PTI'S ROLE IN EPRI RESEARCH PROJECTS

D. D. Wilson, Principal Engineer

It has been the policy of PTI to be very selective in taking on research projects. Maximum relevance and usefulness of an analytical consulting company can be sustained only if the majority of its business emphasis remains with current, rather than future, applications. PTI has undertaken research projects which appear to fill important gaps in the currently applicable field of information. One of these projects, sponsored by the Electric Power Research Institute (EPRI) and dealing with underground cable pulling lengths, is described in this issue. The results of another, reported in the March, 1977 issue has now been released in book form.(1)

To better disseminate the results of this study, EPRI recently sponsored two, three-day compact line design application seminars, one near San Francisco and another in Philadelphia. The seminars considered selection of specific transmission line configurations, electrical performance prediction, design for clearances during conductor motion, and electrical environmental effects. The impact of the National Electrical Safety Code, methods of live-line maintenance, and comparative construction costs were also covered. The final day consisted of detailed design of a compact line by attendees.

The last issue of the PTI NEWSLETTER (January, 1978) described an extension of this compact design effort, i.e. the concept of bundled circuits. A number of other EPRI-sponsored projects have been initiated which will also be of interest to PTI clients. The following paragraphs summarize them.

Phase-to-Phase Switching Surge Strength of Transmission Line Conductors

Phase spacing of compact lines is often limited by switching surge criteria. Unfortunately, very little is known about switching surge strength of conductor-conductor configurations. There is essentially no test data for parallel conductors with insulator clamps, aeolian dampers, and armor rods, and no acceptable method of calculating long line performance from short test samples. Gaussian (normal) statistical functions, frequently used to predict multiple insulator performance, are obviously incorrect for a continuous conductor, particularly for extreme extensions of length. Their use results in overly conservative design spacings.

The new PTI project will provide test data and application methods for more precise long line switching surge performance (continued on page 3)

EXTENDING PIPE CABLE SECTION LENGTHS

J. A. Moran, Senior Engineer

While the installed cost of underground transmission lines varies widely with voltage, power rating, length and nature of the route, the total cost tends to be divided approximately equally between hardware and installation costs. Further, the installation costs generally tend to divide about equally between cost of civil works — excavation and pipe laying operations and the electrical skills — cable pulling, splicing, and terminating.

Although underground transmission remains, in most cases, significantly more expensive than overhead, appreciable savings can accrue from optimizing cable system design and installation methodology.

The high-pressure, oil-filled, pipe-type cable has been the dominant system used for underground transmission in the United States. Among the advantages of the pipe-type system is that the cables can be installed in relatively long lengths, resulting in fewer manholes and splices. With the installed cost of a splice ranging from $20,000 to $60,000, depending on voltage rating and location, the incentive to reduce the number of splices is apparent.

Not so obvious are the peripheral savings; e.g., (1) fewer reels to test, handle, seal, ship, set up and pull, (2) fewer empl­ies to return, store and maintain, and (3) fewer sections to night cap, evacuate, pressurize and monitor.

Furthermore, the crowded environment (above and below ground) in which most transmission cable is installed makes the problem of finding locations for manholes and of maintaining traffic flow during construction loom large, giving further incentive to maximizing pulling lengths.

Technically, the limiting length of pull may be governed either by the mechanical stresses which the cable can safely withstand, by the structural forces imposed on the pipe and manhole, or by the wear imposed on the steel pipe by the wire rope used to draw the power cables through the pipe. In practice, the length in certain cases may be limited by manufacturing and shipping size and weight constraints.

In the course of the pulling operation, the cable is subjected to a complex system of forces; tensile load due to friction, torsion due to the stranding both of the power cable and the pulling wire rope, and bearing pressure as the cable is drawn under tension around horizontal bends and vertical offsets in the route.

Design practice to date has been to limit tensile force and side wall pressure (bearing force per unit length of cable) to values established empirically by various practitioners in the early 1950’s and judged since that time to be generally conservative. User practice varies considerably as based on individual selection of appropriate safety factor.

