PROTECTION OF COGENERATION AND INDUSTRIAL GENERATION

H.K. Clark, Senior Engineer

Most aspects of industrial system protection and its coordination with utility protection are well recognized. In fact most utilities provide useful guidelines to industrial customers. However, there are some aspects of generation protection that are frequently not given adequate consideration. Several of these aspects are addressed in this article.

Industrial motors and generators are subject to shaft and winding damage or loss of life when exposed to reclosing. Reclosing is used in utility systems from distribution voltages up through the highest transmission voltages. Voltage and frequency relays typically open the plant-utility tie breaker before reclosing can occur, but do not provide full protection. Additionally, reclosing on lines not directly feeding a plant can present nearly as much risk as reclosing radial lines to a plant. Such relays are of no benefit in this case. When little or no power is flowing between the utility and the plant, these relays are not likely to sense a utility line trip. Other protective systems useful in some cases, are voltage check relays at the reclosing points, transfer trip, and distance relays at the utility-industrial tie point.

As another example, special protection must be given to induction generators frequently used in industrial and cogeneration applications. Though an induction generator contributes fault current for only a couple of cycles, overcurrent relays on the generator are necessary to detect faults in the generator. Induction generators are also subject to possible self-excitation. Capacitive current from in-plant capacitors, nearby utility capacitors, or from utility line charging can overexcite an induction generator and cause damaging overvoltages. Special system design and overvoltage protection is necessary to reduce risk of damage from this cause.

Out-of-step protection is often reserved for larger generators, but may be valuable where a generator could continue to serve some critical in-plant loads following utility disturbances. The location of this protection is important. In many situations it will be advantageous to put it on the utility tie instead of the generator. Selecting an appropriate setting becomes more difficult, but simulation studies can provide the necessary data. In some situations the out-of-step relay will not respond. This also can be recognized from simulation studies. This is a difficult problem but can be largely offset by careful selection of relay settings.

HARMONICS ON INDUSTRIAL POWER SYSTEMS: MEASUREMENT, ANALYSIS AND CONTROL

S.J. Balser, Manager, System Simulators

J.W. Feltis, Analytical Engineer

Historically, power system harmonics have been caused by magnetic saturation of transformers and certain industrial loads such as arc furnaces and arc welders. However, introduction of reliable and cost effective thyristor power converters has greatly increased the number of harmonic generating devices. In addition to an increase in harmonic generation, systems and loads have, in many cases, become more sensitive to harmonics.

As a result, there has been much more field measurement of harmonics, more analysis of harmonic flow on power systems, and new methods of obviating harmonic problems. Experience has indicated that harmonic problems are quite complicated, frequently requiring both measurements and analysis to lead to effective solutions.

The problem is made more difficult by the dynamic nature of the power system, where switching alters the configuration and therefore the effective impedances and subsequent resonance points. Most loads that generate harmonics are also dynamic with periods of both low and high harmonic generation. Measuring and/or studying harmonics at one instant of time or on one system configuration often provides misleading or incomplete information. Harmonic measurement systems must be able to record extensive system harmonic data over long periods of time with a minimum of operator attention. The dynamic nature of the harmonic problem can then be included in the analysis.

Recognizing the increased concern with the harmonic performance of systems, PTI has used its experience in system analysis and instrumentation to develop a set of relatively standardized tools for measuring and analyzing harmonics on industrial and utility power systems.

