SUBSYNCHRONOUS OSCILLATIONS

The compensation of ac transmission lines affords significant benefits with respect to both the cost of point-to-point transmission and the balancing of loading on looped systems. High degrees of series compensation can, however, lead to the problems of subsynchronous oscillation. The control of subsynchronous oscillation phenomena is, accordingly, of high interest both in the United States and abroad. To support planning of Brazil's Itaipú transmission scheme, PTI has developed a comprehensive library of tools for analyzing subsynchronous oscillation phenomena.

Series compensated transmission systems may exhibit series electrical resonance at frequencies below the synchronous frequency, \( \omega_n \). Currents with these electrical resonant frequencies, \( \omega_n \), excited by the small disturbances of normal operation, can flow in the generator rotors. The currents appear on the generator rotors as current components at frequencies of \( \omega_n \pm \omega_s \). Currents at the higher, supersynchronous, frequency are normally well damped, but oscillations at the subsynchronous frequency can be amplified by the synchronous machines, which act as induction generators when fed at subsynchronous frequency. The build up or decay (stability) of subsynchronous oscillations is dependent on the series resistance and loading level of the transmission system.

While oscillations can build up to troublesome levels as a result of the induction generator effect alone, their most serious consequence at subsynchronous frequency is a pulsating component of electrical torque and hence excitation of lightly damped modes of torsional vibration in the turbine generator shaft. Coupling between the electrical and mechanical modes of oscillation can result in sustained pulsating shaft torques at levels unacceptable in relation to shaft fatigue stress limits. The presence of series capacitors in the transmission system may also exaggerate the shock torques applied to the turbine generator shaft by faults and switching operations.

PTI CONSULTANT TO WORLD'S LARGEST NPPTS

The world's largest Nuclear Power Plant Training Simulator (NPPTS) for the Barsebäck I plant near Malmö, Sweden, is undergoing final acceptance testing. Barsebäck I is a 600 MW bulk unit, designed and built by ASEA and ASEA-ATOM. The simulator is being supplied by ASEA for AB Kärnkraftutbildning (AKU), a company formed by a consortium of Swedish utilities, for training nuclear power plant operators.

PTI was retained by ASEA to provide guidance on the simulator software and modeling techniques. The author spent almost two years in Sweden working with ASEA in both development and checkout phases. The Barsebäck I simulator incorporates the significant advances in computer hardware and software methods in recent years, and is considered the largest and most modern in existence.

The control rooms of Barsebäck I and the simulator are nearly identical with more than 8000 active devices interfaced to the computer system in the control and display panels. A Xerox Data Systems Sigma 8 computer is used for the main tasks and a Digital Equipment Company PDP 11/05 is used as a communications front end.

A very beneficial by-product of the simulator checkout was the identification of actual plant problems in such areas as operating procedures, interlocking logic, control loop instabilities, etc., which were later verified by independent means. This experience tends to suggest that simulators can be a substantial aid in discovering the "bugs" which invariably plague all power plants during their first months of operation.

Since completion of the Barsebäck I simulator, PTI has developed a "third generation" approach to simulator design. The new advance permits more rapid development of sub-models, significantly reducing delivery time and cost. It will be first applied on a new simulator project in Europe to be announced shortly.

REFERENCES


Richard J. Mills, Senior Engineer
NEW APPROACH TO ENERGY MANAGEMENT SOFTWARE

Since the mid-1960's, electric utilities have been installing larger and increasingly complex digital computer-based monitoring, analysis and control systems to assist in the economic and secure operation of generation and transmission networks. The very significant engineering and programming effort required to integrate the operation of a large number of varied functions in a timely and responsive manner in a single computer has often resulted in delays, less than expected performance, and costs which far exceeded estimates. This task has become even more difficult with larger data bases and more responsive and sophisticated CRT-oriented man/machine subsystems. Successful implementation of most projects has also suffered from the degree of customization necessary in designing application programs to meet each utility's system requirements.

