MICRO-PROCESSOR BASED TURBINE CONTROL

A previous article described PTI’s involvement in turbine automation and rotor stress minimization using programs written for power plant computers. However, many controlling units commissioned before the early 1970’s do not have computers capable of controlling thermal stresses on the rotor during turbine startup, load change, and shutdown. The decrease in rotor life due to the cumulative effect of these stresses is compounded by the increased use of these units in cycling operations as base load duty is transferred to newer and larger plants. Thus, concern over the problem of increasing thermal duty of turbines without the ability to monitor or control induced stresses led to the development at PTI of a microprocessor based turbine automation system designed for existing power plants. The device described in this article is designed for use with General Electric steam turbines.

PTI’s Turbine Speed and Load Control (TSLC) is a compact and freestanding control and monitor system for accelerating and loading or unloading steam turbines. The TSLC actually consists of two parts as shown in Figure 1. Each part contains microprocessors and has full computational capability as well as memory. The Input/Output unit is compatible with the signal environment normally found in power plants. All digital inputs are optically isolated. Digital outputs are rated at 125 volts, 2 amps dc. Analog Inputs are capable of 300 volt common mode rejection. The Input/Output unit’s function is to measure the pressures, temperatures, valve positions, etc. necessary for turbine automation. These inputs are digitized and converted to engineering units and then sent to the Control unit which calculates rotor stresses and decides how the turbine is to be controlled. The operator interface is a set of function keys and a seven-color CRT driven by the Control unit.

ADVANCED UNIT COMMITMENT SOFTWARE

A Key to Fuel Conservation

Utilities have long recognized that decisions as to when individual generator units should be started up or shut down may have leverage in fuel economies at least as great as that of on-line economic dispatch. Due to the very modest computer resources required, automatic economic dispatch was long ago implemented on small digital dispatch computers and before that on analog devices. In contrast, economic unit commitment is a much more complex problem requiring the type of computer capabilities which only recently have become commonly available in dispatch centers. Now that computer generated unit commitment is a realistic option, interest in advanced unit commitment software has increased dramatically. The recent increases in cost of fuel and the increased complexity of interconnected system operation have further emphasized the need for such software.

The basic purpose of a unit commitment program is to find the most economic and feasible schedule of start and stop times for generator units given specified loads and interchange power transaction schedules. A feasible schedule is one for which the load, reserve requirements, and other operating constraints are satisfied throughout a given time period.

Among the operating constraints which should be handled are:

- Unit minimum up and down times
- Various categories of on-line and off-line reserve requirements for total system and for areas within the system
- Maximum unit on-line and off-line reserve capability
- Unit minimum and maximum generating limits
- Must-run and must-out units
- Units on fixed generation
- Transfer limitation between areas within the system

The two most important requirements for a unit commitment program are realistic representation of important operating constraints and acceptable execution speed. These needs can be met by means of dynamic programming. This technique consists of an hour by hour evaluation including economic dispatch, cost comparisons of feasible unit combinations, and associated start-up and shut-down sequences. The process is performed in such a fashion that, when computations for the last hour are complete, the most economic and feasible unit commitment can be identified without further searching.

Even though dynamic programming is an efficient search technique, it is impossible to consider all unit combinations for each hour. There are, for example, more than a million possible combinations in a system with 20 units. The selection each hour of from ten or twenty to several hundreds of combinations for testing by the dynamic programming algorithm is therefore a critical part of the process. In total, a few thousand unit combinations may have to be analyzed during a single unit commitment run. Considering that part of the analysis of each combination involves an economic dispatch within operating reserve constraints, even this is no mean task; and it is evident that special high-speed, noniterative dispatch algorithms must be used.

The figure below shows an example output of the PTI program for a three-day period. In the schedule shown, * indicates that the unit is dispatched between upper and lower limits, L and U indicate that the unit is at the lower or upper limits, respectively, and F indicates that the unit is on-line and fixed at a base load value. Note that units are ordered according to increasing average full load cost such that the output tends to resemble an inverted load curve.
Turbine Control (From page 1)

TSLC. Many of the complete boards as well as the components on the boards are offered by several manufacturers, ensuring the future availability of the hardware. The modularity of the hardware means that maintenance is simply a matter of board replacement, and spare parts inventory can be small.

The Intel 8080 family of microprocessors and support chips was chosen for use in PTI's system because of its wide availability and low cost as well as its availability of high level programming languages. Much of the software of the TSLC is written in ANSI 1977 FORTRAN, a structured programming language. The use of a high level programming language, and a structured language in particular, makes software maintenance a manageable task.

Perhaps the best reason to use microprocessors is that the automation system does not look like a computer to the power plant personnel who may not be familiar with the more technical aspects of computer operation. The sophistication of modern microprocessor hardware bypasses complex computer "booting" procedures and replaces them with a simple on/off switch.

Controls

TSLC has direct control of the main stop valve bypass (MSVB), the main stop valves (MSV) and the control valves (CV). During acceleration and loading at low load levels, the MSVBs are manipulated to control the turbine, while at higher loads, the CVs are manipulated through the governor. The transfer of steam throttling control from MSVBs to CVs (full arc to partial arc transfer) is done at a rate that keeps thermal stress in the valve chest at an acceptable level while continuing to load the unit.