MEASUREMENT

The PTI harmonic measurement system is composed of two separate subsystems:

1) Data Acquisition (DAS)
2) Data Reduction

(Continued on Page 2)
PTI's ROLE IN INDUSTRIAL POWER SYSTEMS
(Continued from Page 1)

This staff has developed specialized software to aid in the design, operation and control, and analysis of power systems. Three of the software programs of particular interest to industrial clients are:

• PSS/E — Power System Simulator is a full scale load flow, stability, and general purpose dynamic simulation program for solving power systems problems in balanced three phase systems.
• PSS/U — Utilization Level Power System Simulator will handle load flow, voltage drop, unbalanced fault, load balance, short circuit and circuit breaker duty calculations. It can do circuit protective device coordination via graphic display and can simulate simple electromagnetic transient phenomenon.
• MNT/E — Machine and Network Transient is an interactive computer program which will calculate power system steady-state unbalanced phase flows and voltages; calculate the time varying electromagnetic transient response of the power system network and connected equipment; and calculate system response to harmonic current injections (harmonic load flow).

These and other software programs have been used to solve a variety of problems relating to power systems. The following lists some of the areas that have been studied and investigated:

• Electrical System Conceptual Design
• Utility Service Substation Design
• Load Flow Analysis
• Synchronous Machine Stability
• Induction Generator System Design
• Induction Motor Stability
• Motor Starting
• Motor Transfer Analysis
• Reacceleration Analysis
• Impact Loading
• Drive System Dynamic Analysis
• Static Power Converter Stability
• Flicker Analysis
• Power Factor Control and Improvement
• Harmonic Analysis
• Harmonic Filter Design
• Load Shedding
• Short Circuit and Breaker Duty
• Protective Device Coordination
• Underground Cable System Design
• Overhead Line Design
• Failure Analysis
• Reliability Analysis
• Overvoltage and Surge Protection
• Microprocessor Control Applications
• Emergency Generator Performance Analysis
• Power Plant Performance Analysis
• Cogeneration Economic and Technical Analysis

Each of the above study areas take into account one of the three characteristic time frames of a power system—steady state, dynamic, and transient. The first step in the design or the expansion of an industrial power system is conceptual design. At this stage studies must take into account all time frames to ensure optimum performance of the drives and other utilization equipment. The system must be easy to maintain, it must operate within the short circuit rating of equipments, and it must provide a level of reliability commensurate with cost of load production.

Steady state (load flow) cases show the effects of transformer taps, capacitors, and circuit arrangements on voltages and equipment loadings. Dynamic cases show the system’s ability to respond to short time disturbances such as motor starting and operation of large motors during system disturbances. Transient cases demonstrate the quality of operation of static power converters during commutation and their interaction with drive system regulators. Reliability is assessed both by experience and by quantitative computer analysis.

After conceptual design, and assessing the adequacy of the system equipment, protective device coordination studies ensure that the system will operate satisfactorily as conceived.

It takes an experienced power system engineer using state-of-the-art analytical tools to select the best system arrangement for any particular plant or process.

DIGITAL SIMULATOR FOR INDUSTRIAL POWER SYSTEM

J.M. Undrill, Principal Engineer

An industrial version of the PSS/U power system simulator program is now available. This program includes the PSS/U capabilities described in the April issue of POWER TECHNOLOGY, plus additional capabilities for system one-line diagram display and graphical relay coordination functions.

Figures 1 and 2 show the program’s output from the short circuit program and protective device coordination program. The one line diagram has the short circuit currents printed on the feeder circuits, (first cycle and interrupting) and is used to get the values for the coordination shown in figure 2.

Figure 1

Figure 2

The coordination diagram shown in Figure 2 displays load current and fault current at selected system locations, and superimposes time-current curves of relays and fuses selected by the user. The curves are color coded and the settings selected by the user are displayed in matching color. The user can change time dial, pickup current, instantaneous unit, and CT ratio selections, and see the effect of each change immediately.

Curves for relays, fuses and low voltage circuit breaker trip devices are stored in the programs datafiles. Finalized coordination diagrams can be drawn on a color pen plotter.

The main PSS/U functions are short circuit and circuit breaker duty; load flow; motor starting; harmonics; protective device coordination; simple electro-magnetic transient solution; and general unbalanced multi-wire feeder calculations.

