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PARALLEL PATH ASPECTS OF TRANSMISSION MODELING

J.A. Kavicky

Decision and Information Sciences Division
Argonne National Laboratory
Argonne, IL 60439

S.M. Shahidehpour

Department of Electrical and Computer Engineering
Illinois Institute of Technology
Chicago, IL 60616

Abstract - This paper examines the present methods and modeling techniques available to address the effects of parallel flows resulting from various firm and short-term energy transactions. A survey of significant methodologies is conducted to determine the present status of parallel flow transaction modeling. The strengths and weaknesses of these approaches are identified to suggest areas of further modeling improvements. The motivating force behind this research is to improve transfer capability assessment accuracy by suggesting a real-time modeling environment that adequately represents the influences of parallel flows while recognizing operational constraints and objectives.

Keywords - Power Systems Operations, Transmission Open Access, Parallel Paths

1. INTRODUCTION

Recent estimates indicate that roughly 40% of the electricity generated in the United States is actually sold to neighboring utilities through wholesale transactions [1]. The revenue resulting from these utility transactions is estimated at \$35 billion a year. Although most transactions are established between interconnected utilities attempting to gain economic benefits, the Energy Policy Act of 1992 requires utilities to make their transmission systems accessible to new third-party generation resources. In conjunction with the Federal Energy Regulatory Commission's (FERC's) mandated transmission open access requirements, the end result is the potential loss of previously available transmission capacity and stranded utility investments equating to a likely loss in revenues. Because of the increased interest in wholesale wheeling alternatives now open to third-party generators, electricity transmission modeling has become an important planning and operations activity, which essentially determines the feasibility and economic benefit of proposed wheeling, capacity expansion, and siting alternatives.

Transmission aspects of power systems analysis were typically ignored or treated indirectly in early electrical energy system models [2,12]. Similarly, the lack of stringent environmental, electromagnetic field (EMF), and fuel constraints were not as predominant as in today's planning arena. Compounded with the loss of exclusive control of utility-owned transmission facilities, detailed analysis of transmission transfer capabilities is both essential and mandatory to ensure continued competitiveness in the energy marketplace while maintaining adequate and reliable service.

Adequate transmission capabilities support both economic system operation and increased system reliability. Ensuring necessary reserve requirements, supporting economies of scale and economic generation mix, and enabling economy energy transfers are among the historical features provided by the integrated transmission system [3,4]. Additional capabilities now must include support for increased wheeling transactions and third-party access privileges, thus leading to increased attention on adequate and adaptive transmission transfer capability assessment.

Accurate transfer capability assessment may be motivated by cost analysis studies, but actual transfer capability depends on a variety of physical system limitations. Among the limiting factors impacting transfer capability are stability, thermal, loop flows or parallel flows, voltage support, generation dispatch, and system reliability issues [5]. Most of these factors have been addressed in the literature; however, current methods of modeling parallel flows have relied heavily on power flow simulations to represent their impacts on network behavior and transaction simulation. Because of the present computational intensity of these simulations, real-time operations judgments regarding transaction selection are typically assisted only by established operating heuristics or off-line estimates of parallel network transaction distributions and to a great extent not by mathematical online assessment tools.

This paper examines the present methods and modeling techniques available to address the effects of parallel flows resulting from various firm and short-term energy transactions. A survey of significant methodologies is conducted to determine the present status of parallel flow transaction modeling. The strengths and weaknesses of these approaches are identified to suggest areas of further modeling improvements. The motivating force behind this research is to improve transfer capability assessment

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accuracy by suggesting a real-time modeling environment that adequately represents the influences of parallel flows while recognizing operational constraints and objectives.