One industry trend which is attempting to overcome some of these difficulties is distributed processing — that is, the sub-division of processing requirements into separate interrelated hardware subsystems. In the past five years small computers have been developed which have very high performance-to-cost ratios and powerful operating system software. These computers, although relatively "small" in price, are large in performance and accuracy. These developments make distributed processing quite economic.

Another trend has been the development and use of standardized software. This has resulted in notable accomplishments in supervisory control and data acquisition. However, standardization of application programs has not enjoyed the same degree of success, mainly because previous attempts have been made at a broad level to standardize entire programs in such a way as to accommodate many users' requirements. An approach more natural to application programs is to develop standard single-function, low-level logic modules which can then be readily arranged to operate in specific sequences to formulate a given function. This allows accommodation of unique requirements of different electric utilities at reasonable cost. Such an approach is obviously dependent upon a well-planned data base structure, since many modules of varying nature must work with it while conveniently allowing development of new modules to meet special requirements. Modifications and new developments are at the module level to avoid impacting existing debugged modules; hence, the data base structure is held inviolate.

This approach has been very successful in the design of PTI's interactive PSS/2 software system for engineering use. Experience gained with PSS/2 has now been applied toward the design and development of a similar system, PSS/3, for application in control centers to be used by operations personnel. The design of PSS/3 is such that modules are truly single-function in nature in the majority of instances. This is essential to avoid standardization at too high a level, and to achieve truly flexible software that can be economically applied to virtually any electric utility system.

PSS/3 capabilities include functions ranging from a basic dispatcher's study load flow in a stand-alone system, through advanced security assessment. Ultimate application of PSS/3 includes operation coupled with a compatible computer-directed data acquisition and control system. In all cases, PSS/3 will operate in its own dedicated computer in either a stand-alone or distributed-processing arrangement.

For inclusion in a real-time system PSS/3 need not have man/machine interface. It can operate as a computational extension to a host data acquisition and control computer with man/machine interaction handled therein. This allows the implementor of a new host system to maintain consistency in the design of consoles and man/machine procedures and also enjoy the advantages of a distributed-processing system with standardization of application software. For a stand-alone study system in a control center, a low-cost CRT interface with logging capability is available as an option.

There is interest in incorporating PSS/3 into completely new energy control systems, as a stand-alone operations study tool, and as an add-on to existing installations. All are applications for which PSS/3 is well-suited and have been anticipated in its conceptual design.

REFERENCES

B. F. Wollenberg, Senior Engineer
O. J. Denison, Jr., Senior Engineer

Subsynchronous Oscillations (From Page 1)

generator to be modeled in any level of detail ranging from a basic electrical equivalent circuit to a fully detailed electromechanical model including the effects of all shaft torsional modes, excitation controls, and supplementary control inputs.

An example series compensated system is shown in Figure 1. Figure 2 shows a Nyquist diagram for this system from the stability analysis program with shaft dynamics represented only on Machine 1. This case is stable. Figure 3 shows a Nyquist diagram for the case where shaft dynamics are represented on Machines 1 and 2. The encirclement of the critical point in the Nyquist diagram indicates that subsynchronous oscillations would build up in this case. It is interesting to note here that representing shaft dynamics on Machines 1 or 2 alone would indicate stability, but that the more comprehensive analysis representing both shafts simultaneously shows sufficient machine-to-machine interaction to cause instability.

The frequency domain stability analysis is characterized by relatively low computation costs when applied to extensive network representations. It is, therefore, an attractive tool for evaluating and ranking wide ranges of alternative system design proposals. Once the stability of subsynchronous oscillations is assured, a proposed system design must be simulated in the time domain to evaluate shock torque levels, coordinate capacitor protective gap settings and analyze possible bypass resistor values for capacitor banks. The time domain simulation program has a capacity of 30 branches, 20 buses, and 10 generators. All components are represented on a fully balanced basis and all generators may be modeled in full electrical and mechanical detail. A typical time domain simulation, Figure 4, illustrates both a lightly damped subsynchronous component and a well-damped super-synchronous component in the electrical torque transient, with the subsynchronous component appearing strongly in the shaft torque transient.