The program is supported in full conversational form on IBM PC, DEC VAX, Prime, IBM VM-cms, and Apollo computers. On an IBM PC, it requires 512k-bytes of main memory, a hard disc, a floppy disc, and the MS-DOS 2.1 or 3.0 operating system.

RAY STRATFORD joined PTI early in 1985 as Manager, Industrial Power Systems. Ray is a graduate of Stanford University, and has more than 30 years experience in industrial power systems. In addition to extensive project management in a broad spectrum of industrial power systems engineering disciplines, he developed original techniques to analyze and correct problems caused by harmonic currents from static power converters. Ray is a Fellow of IEEE.
ANALYSIS OF PROCESS AND STEAM SUPPLY TRANSIENTS IN COGENERATION SYSTEMS

F.P. de Mello, Principal Engineer

The coupling between the electrical system and the steam generation process can be a critical factor in the reliable operation of cogeneration facilities. Even in the case of cogeneration normally operating in synchronism with very large capacity networks, loss of utility supply can present large transients to the steam supply as turbine governors operate to maintain balance between generation and load.

The analysis of ability to survive such contingencies must often include the transient behavior of the steam cycle. It does little good to verify that the turbine governor is capable of arresting a frequency drop if it will in fact be overridden by the initial pressure regulator, or if the back pressure control on a noncondensing turbine limits the extent to which turbine power can change.

Dynamic modeling of the steam process is readily accomplished through digital solution of the basic nonlinear differential and algebraic equations which describe the process physics. Laws of energy balance, mass balance, pressure drop, heat transfer, along with steam property relations, nonlinear as they are, can be readily solved using flexible dynamic analysis programs such as PTI's IDAP (Interactive Dynamic Analysis Program).

Such type of analyses can at times lead to beneficial modifications of the basic process and boiler controls. In one instance a large chemical plant was experiencing boiler trips and process shutdowns due to high and low drum level excursions following relatively mild load changes on a particular boiler equipped with the same type of control system as another similarly sized boiler of a different manufacture, which did not experience any such problems. An analysis disclosed that the response of drum water level to a change in feedwater was immediate in the case of the well behaved boiler whereas, due to the baffling in the drum internals and the way the subcooled feedwater was prevented from mixing with the steaming mixture in the drum, the response of level to change in feedwater exhibited a dead time of over a minute in the poorly controlled boiler. The problem could not be corrected through mere control tuning. Through dynamic simulation studies the appropriate control configuration was developed and the problem was corrected.

THE ART AND SCIENCE OF EQUIPMENT FAILURE INVESTIGATION

R.J. Ringlee, Principal Engineer
J.J. Burke, Senior Engineer
S.R. Lambert, Senior Engineer

PTI provides engineering services to assist clients in the analysis of equipment and system failures, particularly where independent third party opinions are needed. Most commonly, the objective of equipment and system failure investigations is to establish the sequence of events leading to failure and the most probable cause. An important outcome of a failure investigation is the preparation of findings and recommendations addressing application, installation and maintenance practices to decrease the likelihood of similar failures.

PTI staff and associate consultants serve as principal investigators for the assessment of equipment and system failures.

Equipment types that PTI has investigated include power transformers, reactors, salient pole and round rotor generators, synchronous and induction motors, high voltage cables and low voltage cables, power circuit breakers, surge arresters, protective relaying systems, bus work including isolated phase bus, and supervisory control systems.

System failures that PTI has investigated have ranged from plant substation failures to system blackouts. These have included investigations of problems in major oil refineries, process industries and bulk electric power systems.

One of the first actions in an equipment investigation involves on-site observation, review of protective relay and data logging information, interviews, inspection and photographic documentation of failed equipment, and gathering of system and equipment data for further analysis. These investigations frequently indicate need for sample and specimen selection and preparation for laboratory analysis. Assistance is offered in decisions for further teardown for inspection.