Operator Inputs

All operator selections are initiated with function buttons.

The plant operator is basically responsible for entering three pieces of information: target load, maximum allowable loading rate and life expenditure. Maximum loading rate places an upper limit on the rate that a turbine will be loaded or unloaded. TSLC continually adjusts the rate of change of turbine load based on rotor stresses. In no case will the rate exceed the operator selected maximum. Life expenditure selection allows the trade off of rotor life for time to reach target load and provides the operator with the ability to choose the maximum amount of rotor life that can be expended in a startup-shutdown cycle. At low life expenditure a new turbine can conservatively complete 10000 cycles before rotor cracks are likely to develop. Medium and high life expenditures are 5000 and 2000 cycles, respectively These are estimated figures. The actual amount of rotor life expended is accumulated and saved for historical information.

In addition to buttons for the three items mentioned above there are also buttons for manual hold, release manual hold, override auto hold, set time and date, etc. Wherever possible, information is entered interactively, with the TSLC asking for a particular item. For example, when the target load function button is pushed, the TSLC asks for a target load to be inserted by the operator.

Operator Outputs

All relevant information about the turbine is shown on a single page video display designed to show a large amount of information in an organized and consistent manner. Since the display format is fixed, it can quickly be learned by plant personnel to get an overall view of turbine status in one glance.
Turbine Control (From page 2)

Critical quantities are plotted as bar graphs. The upper left corner of Figure 2, for example, shows plots of rotor stresses, one of which has exceeded 80 percent of allowable stress, thereby going into alarm. Pressures, temperatures, speed and acceleration are also shown in bar graphs. The center of the screen is devoted to an alarm area. When a new alarm is generated, the messages in the alarm area scroll down and the text of the new alarm is placed on top. When an alarm condition returns to normal, the message enters the top of the alarm area in green.

The bottom of the screen has four programmable strip charts. Any of the analog inputs or calculated values may be plotted against time. Analog inputs include measured temperatures, pressures, speed or load. Calculated values include stresses, steam enthalpy, bore temperatures, acceleration, desired loading rate or actual loading rate. The remainder of the screen contains the current status of the TSLC and an operator prompt area.

Microprocessors offer a convenient and economical way to give existing steam turbines the automation of overstress protection that is becoming a standard part of the modern power plant computer's function.

REFERENCES

DISTRIBUTION SYSTEM HIGH IMPEDANCE FAULTS

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Senior Engineer

When primary distribution conductors fail because of ice, wind, tree limbs hitting conductors, and automobiles striking poles, the impedance of the resulting fault is apt to be sufficiently high that the resulting low fault current does not operate the protective devices and the conductor may remain energized for extended periods. Several utilities, including Pennsylvania Power and Light, Rochester Gas and Electric Company, and New York State Electric and Gas Corporation have been sufficiently interested in the problem to initiate research of their own. However, since the problem is industry-wide, the Electric Power Research Institute (EPRI) has initiated a number of current projects with each contractor pursuing different approaches.

The scope of the PTI project is to conduct a thorough investigation of changes in all electrical parameters due to a high impedance fault. Using statistical analysis methods, pertinent parameters will be selected and functional design specifications prepared. Present results suggest that the solution to this problem will require a synthesis of technology from several areas since detection and discrimination will depend on a combination of effects.

Any scheme for automatic detection of high impedance faults due to downed conductors must consider a variety of technical and economic constraints. The complex and continuously changing distribution system configuration and loading, together with the required service reliability at the lowest possible cost, weigh heavily against certain exotic approaches which might include communication systems and/or computer applications. Requirements for coordination with other protective devices, normal system unbalances and waveform distortion, and transient loads such as welders, all add to the problem complexity.

Initial analysis of the problem suggests several variables as logical detection candidates:
1) 60 Hz quantities, such as phase quantities, symmetrical components, or Clarke components, together with rates of change.
2) Current and voltage harmonics generated by the fault, including frequencies as low as 60 Hz.
3) Injection of a high frequency signal and effects on the signal by the fault.
4) Radio frequency effects produced by the fault.
5) Fault inception transients.

To evaluate the possibilities and to reduce the problem to a manageable scope, formulation of an analytical system model to represent a variety of fault types on a variety of different feeder configurations is necessary. To accomplish this, the electrical properties of the ground connection occurring at the fault must be known. Considerable literature exists in related areas such as the physics of arcs and engineering data on grounding.

Arcs produce noise and harmonics by two mechanisms, both extensively studied at the turn of the century in connection with the development of radio transmitters. The first is the rapid switching property of an arc; an example is radio interference from neon signs. The second is the negative resistance property of the arc, such as was used for early undamped wave transmitters. However, these previously studied arcs occur under controlled conditions using electrodes of known properties. A downed conductor has an arc between metal and earth which presents different cathode materials for the two half cycles.

Arc voltage by itself is low, of the order of a few hundred volts at most, and cannot account for the current limiting effect observed from field data. Ground impedance is dominant. In fact, current may even rise during heavy arcing due to fusing of the earth into liquid globules.