Additionally, over the years numbers of new materials and manufacturing processes have evolved and the voltage ratings of (continued on page 4)
THE TRAINING OF POWER SYSTEM OPERATORS

C. A. MacArthur, Senior Engineer

Operator training is a major concern for utilities throughout the United States. The increased complexity of today’s interconnected power systems places the system operator in a very enviable position. He must cope with a system which he cannot fully observe and may not even fully understand. Once the system deviates from its normal behavior patterns and enters an abnormal condition, it often has no experience to guide it. Yet it is in these abnormal situations where the greatest need for training exists. The opportunity to observe system performance under normal and abnormal conditions obviously cannot be provided by the system itself. It requires the operator to be able to learn from courses which depend on mathematical tools to demonstrate the characteristic of the systems. The mathematics are too complex for the background of the men being trained; thus the training is usually either overly simplified or loses the participants in the complexity of the explanation.

As with many complex processes, the answer lies in formal course work (including text material) supplemented by problems and work exercises on some form of system representation or simulator. Neither alone would be adequate: the text because of the mathematics required; the simulator because it is only a specialized calculator. Together they are a powerful team. The text explains principles and the simulator allows the student to test them and try alternative solutions to a problem where more than one principle is involved. The hands-on simulator exercises are an essential part of the teaching process.

Since the formation of PTI, the company has been involved in the preparation and conduct of courses ranging from dealing with practical engineering concepts to courses aimed at acquiring utility commissions with the most basic concepts of power system structure and operation. In recent months PTI has given considerable thought to the problems of a course suitable for training system operators. The material seems to break up into five natural sections:

The first section would contain four chapters entitled:
I. Basic Principles of Electricity for Power
II. Basic Characteristics of Power Apparatus
III. Steady State Power Flow Concepts
IV. Steady State Voltage Control Concepts

These four chapters would present the basics of power system steady state operation and the related fundamentals of electricity. The characteristics of equipment would be discussed, stressing their functions and capabilities. The factors that determine power flows would be described, along with the means to control them. Voltage standards and the ways and means of controlling voltages (as well as the causes for voltage drops) would be covered also. These are all basic to what follows and time would be spent to ensure a thorough understanding of the fundamentals. Extensive use of the simulator would illustrate the problems involved and the response to control measures that are available to the operator.

Based on this foundation the second section would contain two chapters:
V. Economic Operation
VI. Constraints on Steady State Operation

These would discuss normal economic operation and the constraints imposed by normal hazards. The steady state type (i.e., assuming stability is not a problem), Ways to monitor the system and assess methods of survival would also be described. Further exercises on the simulator would illustrate the principles and effectiveness of various control methods.

In the third section chapters are envisioned:
VII. Dynamic System Performance Concepts
VIII. System Equipment Performance in Dynamic Situations
IX. Normal Operating Hazards

These would cover fundamental concepts of dynamic operation of the system. The effects of switching equipment out of service without fault would be followed by discussion of more serious disturbances. The purpose is to develop an awareness of the physical significance of what is going on and how the parts of the system work together to maintain synchronism.

In the fourth section the concepts of dynamics would be extended through three chapters:
X. Recognition of Hazardous System Conditions
XI. Remedial Measures
XII. Recovery from Major Disasters

These chapters would describe operation in abnormal conditions where loss of synchronism is possible as a result of cascading. It would start with recognition of abnormal situations, using the information available in the control room or by calls to other locations. How to determine the locations and types of trouble would also be discussed. If the situation seemed to be developing beyond hope of control, the means to save as much as possible would be developed, stressing the time available to take corrective steps. If all should fail and the system goes down, ways to restore it would be explained, including the behavioral understanding of the problems of load shedding and would also be described. Problems and work exercises on the simulator would serve to cement the problems and solutions in mind.

The last section would include subjects fitting under the titles:
XIII. Communications
XIV. Modern Software for System Operations
XV. Interconnected System Operations

These would gather together a miscellaneous group of topics such as communications problems, including meters; computer programs available to aid operators and the limitations of such programs; and the principles of operations of interconnected systems. This last topic would be based on the NAPBIE guidelines and would point out the benefits, responsibilities, and constraints of interconnected operation.