The next action is to select possible failure mechanisms and causes and develop a set of bases for testing the likelihood of each sequence of failure mechanisms leading to the cause of failure. This includes the identification of fault modes and the possible mechanisms of degradation as well as the possible operating conditions, ambient conditions, and maintenance actions that may have been significant factors leading to failure.

System studies are often necessary to establish a basis for judging the weight of application issues and questions. They are also needed in some cases to interpret disturbance records and to develop failure mechanism sequences in cases involving progressive faults.

PTI staff have assisted, directed, and performed disassembly and teardown of failed electrical apparatus to uncover parts interiors and to disclose materials conditions following failure that would yield evidence relating to damaging corona, tracking, contamination, wear, fatigue, or other physical deformation or degradation that was present prior to breakdown. Owing to the energy in many electrical faults or mechanical failures, the region initiating failure is frequently so altered as to be beyond recognition or destroyed in the ensuing explosion and fire. Therefore, it is essential that a thorough inspection of the failed equipment be made and that rest positions of remainders and degree of distortion and damage be established to aid in assessment of probable cause.

Contamination induced failures of power transformers have involved situations of moisture ingress at bushing flanges resulting in major insulation failures. Poor contacts in tap-changers have resulted in oil contamination and faults from highvoltage leads to tank. Transmission winding and lead-to-tank faults have resulted in severe fault pressures, winding and tank distortion and fracture, and fire. In several cases, fire damage and water ingress from fire fighting actions eliminated the possibility of direct identification of cause from the post
OVERVOLTAGE ANALYSIS IN INDUSTRIAL POWER SYSTEMS: CASE STUDY EXAMPLES

L.N. Hannett, Senior Engineer

Design practice in industrial power systems have evolved over many years based on theoretical considerations and practical experience and there is little new these days particularly with regard to grounding.

Nevertheless, lessons can still be drawn from the study of failures where voltages to ground may have an important bearing. Two examples of problems recently encountered are described. One involves the occurrence of overvoltages on motors which are not normally grounded i.e. the problem of drifting neutrals. Another involves the resonance between the magnetizing reactance of an ungrounded transformer and the charging current of the cable supply.

To illustrate the problem of drifting neutrals, consider a simple system of an infinite bus and an induction motor with a breaker connecting the two. The neutral of the induction motor is ungrounded, and under balanced conditions its voltage referenced to ground is zero.

Consider now a trip operation of the breaker with one pole failing to open. In this illustration the breaker pole that failed is on phase 'a'.

The voltages on the system side of the breaker are oscillating at system frequency. On the motor side due to the internal flux within the machine corresponding to the conditions prior to breaker opening, voltages will be generated across the windings at one minus slip times rated frequency. Since the motor is ungrounded, there is no current flowing through the machine when two phases of the breaker are opened. The resulting voltages on the motor terminals and neutral are shown in Figures 1 and 2 depicting an instant shortly after poles 'b' and 'c' open and some time later when, due to the motor slip, the phases are aligned to produce maximum voltage of 2.7 times normal.

The above condition results from the assumption of no decay in motor flux. In reality the internal flux of the motor will decay exponentially and for many motors this rate of decay is quite fast. In high efficiency motors this rate of decay will be slower, and the possibility of attaining high overvoltages may exist.

Another problem, also involving failure of a breaker pole to open, giving rise to severe overvoltages, can arise due to resonance between cable charging reactance and the magnetizing reactances of transformers. These possibilities are not evident when designs are checked only for balanced operation. Series resonance occurs when the non-linear transformer magnetizing reactance is close to the cable charging reactance at system frequency. Also involved is the nonlinear characteristic of the iron in the transformer core, giving rise to a phenomenon known as ferroresonance. To illustrate these types of resonance, consider a simple system with an infinite bus and a step down transformer connected to a load center transformer by a long cable as shown in Figure 3. A remote pumping station is an example.

