic performance. Figure 6 shows the torque oscillations in various shaft sections during acceleration of a compressor drive train powered by a synchronous motor. Of particular concern is the magnitude of double slip-frequency torque pulsations as they traverse the regions of resonance with shaft torsional modes. In one case, PTI evaluated rotor saliency characteristics of alternative motor designs as they influenced the degree of vibration during acceleration. For one motor considered, the pulsations due to saliency of the starting motor induced resonant pulsations in the drive train of a running compressor supplied from the same bus to the point of causing the latter to trip. The coupling was through the supply voltage which also oscillated due to pulsations in current drawn by the accelerating motor. Among several parameters influencing this problem that were evaluated were stiffness of the electrical supply, acceleration of the motor as it affected dwell time through torsionals and motor damper winding design as it affected magnitudes of pulsating torques.

THERMAL PLANT SIMULATED FOR EFFICIENCY STUDIES

The technology of dynamic simulation and control is applicable to any physical process. It is thus not surprising that engineers who are expert in analysis of power system dynamics have been able to model the complex dynamics of thermal plants, both fossil and nuclear, involving solution of the non-linear mass flow, energy balance, pressure drop, heat transfer and steam property relationships.

For many years utilities have raised the question of whether one should be concerned with plant efficiency due to regulating duty. Figure 7 shows the elements of a supercritical plant modeled by PTI for investigations of transient efficiency effects. Evaluation of the loss of efficiency due to cycling duty was the main object of that investigation.
THERMAL PLANT (continued from page 3)

Figure 8 shows the nature of the transients of the simulated steam plant's process variables in response to a load change imparted through the turbine valve. The model was derived from first principles in their full nonlinear formulation and included detailed treatment of controls of fuel, air, feedwater, gas dampers and spray atomizers. Notice that the time scale of dynamic effects is in the range of several minutes as compared with electrical dynamic effects usually over in a few seconds. This type of modeling capability has been successfully applied to the development of plant operator training simulators and plant control checkout simulators. It has also been used in several studies of furnace implosion problems and the control strategies required to avoid them.

RAILROAD SYSTEMS — A SPECIAL RELAYING CHALLENGE

PTI was asked to undertake a study for an electrical railroad in 1981, that study included emphasis on fault protection. One would assume this to be relatively simple, the railroad being single-phase (or, to be more precise, two-phase). But the railroad in question used a three-wire system (see Figure 9) and the problem required the accurate representation of a right-of-way comprised of twenty-two separate conductors, i.e., trolleys, feeders, and rails. Mutual reactances were significant to the answer, as was the response of the supply system which had to be modeled as three phases. Apart from being difficult to represent for one case, the study involved relaying for fifteen substations, each requiring some 100 cases or so for adequate evaluation of relay protection. Thus, the challenge was to produce thousands of cases within reasonable cost constraints.

PTI's MNT/E program, intended as a tool for analysis of unbalanced problems, seemed like the best tool, but was designed neither for twenty-two conductor systems nor for large-volume production studies. Hence, PTI engineers modified the program to address both requirements. All of the required cases were produced within a time and budget constraint that would, using conventional methods, have required a much extended schedule, an order of magnitude more funding, and would have had to simplify the problem to an extent which would have introduced very serious errors in results.

SUMMARY

The ability to solve real world problems which, in a commercial environment, invariably carry a rigid schedule and a limited budget, is critically dependent on experienced and analytically oriented staff and the availability of superior user-oriented tools of analysis. The analysis tools in use at PTI almost without exception were developed to solve problems as they arose. We believe very strongly in this approach. It has contributed greatly to our leadership position in analytical studies and made us confident that whether problems are on-road or off-road, we're capable of finding answers in a cost-effective manner. The fact that this success has produced ancillary business undertakings equally successful, has not caused us to forget the source of strength on which those undertakings depend.