2. HISTORY OF PARALLEL PATHS

There have been well known examples of parallel influences in the Eastern Interconnection for many years. For instance, in the mid-1980s the Pennsylvania-New Jersey-Maryland Interconnection (PJM) approached the New York Power Pool (NYPP) with a formal complaint [6]. PJM stated that NYPP was unfairly using portions of PJM-owned transmission capabilities. The situation arose when NYPP was importing large amounts of inexpensive hydro-generated energy from Ontario Hydro in Canada. Significant proportions of energy (about 50%) were split into two main parallel paths: a proportion of energy flowing directly between Ontario Hydro and NYPP and a proportion of energy flowing from Ontario Hydro to NYPP via Ontario, Michigan, Ohio, and Pennsylvania. This predominantly west-to-east power flow significantly reduced PJM's ability to import economic coal-fired energy from nearby utilities to the west. This particular dispute was resolved between PJM and NYPP and resulted in the joint ownership of a phase angle regulator to control the parallel flows. No third-party intervention was necessary.

A similar dispute resulted when American Electric Power (AEP) sold large amounts of energy to Ontario to reduce Canadian sulfur emissions. Although the contract path was specified through Michigan (the most direct approach between Indiana/Ohio and Ontario), Allegheny Power System (APS), PJM, and NYPP observed nearly 50% of the contracted energy flowing through their interconnected systems. Resolution of this dispute required a consortium of involved utilities to discuss the impacts of the transaction on each of their individual systems. The joint collaboration formed the Interregional Transmission Coordination Forum (ITCF) [7].

The ITCF, formed early in 1990, is a group of owners and users of transmission services who agree to exert good faith efforts to resolve disputes through the forum before resorting to other avenues of dispute resolution. Through periodical meetings and ad hoc study groups, ITCF members are aware of transmission planning and operations related issues before various practices are implemented.

Examples of parallel flows continue to impact system transfer capabilities in the eastern, central, and western portions of the United States. For example, the Washington/California coast of the Western Systems Coordinating Council (WSCC) in the United States has relatively large generation resources and demand centers. In addition, nuclear and hydro facilities in Arizona converge into a huge transmission freeway in lower Nevada to serve lower California demands. At the same time, the central portions of WSCC have relatively sparse energy demands yet are rich in generation. The resulting picture of the WSCC

region is often characterized by a huge doughnut-shaped loop flow circulating roughly along its regional boundaries.

3. PRACTICAL PARALLEL MODELING

The Eastern Interconnection network, in particular, is massively parallel and very reliable. As a result, parallel path influences on the operations of the Northeast continue to demand attention by the ITCF. Increased steps are being taken by various member utilities in that region to better understand parallel network influences and to permit a proactive approach to resolving parallel impacts on system operations. To better address these issues, the ITCF has formed the General Agreement on Parallel Paths (GAPP) Committee to study parallel transmission effects [8,9] in greater detail. The GAPP Committee is one such special interest group within the ITCF.

The goal of the GAPP Committee is to demonstrate through a voluntary two-year experiment that the effects of parallel transmission line use can be observed, controlled, and fairly compensated. Because the GAPP Method is presently positioned as an experiment, the following definitions and details may change somewhat as the experiment progresses and matures. In particular, the exact methods and amounts of compensation for imposed parallel effects are currently under development.

The GAPP modeling approach is partly based on existing North American Electric Reliability Council (NERC) interregional operating studies identified by interacting NERC regional boundaries. But because of GAPP's desire to represent the parallel influences caused by any given transaction agreed upon by two cooperating parties, additional network detail is required to understand the transfer capability impacts surrounding an affected control area for the given transaction. This requires that the GAPP method represent additional network detail beyond that of the defined interregional reliability studies. The interregional reliability studies are typically interested in only a dozen or so interfaces between adjoining NERC regions. As a result, the GAPP method makes direct use of the NERC Multiregional Modeling Working Group (MMWG) base case enhanced with additional utility-specific information.