The load center transformer is unloaded. Simulations were made using PTI's electromagnetic transients program (MNT/E) where the electrical network is represented by appropriate differential equations. The nonlinearity of the iron core saturation characteristic is included in the model.

A simulation of the opening of two phases of the breaker at time equal to 0.05 seconds with phase 'a' still energized by the system is shown in Figure 4. The wave forms for phases 'b' and 'c' exhibit an almost cyclic pattern with a high frequency mode of 90 Hz superposed on the fundamental. The voltages on these two phases reached a peak of 3.5 pu.

Another run simulating the opening of the phase 'a' pole with the remaining phases closed is shown in Figure 5. The high frequency oscillation on the phase 'a' voltage varies from 90 Hz to 120 Hz reaching a peak of 4 pu.

This resonance problem is eliminated with a 15% resistive load applied to the secondary of the transformer. Such a solution may not be practical or economical since there may be instances where there is no load on the transformer.

(Continued on Page 7)
INTELLIGENT LOAD SHEDDING ENHANCES SYSTEM RELIABILITY

H.K. Clark, Senior Engineer

Sudden generation overload in industrial plants and electric utilities has historically been addressed by underfrequency relays located in substations and connected to trip load feeders. This is the logical approach in utility systems where load shedding must be spread across a large geographic area. However, in most industrial plants it is practical to trip circuit breakers from a central location, responding to the event which causes load/generation imbalance, rather than its symptoms. This capability, combined with microprocessor technology, allows fast, precise correction of generation/load balance, ushering in a new era in industrial plant load shedding.

Problems With Conventional Approach

The short-comings of underfrequency load shedding schemes include dropping more load than is necessary, and dropping it later than necessary, i.e., after a frequency decay is well along. Frequency variations themselves impose risks of upsetting process loads and generation. During the frequency and voltage excursions associated with underfrequency load shedding, both low voltage limits (e.g., those levels where contactors may drop out or motors stall) and low frequency limits threaten loss of critical loads through instability. Furthermore an underfrequency load shedding scheme is fixed. Specific feeders are always tripped at specific frequencies. The frequency settings and magnitude of load are selected based on typical plant operating conditions, load levels, and most likely contingencies. Set schemes cannot take advantage of variations in operating conditions and load priorities. These limitations lead to conservative load shedding schemes that almost always shed more load than is necessary to balance load and generation.

For example, if it is required to trip 3 MW of load for system recovery on underfrequency and three candidate feeders normally carry 2 MW each but sometimes carry only 1 MW each, all three must be tripped to ensure system recovery. In such a case, twice as much load as is necessary may be dropped.

In plants with a single generator, it is sometimes practical to trip low priority loads upon trip of the utility tie breaker. However, because of the variation in feeder loading, even this approach frequently trips more load than necessary, and will not operate for problems deeper in the utility system which may affect the plant.

How a Microprocessor Based System Solves These Problems

An ideal load shedding system would monitor all loads, generators, and utility interconnections, and, following a disturbance, immediately trip just the precise amount of lowest priority load to balance load and generation. PTI's microprocessor based system does just this by examining the loading of each sheddable feeder, each generator, and the utility tie every 15 seconds. This data, and a load priority list already in memory, are used to calculate the exact action which should be taken for each contingency (generator trip, in-plant tie line trip, utility tie trip, etc.). The microprocessor software calculates the available spinning reserve (accounting for any steam or ambient limitations), and sets up a table of loads to be shed for each contingency.

When a disturbance occurs, the on-going table preparation process is interrupted, and the microprocessor immediately selects the appropriate load shed schedule and sends trip signals to the feeders listed in that schedule. The time from sensing a breaker operation to clearing of the necessary low priority load feeders is on the order of one quarter of a second (0.25 sec), including breaker breaker opening time.

If there is no spinning reserve at the time of the utility tie trip, the rapid tripping of a precise amount of load will typically limit the frequency dip to less than one Hertz. Figure 1 compares the response of an underfrequency relay scheme to that of a microprocessor based system. The latter's advantage in reducing frequency excursion and shedding a minimum amount of load shed is clear.