FIGURE 2 FIGURE 3

FIGURE 4

Studies are in progress to aid in both the fundamental understanding of subsynchronous oscillations and the evaluation of corrective measures including blocking filters, pole face amortisseur circuits, and system design alternatives such as controlled shunt reactive power sources.

REFERENCE
John M. Undrill, Senior Engineer

PTI NEWSLETTER
OCTOBER 1975

- 2 -
APS 230kV CABLE PROJECT
A Study of Standardization Versus Optimization

The Phoenix area served by the Arizona Public Service Company (APS), represents one of the fastest growing load areas in the U.S., and was faced with the need for 13.5 additional circuit-miles of 230kV underground transmission. This project is an interesting one for review, since it explored alternatives to standard handbook cable designs. PTI developed a functional specification for the overall cable system. As a consequence, the completed project was estimated to have saved 30 percent over standard cable installations of the same rating.

FUNCTIONAL SPECIFICATIONS

Functional requirements defined by PTI invited some degree of innovation from bidders, while indicating certain preferences and boundaries. Both pipe and self-contained cables were allowed and both were bid and evaluated. Due to a harsh ambient, extremely high earth thermal resistivity, and considering future load growth, both were bid and evaluated. Due to a harsh ambient, extremely high earth thermal resistivity, and considering future load growth, pipe cable was selected on the basis that it would allow, with minimum initial outlay, provision for increased rating at a later date.

DETAILED CABLE ENGINEERING

The interrelationships among the electrical, mechanical, and thermal parameters of cable systems are complex. For example, reduction in insulation thickness will markedly improve thermal performance (particularly for a forced cooled system) but increases charging current and dielectric loss. Such a reduction in thickness can be effected without sacrificing dielectric strength by choice of insulating paper with superior properties and by unusual care in manufacturing with scrupulous quality control. By specifying and controlling the insulating paper properties (impermeability, for example), butt spaces and taping tensions, and by conducting extensive factory process inspections, the cables produced for APS had significantly reduced insulation thickness, but with suitable dielectric strength. While this did not minimize the cable price (the special paper is expensive), it did effect major project economies by maximizing section lengths (fewer pulls, fewer manholes, fewer splices, and fewer reels to dead-head back to the cable manufacturer).

COMPATIBLE JOINT DESIGN

In oil-circulated systems, joints, owing to their necessarily thicker insulation, are thermal bottlenecks: a cable circuit should normally be derated about 15 percent to keep a conventionally designed joint within rating. Several innovative approaches were incorporated into the joint design for the APS system. Low dielectric loss polypropylene/cellulose (PP/c) joint insulation was used. This composite synthetic/paper insulation was successfully introduced and proved at Waltz Mill. The radial and longitudinal electrical stresses were carefully balanced, yielding a thin joint profile. The mechanical-protection overwraps were copper mesh to provide high thermal conductivity. As a result, the joint actually operates slightly cooler than the cable.

REFERENCES


E. D. Eich, Principal Engineer PTI
PTI NOTES

PTI is offering a special advanced course in Power System Technology in the Summer of 1976. The course is designed to develop engineers with both theoretical understanding and practical problem solving ability in power system planning, design, and operating disciplines. Instruction will be given in PTI's offices in Schenectady starting April 26 and ending October 15, 1976. Mr. C. A. MacArthur is the course director.

A special feature of the course is the inclusion of training in the use of digital computer programs and the use of a computer dedicated to the exclusive use of the course participants. Several of PTI's programs for the solution of load flow, stability, short circuit, and dynamic representation of power systems and their equipment will be available for use by the participants. Training seminars in the use of these programs will be given early in the course so the students may use them freely for their own study.

