POWER SYSTEM SIMULATOR FOR UTILIZATION-LEVEL WORK — PSS/U

J.M. Undrill, Principal Engineer

INTRODUCTION
A striking characteristic of power system simulation in industrial and distribution work is the wide variation in level of detail required. Figures 1, 2 and 3 show a simple single-line representation of a distribution feeder, a detailed four wire model diagram for a feeder model covering unbalanced V-phase extensions (two-phase laterals), and an industrial supply situation where a spare transformer with an unmatched impedance has been used in an emergency. A new member of the power system simulator program family, PSS/U is designed to handle problems like these, where utilization circuits, rather than bulk generation and transmission, are of principal interest.

PSS/U handles load flow, short circuit, circuit breaker duty, and motor starting calculations. It also includes the basic graphics functions needed for its system analyses, and a simple electromagnetic transients simulation module. The PSS/U package is fully supported on IBM PC computers, on Apollo work stations, and on Prime, VAX, and IBM general purpose computers.

MODELING
PSS/U provides modeling on an individual conductor basis, and hence is readily able to handle situations like those shown in figures 2 and 3 where the system is distinctly not balanced. No specific number of phases is assumed. Rather, each conductor may be a phase wire, shield wire, cable sheath, railroad catenary, rail or any other indentifiable current path. All voltages are expressed with reference to a "far" ground point so that, in addition to phase-to-phase and phase-neutral voltages, ground impedance, neutral voltage, and ground currents are readily identifiable.

Such detailed modeling poses no difficulty with respect to mathematics or number-crunching power in modern computers, small or large, but it does demand careful attention to data handling. In particular, it is not practical for the user to specify self and mutual impedances for a large number of individual conductors. The entry of this data is done via an internal dictionary containing per mile impedance and shunt susceptance data for lines and cables, identified by "construction type". The user can add the complete data for his own "standard" constructions to

AN EXPANDED ROLE FOR BACK-TO-BACK DC CONVERTERS?

H.K. Clark, Senior Engineer

A recent issue of POWER TECHNOLOGY took a fresh look at the role of HVDC. It pointed out that the rationale for most recent projects was not anticipated in the early debates on HVDC's future. One of the surprises in DC's evolution has been the growing number of back-to-back installations. All function as interconnections between asynchronous systems, providing the benefits of interconnection without the stability problems of weak AC ties. Their success has shown that some synchronous systems with stability limited AC ties may benefit from desynchronization by the installation of back-to-back converters in existing AC ties.

Desynchronization would increase transfer capability towards the thermal limitations of lines and station equipment and to voltage limits of voltage support equipment. If voltage support is provided in the AC systems and station equipment limitations on transfer are corrected, transfer capability can approach line thermal rating. In some cases this may be an increase of more than 50% over existing stability limits.

For a conversion to be economically attractive, the savings from increased transfer must cover the higher AC system losses, the converter losses, and the operating costs, and must pay back the investment in the converter and voltage support equipment within a reasonable time. For example, if the following are assumed:

- A 50% increase in transfer capability
- A 75% capacity factor for the incremental capacity
- Back-to-back converter cost of $100/kW
- Annual O&M costs of 1%
- Converter losses of 2.5%
- Incremental AC system losses of 10%
- Energy generated at 20 miles/kWh
- Displaced generation at 40 miles/kWh

then the annual costs per kW of increased transfer capability are $44.61/kW. The annual energy cost savings for a cost differential of 20 miles/kWh is $131.40/kW, resulting in a net annual energy cost saving of $86.79/kW/yr. This analysis recognizes that, if line capability is to be increased by 50%, converter rating must be 150% of the original capacity since both the original and the incremental capability must be converted. Thus for two terminals the cost per incremental MW is 2 x 1.5 x $100/kW = $300/kW, and the payback period for the converter investment is:

$300/$86.79 = 3.5 years

The potential benefits of asynchronous operation and inherent network control capability provided by DC ties are:

- Stability limitations for transfers across the asynchronous interface would be eliminated.
- Normal and emergency interchange capability may be maximized by forcing power flow patterns that take maximum advantage of AC system thermal capacity and voltage control equipment.
- Cascading due to AC system overloads and voltage problems would be contained within AC "islands."
- Controls on the DC ties might be used to help halt cascading within the AC islands.
- Controls might also provide improved transient and dynamic stability within the AC islands.

(continued on page 3)
POWER SYSTEM SIMULATOR FOR UTILIZATION-LEVEL WORK (continued for page 1)

As with lines and cables, transformers are modeled in detail by the leakage impedance, magnetizing impedance, base voltage, tap positions, and base kVA for each winding. The connection of windings in star-delta or other combinations is specified by the user. Systems may be radial or looped.

For load flow work the program recognizes constant kVA or impedance loads, voltage regulating transformers, and automatically switched capacitors. Voltage regulators and switched capacitors may be adjusted to hold a specified voltage profile or power factor, or may be locked for perturbation cases.

Motors are modeled as a balanced set of voltage sources behind a characteristic (e.g., subtransient) impedance. The amplitudes and phase of these are adjusted in load flow solutions, and are held as fixed quantities for short circuit and circuit breaker duty work.