The intention throughout would be to keep the level of instruction non-mathematical but accurate. With various simulation options to illustrate the points and solve the mathematics, there would be no need to simplify the principles of the systems and its dynamics. On the other hand, it is not intended to provide text material to enable students to design a system, but just to be able to operate one intelligently.

The coordination of the text with a simulator would form a powerful teaching tool that would give the trainee an intuitive and physical understanding of how the system works and why it reacts as it does to disturbances and control actions. It is not intended to provide the conditioned response that is attained through aircraft flight training types of simulators. The aim of the trainer is to develop an operator who can reason out what is happening and what to do about it. Any program that does less than that is not fully satisfactory.

Obviously the process of operator training is an on-going one that never ends. New operators come along; old ones need refreshing and enhancement of their skills. In the long run it seems desirable that any training program should grow into a self-instruction type, possibly with a supervisor to add unexpected events to the lesson on occasion. Before this is attempted, a good basic text and program must be developed and tested.

In conjunction with the self-instruction concept, it would be desirable for the simulator to be low enough in cost that it could be used by the training department so programs could be released for short times as their duties allow and without tying up the main operating center computer with training sessions.

There is another aspect to the problem of operator training. It is probably necessary that action be started as soon as possible. It may not be satisfactory to wait until a training text is finished before beginning the training of new operators. PTI is already working on programs for the present operators. For the training of these experienced men a simulator is needed now.

For the experienced operators there are two programs PTI already offers that simulate power systems. The PSS/E version represents the steady state and dynamic characteristics of large systems with its operation oriented toward use by engineers involved in planning or engineering design. The PSS/O version is aimed at the steady state operating problems of the system with features that make it particularly useful for the operator. For example, switching of System PTI is done through specific breakers at both ends of a line. If in the course of switching, the system is divided into separate parts, each will solve if the generation available is enough to supply the load.

For the beginning operators, a smaller simulator is indicated. This would be programmed with a dynamic system representation that closely correspond exactly as a system disturbance were imposed. It would be large enough to be representative of a typical system of today but small enough that the principles to be demonstrated would not be lost in the mass of details. A prototype is available.

This article has briefly addressed an approach to power system operator training using a text and simulator together. PTI would welcome system operators or any others that might come from the industry on this subject. Interested companies should contact C.A. MacArthur, Senior Engineer.
(Continued From Page 1)

prediction. The data will be applicable to lines in the 115-230 kV range, both conventional and compact. A statistical function for calculating long-line switching surge performance from short test samples will be established. The project is scheduled for completion in 1979.

Measurement of Fault and Cold-Load Pickup Currents on Power Distribution Systems

Although it is easy to calculate fault currents on distribution circuits when all system constants and the fault impedances are known, those constants are seldom known with much accuracy. Yet, maximum values and the statistical distribution of fault and inrush currents must be assigned values if systems are to be designed and if equipment is to be selected properly. The present lack of this type of data has often led to very conservative practices. PTI has been asked to determine the actual frequency distribution of fault current levels. Cold load pickup characteristics will also be documented. The project will include development and deployment of 50 recording instruments on approximately 13 participating utility systems. These instruments are to be designed, built, and installed by early 1979. Data collection and analysis should be completed within two years thereafter.

Detection and Discrimination of High Impedance Faults on Distribution Systems

Distribution line faults are generally cleared by interrupting devices which sense the overcurrent produced by the fault and then disconnect the faulted line from the source. Though these devices must trip for serious overcurrents, they must not respond to normal or even very high fault current overcurrents. Inrush. Thus, the threshold of operation must often be set at a current level so high that the device fails to trip when there is a high impedance fault.

A newly initiated research project, sponsored by EPRI, will develop functional design specifications for a device capable of distinguishing between high impedance faults and load currents. The project is scheduled for completion in mid-1980.

Development of a Leak Location System for Use on Underground Cables

Finding leaks in HPOF, LPOF, and HPGF cables is presently a very slow process and very expensive in terms of manpower, oil loss, and feeder downtime. It is important that fast, accurate, and economic techniques be developed for leak location and detection. A recently authorized EPRI project will investigate, in depth, approximately six location methods. Promising candidates will be evaluated from standpoint of cost, system operating requirements, environmental compatibility, and regulatory/political constraints. The project will be completed in late 1979.