The GAPP Committee plans to "explore the practicability of replacing the single contract approach with a multiple contract path approach such that the transmission systems which are impacted by specific transactions are appropriately involved from a contracting, scheduling and operations perspective" [8]. The motivating force behind the effort is that an alternative to the present single contract path approach must be devised to fairly compensate utilities and systems affected by parallel path influences. Some of the root causes for forming the ITCF stem from a predominantly unidirectional (west to east) base power flow across Eastern Interconnection transmission facilities. These flows continue to impact the same systems repeatedly with operational transmission overhead that typically forces noneconomic dispatch due to fully loaded transmission facilities. Utilities

or systems operating under these adverse conditions deserve a form of compensation for this inconvenience — something that the present contract path approach fails to provide.

Affected systems would prefer to alter the conditions such that transmission facilities would not be negatively impacted by any particular transaction. There are several ways of achieving this goal. A system could, for example, refuse to support the reservation or approval of a transaction that negatively impacts its transmission facilities. Without the system's consent and approval, the proposed contract never would be initiated. A second approach is to modify the schedule of the transaction by giving affected systems the right to reduce the magnitude of a particular transaction, thereby reducing the negative transmission effects on utility-owned facilities. Finally, in extreme situations, an affected system could enforce prioritized control of the transaction in response to transmission system thermal overloads, voltage collapse, or stability contingencies. All three options offer varying degrees of system involvement and participation when particular transactions impact system operations.

These three optional methods of impacting a proposed or existing transmission contract are formally named in the GAPP Method as reservation, scheduling, and control, respectively. Reservation and control also have an associated threshold that triggers each method.

Reservation refers to the notion of obtaining formal approval for a transaction through an actual reservation of a system's transmission capacity. If a transaction impacts the reservation right of a particular system beyond the assigned threshold, an affected system can inhibit a transaction from occurring by refusing to grant participation in the proposed contract. Without the prior approval of all involved systems with reservation rights, a particular transaction cannot be initiated.

Scheduling reflects adjustments made to the total reservation capacity (or level) that may be needed to work around existing or likely problems or contingencies that could be encountered if the transaction takes place at the total reservation level. Scheduling is typically an *a priori* event determined when considering the commitment level of a particular transaction.

Special consideration is given to adverse operating situations through the control option of the GAPP Method. Control refers to system operating events that are required to respond to system dynamics (caused either by emergency or through constrained economic conditions) that occur after a particular transaction is in place. Once again, the schedule is impacted, but on an *a posteriori* basis governed by the system's transmitting participation of an active transaction.

4. REPRESENTING TRANSACTION PARALLEL FLOWS

For any given transaction between a buyer and a seller, various parallel path flows are observed on interconnected

paths. Percentages of the total contracted power flow through interconnected systems, which use a portion of neighboring systems' transmission capacity. These percentages, along with the amount of the power transferred between two systems, are maintained in two important matrices fundamental to the GAPP Method.

Recall that the GAPP Method makes use of the MMWG model with additional utility enhancements to form the basis for determining parallel flows between systems. Similar to the MMWG modeling effort, all generation, demands, and transmission facilities are defined and implemented in the GAPP model. Normal firm commitments (identified as everyday base flows) are represented in the model by adjusting loads to simulate network base flows. In addition to these conditions, incremental flows are simulated by adjusting system loads. This methodology is consistent with several recent modeling projects [10-13].

Suppose System A wishes to sell energy to System B. To simulate this condition, System A would reduce its load while System B increased its load. Incremental power flows resulting from the transaction are recorded as fractional additions (or reductions) in capacity. These fractions (or percentages) illustrate the transmission impact on the network for a particular incremental transaction. The process is identical to that followed by various interregional reliability groups who determine Transfer Distribution Factors (TDFs) or Power Transfer Distribution Factors (PTDFs). The GAPP Method, however, packages this data in a different manner to support accounting and control procedures required to make the method administratively feasible through the use of Transaction Participation Factors (TPFs) and Interface Participation Factors (IPFs) — both represented as matrices in the GAPP Method.

The transaction participation factor represents the total participation through a system involved in a particular transaction. A TPF exists for each system that is part of each possible buyer/seller pair.

TPFs are used to determine a system's reservation, scheduling, compensation, and control rights on an individual transaction basis. If the TPF is more than the associated threshold, a system can participate in the negotiation or control of the transaction.