A test facility was constructed at the Saratoga Research and Development Center to investigate the ground/arc properties. With 5000 volts line to ground available and a predetermined current limiting impedance to avoid overheating the feeder, the facility has been used to gather data on the nature of the ground connection. Similar testing at higher voltage has also been conducted at a site operated by Rochester Gas and Electric, where a variety of surfaces is available, including earth, asphalt, concrete, and reinforced concrete. Both bare and covered conductors were tested. Results are similar with the two conductor types although the current on covered conductor concentrates the energy at the earth interface.

Preliminary results confirm the complexity of detection. With both asphalt and a thin ice and snow cover, fault currents as low as about 50 milliamperes can occur. For example the table shows the buildup of fault current with about 12 inches of hard-packed snow and ice on the ground and a fault voltage of 5000 volts. A period of 115 minutes was required for the current to surpass 100 mA, and 160 minutes until the current exceeded 1 ampere. Thereafter the current rose rapidly to fuse rating.

Sample Fault Current Buildup

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The opposite has been experienced on dry soil where fault current dries the ground, resulting in a fault current which decays to zero over a period of several minutes. The best possible ground connection occurred on the reinforced concrete sidewalk segment. The fault current burned a hole in the sidewalk and the current in the reinforcing rods caused water to migrate up through the concrete, allowing the outline of the rods to be seen on top of the sidewalk.

The figure illustrates representative high impedance fault current oscillograms. Occasionally, pronounced harmonics result from the switching nature of the arc (a); sometimes a very low current, say 50 mA, would exist for an extended period of time with occasional bursts of much higher current (b); and at times a very low current occurs with minimal harmonic content, such as when the conductor falls into a puddle (c).

Data from these tests have been recorded on analog magnetic tape for subsequent conversion to digital form for numerical analysis.

(continued on page 4)
Unit Commitment (From page 1)

PTI has supplied unit commitment software for systems ranging from 20 to 200 units. Program objectives have covered daily generation scheduling, transaction cost evaluation, billing reconstruction, and evaluation of cost penalties associated with various operating constraints. In a recent application, the unit commitment software served as a subprogram to a transaction evaluation program which was designed to compute the incremental system cost or savings of proposed transactions. In an “after the fact” mode, the program computes the actual incremental cost of past transactions, taking into account the economic impact of differing shut-down and start-up schedules. The transaction analysis with a unit commitment program includes direct costs of the value of on-line and off-line reserve whether received through a purchase or committed through a sale. It can therefore provide a solid foundation for assessing transaction capacity charges as well as transaction energy charges.

The program can also be used in a study mode as an aid to operators and planners. Examples of such study mode applications are:

- Determine the true cost of reserve requirement rules
- Determine savings obtainable by equipping units to cycle on a daily or weekend basis
- Determine the cost penalty of maintaining a given operating margin between upper economic dispatch limit and maximum unit capability
- Determine the operating cost benefit of pooling arrangements
- Determine the operating cost benefit of increased transmission capability between system areas
- Perform detailed operating simulation with alternate unit additions at the planning stage
- Determine the true operating cost benefit of reduced unit downtime due to repair or maintenance
- Predict fuel consumption by plant and by fuel type in cases where prediction techniques based on load-duration models may be inadequate.

The computer resource requirement for PTI’s unit commitment program is not excessive. Example solution times for a three-day unit commitment run are 3 minutes for a 15-unit system on a DEC PDP 11/60 computer and 10 minutes for a 110-unit system with transmission constraints on a large IBM 370 series computer.

The savings in operating cost resulting from use of a modern unit commitment program can be quite substantial. One can gauge the sensitivity of cost to judgmental errors by artificially perturbing the optimized commitment schedule produced by the program. For example, for the case illustrated, a decision to keep “OLD 4” on line rather than cycling off, as shown, would increase operating cost for Friday alone by $15,000, an increase of about 5 percent of the total operating cost on that day.

In summary, the benefits of an efficient unit commitment program in daily scheduling are threefold:

- Significant direct savings in operating cost
- Better cost and benefit evaluation of transactions
- Assurance that system reserve capability is adequate for the predicted load.

In addition, a program of this type may serve as an efficient general purpose operation planning and evaluation tool.

Apart from the hourly schedule of units, the printout includes total operating costs for the commitment interval, broken down into fuel cost, maintenance cost, and start-up cost. These total costs have been minimized by the program’s logic, subject to the operating constraints. Detailed output of unit status and dispatch and a system summary of load, generation, transactions and reserves are also available for each hour of the unit commitment interval.

High Impedance Faults (From page 2)

![Figure 1](image_url)

Presently the extensive test data is being analyzed and mathematical fault models constructed which can be inserted into the PTI MNT-3 computer program. This program is a detailed 3-phase system representation including nonlinear effects. Using this technique, it is possible to investigate different earth surface conditions, a variety of system configurations, and system loading to more precisely evaluate the various possible detection parameters. The results will also aid in defining further field test requirements. The schedule for this broadly based project anticipates functional specifications for one or more methods of practical high impedance fault detection by spring of 1980.