If there is some spinning reserve, a microprocessor based system can quickly reduce the load to within the maximum capability of remaining generation. With typical generator governing characteristics, the frequency dip is limited to two Hertz or less.

A key advantage of a microprocessor based system is the ability to handle complex utility tie trip logic. The trip logic would, ideally, take into account:
- power flow from or to the utility before the disturbance.
- power flow from or to the utility after the disturbance.
- amount of low priority load available for shedding.
- inertia of plant generators and loads.
- spinning reserve available in plant generators.
- utility load shedding frequencies.
- history of utility service outages to plant.

All of these can be integrated into the logic of a microprocessor based system. For instance, if frequency decay is slow (the utility is likely to survive), and there is little or no spinning reserve or low priority load in the plant, then the trip should be delayed until frequency is 4 or 5% below normal. If frequency decay is rapid or there is ample spinning reserve or low priority load, then tripping should be initiated with little or no delay. In either case, the microprocessor system will trip low priority loads to balance load and generation in the plant. The microprocessor can accommodate the complex utility tie trip logic necessary to minimize nuisance trips yet safely separate the plant from the utility when necessary.

The load priority list can be extensive. Single feeders or a group of feeders can be listed under one priority level for tripping.

Other Tasks for the Microprocessor

PTI's LD/1 Load Shedding System uses state-of-the-art microprocessor technology. Bulletins giving more detail on this system are available on request.
HARMONICS ON INDUSTRIAL POWER SYSTEMS...
(Continued from Page 1)

The system voltages and currents at the measurement location are recorded from existing pt and ct secondaries and stored within the data acquisition system. The recorded data includes a real-time clock so that the harmonics can be correlated with system events. Because of the large volume of data required, an instrument grade tape recorder is used. The signals from the power system potential and current transformers are buffered with appropriate amplifiers. Filters can be used to reject the 60 Hz component to increase resolution of harmonics.

The DAS is designed to be installed and operated with a minimum of effort. The DAS is configured to simultaneously record three voltages and three currents.

![Figure 1. Data Acquisition System](image)

Once sufficient data is recorded, the DAS is returned to PTI where the tape is played into the Data Reduction System and the harmonic information is calculated and tabulated. Depending upon the nature of the harmonic problem, additional analysis and recommendations can be provided.

HARMONIC STUDIES

Harmonic studies are performed for a variety of reasons including investigation of equipment failures, suspicion of high harmonic levels due to nearby harmonic sources, or the planned addition of new harmonic sources. Addition of capacitor banks for power factor correction near harmonic sources often requires a harmonic study to ensure avoidance of harmful resonant conditions and to check that harmonic voltages and currents are within acceptable limits.

The primary tool in harmonic analysis is the harmonic load flow. A harmonic load flow is a computer program that shows the harmonic currents and voltages throughout the plant and nearby utility system for specific operating conditions. Like a conventional fundamental frequency load flow, the harmonic load flow allows changes to the network to be conveniently examined. This is useful in exploring many plant operating conditions, equipment outages, and future equipment additions. Typical solutions to harmonic problems include moving capacitor banks or changing their sizes to eliminate resonances, adding filters, or converting existing capacitor banks into filters. All of these are easily explored with a harmonic load flow.

The harmonic load flow program can also automatically scan a wide frequency range to show at what frequencies and locations troublesome resonances will occur. The output of a harmonics scan are plots of voltages or currents which are useful in both identifying the problem and determining solutions. Figure 2 shows a plot of bus voltages versus frequency from a recent study of the effects of an arc furnace on a nearby industrial plant. The plot shows that resonances in the plant and the utility system may create problems even though the source of harmonics is several miles away.