Whereas a TPF reflects the total impact of a transaction on a system as a whole, an interface participation factor represents the percentage of power flow across the interface connecting two adjacent systems. Adding (or subtracting) all concurrent IPFs at any instance of time yields an aggregated IPF that is particularly useful to system operators as a signal of system security. IPFs are analogous to TDFs and PTDFs used by interregional reliability groups [14,15].

Operating under a critical IPF value ensures system operators that complications due to defined contingencies are rather unlikely. Consequently, IPFs are used to assess control responses. Suppose a proposed transaction contributes to the

present aggregate IPF of an affected system. If the resulting IPF threatens sustained reliability, the affected system may be able to use its reservation right to block the proposed transaction. As a result, IPFs play a key role in determining a system's reservation and control involvement, assuming appropriate thresholds are satisfied.

The GAPP Information System (GIS) is used to manage the various tasks needed to implement the GAPP Method [16]. A hierarchical network comprising off-the-shelf software is provided with additional enhancements to facilitate the information needs of the GAPP reservation/schedule, reliability control, equity compensation, history file, billing, and auditing components.

Through the GIS, all GAPP participants are immediately provided with complete transaction awareness. Electronic transaction soliciting, posting, and institution provides participating systems with an understanding of potential and actual transactions taking place during a particular instance of time. This advantage alone increases recognition of likely conflicts that may impact a system's transmission facilities. If probable uses of these facilities are known, control procedures and responses can be initiated that may play a major role in preserving system availability and security. Enhanced contract management is a key communication advantage offered by the GIS.

The GIS is responsible for making the TPF and IPF matrices available to all participants, so that reservation, schedule, and control privileges are appropriately administered and supported. If the total transmitting participation and interface impacts of various transactions are known, remaining components of the GAPP Method can be implemented in a fair, objective manner. The crux of assessing parallel path impacts lies in the application of TPFs and IPFs in the GAPP Method — a capability beyond simplistic transaction management systems and bulletin boards.

Although the GAPP Method is presently being proposed for portions of the Eastern Interconnection, the fundamental modeling methodologies followed in the GAPP model have long been used and refined by other interconnected systems. For instance, NERC Regions, interregional study groups, and interconnected systems generally follow the same methodology for determining transfer capabilities [14,15,17-20]. Parallel path influences are also studied at the regional, interregional, and system level through PTDFs and TDFs determined for key monitored transmission ties between interconnected subregions. Monitored interfaces may be based on definitive system boundaries or on boundaries determined by critical facilities that often impact system operations. PTDFs play a critical role in predicting potential system reliability threats.

Given an energy transfer from Bus A to Bus B in a network, the PTDF is the percentage of the resulting power transfer that flows on any specific branch (or collection of branches) in the network. This incremental power flow must

be superimposed on the pretransfer flow on the interface resulting in a net increase or decrease in its branch current. Because of the additive nature of this method through superposition, linear network analysis (DC load flow analysis) is used. The PTDF of a particular nonsimultaneous transfer test level through a given branch is expressed as:

$$\text{PTDF} = [\text{Flow during transfer} - \text{base case flow}] / \text{Transfer test level.} \quad (1)$$

Another important modeling parameter across the interface characterizes the incremental transfer capabilities resulting from outaged facilities. Assume that the outage of a given branch in the network is analyzed. The Outage Distribution Factor (ODF) or Line Outage Distribution Factor (LODF) is the percentage of the pre-outage (precontingency) power flow that would be carried by the outage branch but now flows on an associated branch that remains in service. This incremental power flow is superimposed on the pre-outage flow of the given branch, resulting in a net increase or decrease in branch current. The LODF is expressed as:

$$\text{LODF} = [\text{Postcontingency flow on monitored facility} - \text{base flow on monitored facility}] / [\text{Precontingency flow of the outaged facility}]. \quad (2)$$

Both factors assume linear conditions incidental to DC load flow analysis. Variations in voltage and VAR levels, real power losses, and transmission configuration are ignored during the derivation of these parameters. LODFs and PTDFs are related to the thermal limitations of the First Contingency Incremental Transfer Capability (FCITC) and the First Contingency Total Transfer Capability (FCTTC) parameters useful in representing the transfer capability between two interconnected areas [17].