Transient Efficiencies in Power Plant Thermo-Mechanical Processes

This research effort will derive quantitative relationships between the efficiency of power production in fossil-fueled plants and transient duty imposed on such plants, considering the entire thermo-dynamic cycle. Twenty-five percent of those additions, however, were identified as peaking or dispersable units. The present project will repeat the expansions, but dispersing the latter components in blocks which may be as small as 100MW.

Penetration Analysis of Fossil Fuel and Advanced Power Generation Systems

The project, directed to central station plants, concerns new generation technologies which use fossil fuels—primarily coal—or which convert fuel or energy to other forms prior to power generation. Advanced systems include coal liquefaction, coal gasification, regenerative flue gas desulfurization, combined cycles, fluid bed combustion, central solar thermal, MHD, and fusion. Commercially available options which are deemed to meet present and projected environmental limitations are included as competitive references and as input to the base case firing. Savings are then calculated.

The study plan includes an evaluation of the advanced concepts, assuming all alternatives are successfully commercialized and an evaluation which presumes each, in turn, is the only successful addition to presently available generation. Thus, maximum benefits resulting from the implementation of each generation system are to be tempered by corresponding results that are limited by the capacity additions necessary to meet load growth. The project is scheduled for completion in August of 1979.

Dispersed Generation Systems

In 1976, PTI completed detailed definitions of five “synthetic” power systems for use in studying new system design ideas, equipment applications, etc. These systems averaged about 40 GW in capacity and ranged from 5,000 to 30,000 bus load trans­mission. A summary of the project was included in the January, 1977 NEWSLETTER.

All six systems were later expanded to the year 2000, assuming that all generation additions would be at central generating locations. Twenty-five percent of those additions, however, were identified as peaking or dispersable units. The present project will repeat the expansions, but dispersing the latter components in blocks which may be as small as 100MW. Transmission system reliability will be maintained at the prior level. Differences in transmission and substation costs for the central and dispersed generation expansions will then be compared. The project is scheduled for completion in July of this year.

Potential Cost Advantages of Peak Load Pricing

In 1975, EPRI and the Edison Electric Institute started a joint research effort for the National Association of Regulatory Utility Commissioners to examine “Electric Utility Rate Design.” Ten task forces were formed to examine the costs and impacts of time of day rates. PTI was retained to develop methods for assessing load shifting advantages which might result from time of day pricing. The project identified the data required to conduct cost/benefit analyses, established methods for making such analyses, and applied the methods to a representative situation. The results of this study were reported in a November, 1977 report, “Rate Design and Load Control — A Report to the National Association of Regulatory Utility Commissioners.” PTI is currently working with Northern States Power Co. to extend methodology to consider the optimal total load pattern for the generation system and the means by which the optimal load pattern might be achieved. This will include a cost/benefit analysis of various degrees of load management considering both overhead and underground trans­mission, subtransmission and distribution systems. The project is scheduled for completion by the end of 1978.

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(1)“Transmission Line Reference Book — 115-138 KV Conductor Line Sign” (Book) Published by the Electric Power Research Institute (EPRI) Palo Alto, California.

COMPUTER RATES REDUCED

Increase in computational efficiency has enabled PTI to make several major reductions in computer rates effective April 3rd, 1978. The basic rate of $33.00 per computer resource hour (CRH) will be reduced by 30% to $23.00. In addition, the CRH formula for background queue service and for non-prime time will be changed so as to yield approximately 2.5 and 3.7 times more computer cost per CRH respectively, compared to prime-time inter­active use.

PTI’s computer charges are also subject to a program use multiplier, the purpose of which is to recover prior program development effort and to support new program development work. Widespread client acceptance of the PSS/2 and PSS/E programs, and the intensity of their use at PTI, has allowed the use surcharge on these programs to be cut in half. The use multiplier, formerly 1.5, will be reduced to 1.25.
(Continued From Page 1) For the past year, PTI has had several levels. The effects of these changes related to cable pulling are largely unknown.