FUNCTIONS

Load Flow

PSS/U can be used at a modeling level appropriate for each specific problem. For a straightforward feeder voltage and short circuit current review corresponding to figure 1, the system would be modeled on a single wire basis using positive and zero sequence data and neglecting phase unbalance. Figure 4 shows a representative computer output. Voltages are given in phase-to-ground volts and currents are in amperes.

A more complicated application is illustrated in figure 3. One phase of the transformer bank has failed and has been replaced by a spare unit of different impedance. Here, the model of the 69/4.16 kV transformer bank is set up by establishing the node-to-node connections of each winding. The line to the transformer is modeled by its self and mutual phase impedances, and the 69 kV supply by three voltages of 69/3 kV at phase angles of 0, -120 and -240 degrees. The motor is modeled by balanced voltages behind a reactance of 0.2 p.u. on the motor's 4500 kVA base. Figure 5 shows load flow results. The transformer secondary voltages are very slightly unbalanced about the nominal phase-to-ground value of 2400. Note that their phase angles of -35.5, -164.5 and 85.5 degrees reflect the 30 degree shift of the delta-wye transformer, as do the motor internal voltages. The results of interest are the motor phase currents; 551.6, 551.1, and 511.1 amps. These currents correspond to positive and negative sequence values of 537 amps and 13.5 amps, respectively, giving 2.5 percent negative sequence content. Conversions between phase and symmetrical components are available on command.

Short Circuit — Circuit Breaker Duty

The short circuit and circuit breaker duty function of PSS/U scans the system model, calculating the 3-phase and single-phase fault current at each node in turn. The individual conductor model is simplified to positive and zero sequence modeling for this calculation, motor internal voltages are frozen at either "nominal" or load flow solution values, and loads are either ignored or treated as constant admittance. The short circuit and X to R ratio calculation may use either a "correct calculation" based on complex arithmetic or the approximation recommended by the ANSI Standard C-37 on circuit breakers in which the system is divided into separate resistance and reactance networks.

In either case, the fault current may be corrected by the factors given in ANSI Standard C-37 to account for the unidirectional component of current and for decrement to obtain the effective symmetrical or total interrupting duty. To use this capability the user must specify the circuit breakers to be considered at each node in terms of nominal interrupting time and contact parting time.

Transients Simulation

The electromagnetic transients simulation section of PSS/U responds to the need for a simple, straightforward tool for basic transients calculations. This part of the program uses the same system model as all other parts, and hence can represent lines or cables on an individual conductor basis by the multiple pi-sections with constant parameters, but to be consistent with its objectives of simplicity and economy, it does not model non-linearities such as transformer saturation and discontinuous devices such as lightning arresters.

The transients capability of PSS/U is useful for exploratory work on subjects like capacitor switching, for calculation of exact current-time traces seen by circuit breakers in industrial systems with very high X to R ratios, and so on. It is not intended to compete with full scale electromagnetic transients programs...
such as the PTI MNT/E program which include extensive treatment of magnetic non-linearity, rotating machines, thyristor, and other switching devices. Figures 6 and 7 illustrate a representative capacitor switching simulation made with PSS/U.

**FIGURE 7**

**APPLICATION**

PSS/U will be valuable to engineers in municipal, distribution cooperative, and industrial organizations where utilization level issues predominate. It will also be useful to engineers in the distribution, protection, and engineering departments of the larger utilities when it is necessary to carry the unbalanced system modeling beyond the symmetrical components level of the PSS/E program package and where transients are of interest.

**AN EXPANDED ROLE FOR BACK-TO-BACK DC CONVERTERS? (continued from page 1)**

- Wheeling could be controlled so that power would flow over direct or indirect routes according to the contractual obligations of the participants.
- Emergency aid provided to neighbors could be controlled so that the supplying system has little or no exposure or risk should the problems grow worse in the troubled system.
- Routing of transfers could be controlled so as to minimize transmission losses.
- The access to generating reserves would be enhanced so that greater sharing and sale of reserve capacity is possible.
- Three-terminal back-to-back converter stations could be used where three systems meet or independent loading control on two AC lines in an island is desired.
- New DC lines between islands would not require the extra cost associated with short-time over load that is necessary to make them compatible with parallel AC lines.
- Inadvertent interchanges could be avoided or corrected quickly.

The controls to achieve these benefits would likely be local at the converter stations as well as central. Communication between the central control equipment and the DC converters is important. Computers in control centers and microprocessors at the converters should continually monitor system conditions for the best response to be taken to each of a wide range of possible system disturbances.

Existing weak AC interconnections between systems with widely varying energy costs are clearly the most attractive candidates for conversion to asynchronous operation. There are at least six major candidates for conversion in Central and North America, and a larger number of smaller scale candidates. Although there are other options that must be considered in any investigation of increased transfer capability in stability limited systems, conversion to asynchronous operation is one option whose time may have arrived.