![Figure 2. Bus Voltages as a Function of Frequency](image)

HARMONIC LOAD FLOWS are an effective tool to develop an understanding of the propagation of harmonics, whether these harmonics originate inside the plant or out on the utility system. Coupled with harmonic measurement, they enable the determination of cost-effective solutions to harmonic problems.

THE ART AND SCIENCE OF EQUIPMENT FAILURE INVESTIGATION (Continued from Page 3)

failure condition of the winding and lead insulation or of the insulating oil. The causes were identified from detailed inspection of accessory parts and appreciably distant from the paths of the arcs. Similar cases have been observed in equipment, such as arc furnace transformers, in which terminal board flashovers destroyed the evidence of the contaminants. Care must be taken to assure that the effects of ambient conditions prior to the failures are established and that the role that ambient plays in the performance of protective relaying and circuit breakers as well as the state of moisture in electrical insulations is considered.

The next step in the investigation is to analyze the events leading up to failure and to develop supportive simulations and calculations to correlate observations with proposed failure mechanisms. Such analyses may involve the use of static and dynamic simulations to predict power system response and to develop fault levels for estimating electromagnetic forces on leads and windings and pressures in electrical arcs.

Analysis and inspection may establish the need for additional field and laboratory tests to help confirm conditions at the time of failure. Recognizing that field and laboratory tests may be lengthy and expensive, strong effort is made to extract as much information from analytical approaches as possible before pursuit of further field and lab tests is made.

Reporting findings and recommendations is an important last step of any investigation. No failure report is complete until it contains conclusions relating to the most likely sequence of events and probable cause as well as reviewing questions relating to applications and applicability of standards and codes. Reports of findings should address ways to eliminate or minimize the risks of repeat failures.

Although no one likes to see failures proceed to litigation, PTI will, if requested, assist in the presentation of information at hearings or, as necessary, provide testimony.

PTI engineers believe that a strong analytical approach to a problem is often the most cost- and time-effective means to get the answers. To make effective use of analytical methods, however, one must have considerable practical experience in the design, application, and use of apparatus and in the design and operation of power systems. As in most engineering undertakings, the art of modeling and the skill in making the correct assumptions are the key to the correct identification and solution of the problem.
Another solution is to provide a resistive load in the zero sequence path on the transformer side of the breaker. For the sample network, a small wye connected distribution transformer, with the neutral of the distribution transformers grounded and an appropriate resistor inserted in its delta secondary, is used to alter the zero sequence path. Simulation results of the opening of two phases and of one phase respectively for the system with the distribution transformer is shown in Figure 6 and Figure 7. Both plots show that altering the zero sequence path in that circuit with the distribution transformer was quite effective.

Studies of possible overvoltage conditions during abnormal breaker operation should be undertaken as part of the normal design. With the available software on digital computers this task is not as difficult as in the past and such checks can be made routinely.

Loss-of-field protection is another example of protection that requires special consideration. In utility systems loss-of-excitation relays protect the generator from damage, but also limit the effects of power surges and low voltage that accompany loss of excitation. In an industrial plant the voltage may not drop significantly when loss-of-excitation occurs, compounding the chance of generator damage.

Wholly static exciters are now frequently used on industrial and small power producer installations. These excitation systems present a very difficult protection problem. With conventional excitation systems the generator fault current will decay to 200% to 250% of generator full load current in one or two seconds. Though it is sometimes difficult, overcurrent relays and generator "external fault backup relays" can usually be set to successfully detect all faults in spite of this problem. However, with static excitation systems, the fault current falls to zero in one or two seconds, leaving the overcurrent relays with no current if they do not operate in the first second or so after a fault occurs. This problem usually requires a major sacrifice in selectivity to ensure faulted elements will be removed from the system. Simulation of the actual fault current, including contributions from induction and synchronous motors and the utility are very helpful in ensuring that protection will function.