Because the use of distribution factors assumes that the network is linear and that voltages remain constant, the limiting conditions identified in the DC power flow analysis used above are further verified through AC load flow analysis to ensure that system voltage constraints are satisfied. Values determined after this stage of simulation are published by the study groups. Additional operating guides expressed as curves are often used to illustrate the relationship between system voltages and permissible power flows at various critical facilities.

5. POTENTIAL MODELING IMPROVEMENTS

The regional and interregional methods described above begin to address the issue of parallel flows. In particular, the GAPP Method effectively addresses many aspects of parallel flows, including power transfer distribution, tariffs, interutility transaction posting, communications, billing and transaction audit trails. Although not specifically stated, the overall GAPP Method undoubtedly fosters trust and a level playing field among involved participants by destroying or minimizing political roadblocks between competing systems. Because of the magnitude of issues represented in the

method, many compromises were made to resolve debatable issues. The fact that the GAPP Committee has evolved to the point of conducting the two-year experiment is very commendable. From an engineering perspective, however, there may be additional ways of improving the representation of shorter-term network modeling characteristics.

Recall that parallel paths are realized through TPFs and IPFs represented as matrices. Although these values specifically apply to the GAPP methodology, earlier examples illustrated how various interregional reliability groups use TDFs or PTDFs in their analyses. The practice of applying off-line modeling techniques to determine transfer distribution factors is widely used and accepted. Resulting estimates are routinely used to assess interregional transactions and guide system operations.

Interregional study groups and the GAPP Committee determine and verify these values by using off-line AC load flow simulations on a seasonal basis [16]. When significant outages are projected, the modeling staff may justify recalculating the two matrices to reflect more accurate system operating conditions. In either case, the matrices seldom represent daily network dynamics, often dictated by unknown system contingencies and maintenance schedules in real-time. Consequently, more careful modeling may benefit short-term transaction responses promoted by varying network configurations.

The manner in which transactions are simulated affects modeled outcomes. For example, the approach followed to date represents various transactions as a simultaneous adjustment in system loads of the two involved participants. Whether the transactions are long or short term, system generation levels remain constant throughout the entire modeling scenario from which TPFs, IPFs, and PTDFs are derived. Adjustments in system loads are used to cause transactions to occur between identified systems. In reality, system operators shift generation injection to implement energy transactions. But transfer capabilities are often affected by changes in generation levels, thereby modifying a transmitting system's ability to transmit the desired energy.

The GAPP Method intends to tackle simultaneous transactions as a pure summation of individual IPFs [8, 9, 21]. This method is also applied in [15] resulting in a series of linear graphs that assist system operators. Applying superposition requires linear estimates of nonlinear network characteristics. The GAPP Matrix Committee has simulated numerous transactions occurring at the same time and feels that the overall accuracy of applying superposition is appropriate for the GAPP Method. However, committee members are certain that system losses are not represented properly because of the nonlinear nature of losses. Improvements in loss accounting and the effects on nonlinear loads would be beneficial in more detailed network representations. Regardless of network detail, representing system nonlinearities would improve the assessment of simultaneous transactions and the resulting accuracy of simultaneous transfer capability estimates.

A particular requirement of control areas performing many decisions on an hourly basis is the need for real-time data to properly assess various interchange options [22]. As the number of interchange options increases during a particular hour, the ability to assess and react quickly becomes a key element of an open systems market. Economic benefits are highly dependent on the ability to import or export energy across available transmission facilities [23]. Such actions may preserve system security while sacrificing economic dispatch. A control area's proper response to alternative exchange options and system contingencies ensures system integrity and availability. The GAPP Method provides a communication methodology, but it is based on the existence of a particular contract and estimated parallel influences — not on actual monitored system data. Neither of the approaches described above adequately addresses the real-time aspects of transfer capability assessment.