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**NEW 12-PHASE PROJECT BEGINS**

James R. Stewart, Senior Engineer

Previous issues of the "PTI Newsletter" have described the concept of transmitting power by more than three phases to increase the amount of power transfer for the same cross section area occupied by the line. This idea was discussed as far back as Issue Number 1 in June, 1975. Issues Number 22 (October, 1980) and 24 (January, 1981) summarized experimental work being conducted by PTI at the Saratoga Research and Development Center under sponsorship of the Division of Electric Energy Systems, U.S. Department of Energy. PTI's work on this subject resulted in three DOE reports and several technical papers, the conclusion being high phase order is technically and economically feasible. Six-phase, now ready for the next step of prototype testing on a utility system, is attractive both for new construction and as a means of upgrading double circuit three-phase lines where the conductor size would otherwise be too small for the next higher voltage. Equipment, substation layout and protective relaying appear to have straightforward solutions for six phase systems.

One of the surprises in PTI's six-phase work was the conclusion that twelve-phase may be preferable for EHV applications. Most EHV six phase lines would still have two conductors per bundle which led to the question, "if you are going to string twelve conductors and support them mechanically, why not apply voltage to each separately...particularly if the space required doesn't increase?" PTI's original project built and mechanically tested six and twelve-phase lines, but energized and electrically tested only the six-phase line. This at least demonstrated that there were no major mechanical problems at twelve-phase. In fact both technical and economic considerations combined to encourage further development of twelve-phase.

A contract was signed early in 1985 for continuation of the twelve-phase studies. Joint sponsors are the U.S. Department of Energy through Martin Marietta Energy Systems (Oak Ridge, TN), New York State Energy Research and Development Authority, and Empire State Electric Energy Research Co. Project work will include (but is not limited to):

- Construction of a twelve-phase substation to energize the twelve-phase test line at 138 kV phase-to-ground (138 kV to ground is selected as a convenient test line voltage though ultimate application would likely be at substantially higher voltage.)
- Construction of a new twelve-phase steel lattice tower of a partial design of the same general shape as the one pictured in Newsletter Number 22, but with newer structural features
- Construction and evaluation of a new insulator configuration developed from the earlier testing
- Electrical testing including electric field, radio and audible noise, corona loss, secondary arc currents and the effect of single phase switching

Orders are being placed for the equipment and construction is expected to take place during the summer of 1985.

What about still higher phase orders? Switching surge studies indicate that above twelve phases, phase-to-phase switching surges may limit the inherent compaction advantages of HPO. Also, the mutual impedances between conductors further reduce the incremental improvement in surge impedance loading. Thus, twelve-phase is the highest now under study, although this project too could yield some surprises.

**References**


PERSONNEL NOTES

Baldwin P. Lam and David J. Lawrence, both of PTI's Transmission and Distribution section, were recently named Senior Engineers. Lam joined PTI in 1975 and has been involved in transmission reliability evaluation, operations scheduling, and short range load forecasting. Lawrence, who has worked on fault detection and analysis in distribution systems, operations scheduling, and hydro thermal coordination, has been with PTI since 1976.

PTI has also made several appointments to its technical staff.

Matthew Battle, an Analytical Engineer/Technical Writer assigned to the Educational Programs section, is responsible for the development of course materials. Matt is a graduate of New York Maritime College with a BS in Electrical Engineering, and a U.S. Coast Guard Engineers License.

Christopher Duffy joined PTI's System Performance, Design and Operations group as an Analytical Engineer and is involved in a series of load flow and stability studies. Chris is a graduate of Kansas State University where he received both the BS and MS degrees in Electrical Engineering.

Bernard Fitzgerald, an Analytical Engineer with the Simulator, Control and Instrumentation Systems section is responsible for design and implementation of hardware and software for data acquisition and control systems. Fitzgerald received a BS degree in Electrical Engineering from Rensselaer Polytechnic Institute and is currently pursuing an MSEE from Union College.

Martin Glynn and Howard Halstead, both Computer Systems Analysts, have joined the Software Packages section. Marty is responsible for the implementation of PTI's software products on IBM MVS/TSO systems. He is a graduate of Rensselaer Polytechnic Institute with a BS in Applied Mathematics. Howard is involved in the support and enhancement of the graphics capabilities of PTI's software products. He received the MS and BS degrees in Computer Science from Union College.

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FALL 1985 SHORT COURSE SCHEDULE
Courses to be presented at PTI offices in Schenectady, N.Y.

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<tr>
<th>Dates</th>
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<tr>
<td>September 8-13, 1985</td>
<td>Power Plant Performance</td>
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<td>September 16-20, 1985</td>
<td>Power system Dynamics</td>
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<tr>
<td>September 23-27, 1985</td>
<td>Utility Economics &amp; Finance</td>
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<td>September 30 — Oct. 4, 1985</td>
<td>Underground Cable Systems</td>
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<td>October 7-11, 1985</td>
<td>Power System Scheduling &amp; Operation</td>
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<td>October 15-18, 1985</td>
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<td>October 18-19, 1985</td>
<td>Power Plant Maintenance Scheduling</td>
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<td>Power system Planning Techniques</td>
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