Corporate models are valuable strategic planning tools. Traditional corporate models are expensive to develop and cumbersome to run. Planners can use electronic spread sheet programs, available on personal computers, to rapidly build corporate models. This course teaches how this is done and shows how to avoid many common errors. Case studies show how important conclusions can be drawn from simple and understandable models.

A corporate model is a simulation of the basic financial statements of an organization: the income statement, the statement of sources and uses of funds, and the balance sheet. The relations among these statements include important dynamics.
NEW SHORT COURSE: CORPORATE MODELS FOR STRATEGIC PLANNING (Continued from Page 7)

For many strategic planning problems, much less detail is needed than is normally assumed necessary. (It has been observed that “an approximation to the right answer is much more useful than the wrong answer to six significant figures.”) Flexibility, rapid turnaround and ability to take quick looks at a variety of radically different scenarios are important.

Figure 1 is from a course case study on whether a utility should fight hard to retain its fuel adjustment clause (FAC). With the FAC there is no lag in the recovery of fuel costs. Without the FAC and with annual rate cases, there is a one year lag in fuel cost recovery. With rising fuel costs, this leads to a permanent reduction in earnings per share! Furthermore, effects of nuclear refueling cycles, changes in inflation, and changes in load are amplified and cause earnings per share to oscillate. This behavior is more severe the greater the escalation in fuel prices and is affected by load growth and other parameters as well.

This is typical of the kinds of issues that can be studied using corporate models developed in this course.

INDUSTRIAL POWER SYSTEM COURSES

PTI offers a variety of industrial courses for continuing education. Two new three day courses are offered for the Fall term.
• The SYSTEM HARMONICS AND CAPACITOR APPLICATIONS course includes a review of fundamentals of watt and var requirements of power system and the most economical application of capacitors or other var sources to meet load requirements. Static power converter theory is taught to understand where harmonics originate and the effect they have on system equipment. Control of harmonic currents through design and filters is covered.
• The INDUSTRIAL POWER SYSTEM PROTECTION course covers protective device characteristics, power equipment and substation protection, power system protection philosophy and terminology, and device coordination.

FALL 1985 SHORT COURSE SCHEDULE

Courses to be presented at PTI offices in Schenectady, NY

<table>
<thead>
<tr>
<th>Dates</th>
<th>Course</th>
<th>Fee (per participant)</th>
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<tbody>
<tr>
<td>September 9-13, 1985</td>
<td>Power Plant Performance</td>
<td>$900</td>
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<tr>
<td>September 16-20, 1985</td>
<td>Power System Dynamics</td>
<td>$900</td>
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<tr>
<td>September 23-27, 1985</td>
<td>Utility Economics &amp; Finance</td>
<td>$900</td>
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<td>September 30-Oct. 4, 1985</td>
<td>Underground Cable Systems</td>
<td>$900</td>
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<tr>
<td>October 7-11, 1985</td>
<td>Power System Scheduling &amp; Operation</td>
<td>$900</td>
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<td>October 15-18, 1985</td>
<td>Transmission Reliability Assessment</td>
<td>$800</td>
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<td>October 16-18, 1985</td>
<td>Power Plant Maintenance Scheduling</td>
<td>$700</td>
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<td>October 21-25, 1985</td>
<td>Power System Planning Techniques</td>
<td>$900</td>
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<td>October 29-31, 1985</td>
<td>System Harmonics &amp; Capacitor Applications</td>
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<td>October 28-Nov. 1, 1985</td>
<td>Power Distribution Systems</td>
<td>$900</td>
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<td>November 6-8, 1985</td>
<td>Corporate Modelling Using a Personal Computer</td>
<td>$800</td>
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<td>November 13-15, 1985</td>
<td>Cable &amp; Accessory Failure Analysis</td>
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<td>November 19-22, 1985</td>
<td>Steam Turbine Performance &amp; Optimization</td>
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For further information contact: Barbara E. Gnat, Administrative Assistant Educational Programs