6. PARALLEL PATH MODELING RECOMMENDATIONS

Several shortcomings of discussed methods are pointed out in the previous section. These limitations are understood and clearly identified in model formulations. Various simplifying assumptions make these approaches practical and reasonably demonstrate realistic modeling objectives. But with the addition of third-party transactions, cooperation now taken for granted between interconnected utilities and systems may be impeded when independent power producers (IPPs) and nonutility generators (NUGs) observe reduced profit margins resulting from imposed transmission control actions. More and more, such actions will need to be justified to not only affected IPPs but also to FERC. In a similar fashion, transmitting systems are seeking fair compensation for the use of their transmission systems and for reimbursement associated with noneconomic dispatch resulting from various FERC-mandated restrictions. More accurate transmission modeling approaches are justified.

Advancements in capturing the dynamics of generation availability and transmission network configuration are essential in addressing system security, short-term generation scheduling, spinning reserve requirements, and generation availability concerns (in particular for nondispatchable IPPs and NUGs.) Changes in generation dispatch can directly affect available transfer capabilities between key areas that may be relied upon for spinning reserve margins. Similarly, network outages can directly affect reserve requirements through changes in available interarea transfer capacity. Also impacting generation levels are present scheduled transaction commitments to/from adjacent areas. Modeling these concerns requires adjustments in generation injection to realize transactions, whether for sales-for-resale or wheeling contracts.

An enhanced representation of system losses and nonlinear loads may significantly impact the economic results of simulations based on detailed network representations. Consequently, reactive power wheeling

requirements may need to be expressed to adequately represent transfer capability as a function of voltage-limited facility performance. These enhancements also will improve the assessment of simultaneous transfer capabilities.

Detailed data exchange and improved coordination are needed to sufficiently collect, assess, and determine appropriate real-time transfer capabilities and feasible energy transactions. Coincidentally, improved system communication is required to facilitate system security requirements and likely coordinated emergency operations.

In all these cases, accurate real-time transfer capability values are either impacted by or directly contribute to changes in system operations. Because proper transfer capability assessment is directly impacted by network topology, the presence of parallel path influences is fundamental in performing accurate system evaluations. Representing parallel paths appropriately is a vital aspect of system operations. An alternative or extension to the present use of PTDFs is desirable to capture and model dynamic network characteristics.

7. CONCLUSIONS

This paper surveys and explores the present state of practices used in determining transfer capability assessment and the effects of parallel paths in system network topology. Various NERC regional and interregional studies, the GAPP Method and several modeling approaches identified in the literature are used to illustrate practical methodologies. Limitations are identified, resulting in a tentative list of modeling enhancements indicating future research areas having a great impact on transmission modeling in the era of transmission open access.