In July, 1975, PTI was selected by EPRI to investigate the elements of the problem related to the cable's mechanical endurance, and to establish an updated data base by tests on current cable constructions. The investigation promises to provide a sound basis for consideration of increasing section lengths over present practice.

The experimental program includes:
(a) Determining effective coefficient of friction for combinations of all commercially utilized cable skin wire materials and lubricating oils over a broad range of cable weights and diameters in the appropriate sized coated steel pipes.
(b) Conducting tensile and elongation tests on cables with both copper and aluminum conductors over the size range of modern application (1000 kcmil to 3750 kcmil) and voltage ratings from 138 kV through 345 kV. These tests are carried out through the apparent yield point of the complete cable to determine whether significant disarray of the laminar paper-oil dielectric has occurred.
(c) Testing at higher-than-normal side wall pressures (dynamic) to establish the threshold of damage.
Insulation damage is assessed by physical examinations augmented by high resolution radiographic inspections and by measurements of insulation compactness. Comparative dielectric strength measurements on cell models simulating observed distress are planned.

A demonstration pull (see photo) conducted in a commercial 230 kV installation imposing (in an expendable portion of the length) the limiting side wall pressures inferred from the experimentation, generally corroborates the experimental findings. Another demonstration on a 345 kV installation is being planned for later this year.

The final report on this program is expected to be issued to EPRI in late spring of 1978.

UNDRIll NAMED PRINCIPAL ENGINEER

On January 25, PTI announced the promotion of John M. Undrill to a principal engineer's post in the firm. Undrill joined PTI as a Senior Engineer in 1971 and has been responsible for studies of dynamic problems in electric utility networks as well as for the development of interactive computer programs for that purpose. PTI's Power System Simulator Program (PSS/E), developed under Undrill's direction, has been widely applied by utilities in the U.S. and abroad. His work in the field of interactive power system computing led to his election as a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) in December of 1977.

Undrill received a Bachelor of Engineering degree from the University of Canterbury, Christchurch, New Zealand, in 1963, and a Ph.D. from the same University in 1965. Following a Post Doctoral Fellowship at the University of Toronto, he joined the General Electric Company's Electric Utility Engineering Operation in 1966, where he worked until joining PTI.

In his capacity as principal engineer, Undrill will be responsible for continued development of the PSS/E program and for the extension of related methodology to other PTI program developments. He will also continue to contribute in specialized dynamic studies, particularly those involving subsynchronous resonance and related equipment structure effects.

PTI's activities are now directed by eight principal engineers. Although no rigid scope boundaries are maintained between these sections, the background and field of primary interest of each principal results in a natural division in emphasis. Sections in PTI have been purposely kept reasonably small in order that principal engineers be able to devote the majority of their time to technical rather than administrative matters.

NEW BULLETINS AVAILABLE

The following bulletins have been issued since the January issue of the NEWSLETTER. Copies are available on request.

PTI/103 — MULTI-AREA RELIABILITY PROGRAM (MAREL) MAREL computes the loss-of-load probability (LOLP) Index for large power pools and reliability councils as well as individual utilities within an interconnection. Up to seven areas can be separately identified in order to assess area reserve interarea interconnection requirements.

PTI/104 — TRANSMISSION LINE CHARACTERISTICS PROGRAM (TMLC) TMLC calculates a variety of transmission line constants, including series resistance and reactivity and shunt admittance parameters. Output options include formats specifically designed for use with PSS/E. The program is interactive and capable of accommodating HVDC lines and a variety of unusual AC options, including high phase order (HPO) designs.

PTI/105 — LINEAR SYSTEM ANALYSIS PACKAGE (LSAP) LSAP allows the engineer to examine stability and other characteristics of power systems by calculation of eigenvalues, eigenvectors, and frequency response from linear differential equations in the "state space" form. The linear system characteristics are derived automatically from the power system operating condition by perturbation techniques. This program, built as a group of additional "activities" for PSS/E, provides additional insights into the dynamic behavior of systems.