The Power Technology Course will be taught by engineers who are internationally known for their contribution to modern engineering methods. Included in the topics taught are: Power Circuit Analysis, Transmission Line Theory, Insulation Coordination, Generation Dynamics and Control, Electric Machine Dynamics, Economic Operation, Utility Economics, Probability Methods, and Relaying and Protection. In addition to the formal classes, special seminars and inspection trips to utility, manufacturing, and research installations are planned. PTI Bulletin 35A contains further information about the course.

Robert W. deMello has joined the engineering staff of PTI. Bob was previously with Systems Control, Inc., where he was a principal investigator for EPRI Project RP90 (Phase II) which sought to simplify models used for transient stability analysis. His work assignments will include power plant dynamics studies and training simulator projects.

Two papers by PTI authors were presented at the 1975 Engineering Foundation Conference "Systems Engineering for Power" at Hanover, New Hampshire, August 17-22, 1975. "Probabilistic Methodologies — A Critical Review" by N. D. Reppen, R. J. Ringlee, B. F. Wollenberg and A. J. Wood of PTI, and K. A. Clements (Worcester Polytechnic Institute) and "Equipment and Load Modeling in Power System Dynamic Simulation" by N. M. Undrill resulted from projects sponsored by the Energy Research and Development Administration (ERDA). The papers review the developments and define the present state of these important areas.

Mary A. Sager, Senior Engineer, was elected chairman of the Schenectady Chapter of IEEE PES.

D. E. Hedman, Principal Engineer, was recently named Secretary of IEC Technical Committee 37 (Lightning Arresters).

PTI staff is helping organize and will participate in the tutorial session at the 1976 Winter Power Meeting on Application of Optimization Methods to Power System Engineering. A. J. Wood is organizer and editor of the course text. B. F. Wollenberg and R. J. Ringlee are co-authors of a paper which presents an overview description of methods.

CONTRIBUTORS

John N. Undrill, Senior Engineer, has made contributions to the dynamic analysis methods available for large interconnections of synchronous machines, and has applied these methods on problems ranging from electric utility power swings to torque magnetizations in industrial drive systems. Since joining PTI in 1971, he has been responsible for the development of interactive computing systems for electric power system simulation and for general-purpose industrial process dynamics and control studies.

Richard J. Mills, with PTI for five years, has been very active in the fields of power system dynamics and real time control of power systems. His experience includes studies of load rejection (overvoltage), multi-machine stability analysis, and the development of prime-mover and energy supply system models for use in these studies. Other assignments have included software development for real time factory checkout of turbine controls, for direct digital control applications, and for the Dresden BWR Operator Training Simulator.

Bruce F. Wollenberg joined PTI in October, 1974, as a Senior Engineer engaged in development of energy control center software, system adequacy assessment techniques, and a variety of applications involving optimization methods. He was formerly with Leeds and Northup Company, where he pioneered development of on-line load flows and security dispatch optimization applications. He has participated in feasibility studies for several large power pools and utility control centers, and was subsequently responsible for development and field checkout of security analysis programs.

Oscar J. Denison, Jr. joined PTI in June, 1975, as a Senior Engineer engaged in the area of application engineering for energy management, supervisory control, and data acquisition systems. He is principally involved in the specification and design of application software for electric systems. He was formerly with TRW Controls Corporation and the General Electric Company. His experience includes programming, project management, specification of applications software, design guidance for both software, and hardware, computer evaluation, and technical marketing for these systems.

Edward D. Eich joined PTI as Principal Engineer of Underground Cable Systems in 1971 following a 22-year career at Anacosta Wire & Cable Co, where he was Chief Engineer, High Voltage Cables. Mr. Eich has continued specialization in underground transmission cables in the areas of forced-cooling research, product development, economic comparisons among cable systems, consultation on spacer-gas systems, cryogenic cables, and the design of sophisticated EHV installations of conventional pipe cable. He has worked with public service commissions and utilities in consideration of overhead-underground alternatives.

This newsletter is prepared for PTI clients. Authors should be contacted for further information on specific topics. Requests for PTI Bulletins and comments on content are welcome.

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