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REFERENCES

- [1] J. Douglas, "Buying and Selling Power in the Age of Competition," *Electric Power Research Institute Journal*, pp. 6-13, June 1994.
- [2] R.T. Jenkins and D.S. Joy, *Wien Automatic System Planning Package (WASP) and Electric Utility Optional Generation Expansion Planning Computer Code*, ORNL-4945, Oak Ridge National Laboratory, Oak Ridge, TN, July 1974.
- [3] North American Electric Reliability Council, *Electric Transfers and Reliability*, Princeton, N.J., October 1989.
- [4] North American Electric Reliability Council, *Transfer Capability — A Reference Document*, Princeton, N.J., October 1980.
- [5] Electric Power Research Institute, *Technical Limits to Transmission System Operation: An Overview*, EPRI EL-6549, Palo Alto, CA, 1989.
- [6] W.J. Balet, "Competing Uses of Transmission In Eastern North America," in proceedings of the *Second Annual Transmission and Wheeling Conference*, November 1991.
- [7] Interregional Transmission Coordination Forum, *General Forum Literature*, April 1994.
- [8] Interregional Transmission Coordination Forum, *General Agreement on Parallel Paths*, May 1992.
- [9] General Agreement on Parallel Paths Committee, *Outline of the GAPP Method for Use in an Up to Two Year Experiment*, December 1993.
- [10] N.S. Rau and C. Neculescu, "A Model for Energy Exchanges in Interconnected Power Systems," *IEEE Transactions on Power Systems*, Vol. 4, No. 3, pp. 1147-1153, 1989.
- [11] E. Vaahedi, R.J. Poirier, C. Neculescu, and A.N. Karas, "Benefits of Economy Transactions and Wheeling in Canada," *IEEE Transactions on Power Systems*, Vol. 8, No. 3, pp. 1299-1305, 1993.
- [12] T.D. Veselka, et al., *Impacts of Western Area Power Administration's Power Marketing Alternatives on Electric Utility Systems*, ANL/DIS/TM-10, Argonne National Laboratory, Argonne IL, January 1994.
- [13] J.A. Kavicky and T.D. Veselka, "Modeling Regional Power Transfers," in *Proceedings of the American Power Conference 56th Annual Meeting*, Vol. 56, April 1994.
- [14] MAAC-ECAR-NPCC Study Committee, *MEN 1993 Summer Operating Study*, May 1993.
- [15] MAIN Transmission Assessment Studies Group, *1994 MAIN Summer Transmission Assessment Study*, May 1994.
- [16] General Agreement on Parallel Paths Committee, *An Information System to Support the General Agreement on Parallel Paths*, April 1994.
- [17] Southwest Power Pool, *Coordinated Regional Bulk Power Supply Program*, OE-411 Report, Little Rock, AR, April 1993.

- [18] Southwest Power Pool, *1993 Summer Peak Operating Study*, Little Rock, AR, April 1993.
- [19] Commonwealth Edison, Co., *FERC Form No. 715*, Chicago, IL, April 1994.
- [20] VACAR-ECAR-MAAC Study Committee, *1993/94 Winter Operating Study*, December 1993.
- [21] L.G. Leffler, GAPP Project Manager, Phone conversation, May 13, 1994.
- [22] K. Kato, et al., "Real-Time Data Exchange for On-Line Security Assessment," *IEEE Transactions on Power Systems*, Vol. 7, No. 3, 1992.
- [23] Federal Energy Regulatory Commission, *Electricity Transmission: Reality, Theory, and Policy Alternatives*, October 1989.
- [24] Y.Z. Li and A.K. David, "Optimal Multi-Area Wheeling," *IEEE Transactions on Power Systems*, Vol. 9, No. 1, 1994.
- [25] H.H. Happ, "Cost of Wheeling Methodologies," *IEEE Transactions on Power Systems*, Vol. 9, No. 1, 1994.
- [26] N.I. Deeb and S.M. Shahidehpour, "Cross Decomposition for Multi-Area Optimal Reactive Power Planning," *IEEE Transactions on Power Systems*, Vol. 8, No. 4, 1993.

- [27] R.D. Tabors, "Transmission System Management and Pricing: New Paradigms and International Comparisons," *IEEE Transactions on Power Systems*, Vol. 9, No. 1, 1994.

BIOGRAPHIES

J.A. Kavicky received his BS in Electrical Engineering from Valparaiso University in 1982 and an MS in the same field from IIT in 1988. He is currently a Ph.D. candidate in the ECE Department at IIT and a full-time staff member at Argonne National Laboratory. He has several years experience in transmission modeling of which parallel path simulation techniques and transmission open access are presently of interest. He is a member of IEEE and Tau Beta Pi.

S.M. Shahidehpour received his Ph.D. in Electrical Engineering from the University of Missouri-Columbia in 1981. He has been with IIT since 1983, where he is currently a professor in the ECE Department and Dean of the Graduate School. He has published more than 120 papers on power systems planning and operation. He was the vice-chairman for the 1992 IEEE International Conference on Systems, Man and Cybernetics, and received the 1993 Edison Electric Institute Award. He is a senior member of IEEE.