HARRISON K. CLARK, Consultant

Mr. Clark received the BSEE degree from California State Polytechnic University (Cal Poly), San Luis Obispo, CA in 1966. He joined General Electric that year and over the next four years completed several graduate level courses including the GE "A Course" while performing conceptual design, power flow, stability, and protection studies for GE's largest paper, chemical, and petroleum clients.

In 1970 Mr. Clark joined Power Technologies, Inc. (PTI). His work at PTI included equipment failure analysis, transmission planning, blackout investigations and criteria development. He helped guide development of the PTI PSS/E stability program and has analyzed stability and voltage collapse problems and developed protection philosophy and solutions to overvoltage, loss-of-synchronism, and self-excitation problems.

His transmission planning work has involved all voltage levels and all of the available techniques for maximizing transfer capability including re-closing, series capacitors and reactors, shunt compensation, braking resistors, unit tripping, stabilizers, fast valve actuation, high performance excitation systems and remedial action schemes. He developed new extensions to digital governing on hydro plants in Alaska, including novel use of Pelton turbine deflectors for both stability and rapid black-out recovery.

Mr. Clark's early industrial experience allowed him to make significant contributions to electric power industry efforts to improve simulations of customer loads in first-swing, oscillatory and voltage stability analysis. Models he developed include induction motor dynamics, discharge lighting, magnetic saturation, and the effects of manual and automatic load controls such as thermostats. He developed QV analysis and other analytical methods and solutions to voltage collapse, as well as criteria to control risk of voltage collapse. He was an invited presenter at the first joint NSF/IEEE/EPRI Conference on Voltage Stability in 1988 and has made many subsequent presentations at WSCC, IEEE, and EPRI events.

He investigated nine major blackouts including the 1977 New York City blackout. This experience led to development of transmission planning and operating criteria for clients in Canada, the U.S., Norway, and Central America. He has presented expert testimony in legal proceedings in Canada and in both State and Federal proceedings in the U.S.

Mr. Clark has taught PTI Short Courses on System Dynamics, HVDC, and Static Var Systems and portions of the two-year Power Technology Course. He created the PTI Voltage Stability Course, presented to over 1000 students world-wide. He was a major contributor to EPRI's first operator training course.

At PTI Mr. Clark was promoted to Senior Engineer in 1974; Manager, Utility System Performance in 1984; and Manager, Western Office in 1987. He is a Senior Member of IEEE and has presented or published 32 papers and articles. Mr. Clark retired from PTI in 1996 and is now an independent consultant. In 1977 he was selected by BPA to serve on the Blue Ribbon Panel assembled to guide BPA in addressing major 1996 WSCC disturbances.

Recent activities include contributions to the Western Governor's Association August 2001 report "Conceptual Plans for Electricity Transmission in the West," several testimony assignments, assistance to a industry leading consulting firm on several voltage stability analyses, and assistance to clients in the Northeast following the August 14, 2003 blackout.

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Publications

1. "Load Shedding for Industrial Plants," Paper No. ICP-WED-PM2 725, presented at Eighth Annual Meeting of IEEE Industry Applications Society, October 8-11, l973.

2. "Voltage Control in a large Industrialized Load Area Supplied by Remote Generation," Paper No. A 78 558-9, presented at IEEE PES Summer Meeting, July 17, 1978, (co-authors, T.F. Laskowski, A. Wey filho, and D.C.O. Alves).

3. "Transient Stability Sensitivity to Detailed Load Models: A Parametric Study," Paper No. A 78 559-78, presented at IEEE PES Summer Meeting, July 17, 1978, (co-author, T.F. Laskowski).

4. "Considerations in the Evaluation of Series and Shunt Compensation Alternatives," presented at the T&D Expo, Chicago, IL, May 14-16, 1985.

5. "Microprocessor Based Load Shedding for Industrial Plants," presented at the IEEE Industry Applications Society I&CPS Conference, Cleveland, OH, May 5-8, 1986.

6. "Enhancement of AC Systems by Application of DC Technology," EPRI Transmission Limitations Panel, IEEE-PES Winter Meeting, New Orleans, LA, February 2-6, 1987, and presented at the Symposium on Electrical Operational Planning, Rio de Janeiro, Brazil, August 17-21, 1987, (co-author, F.P. de Mello).

7. "Modeling to Define Limits to Shunt Compensation Use," Panel on Reactive Modeling Considerations, IEEE-PES Winter Meeting, New Orleans, LA, February 2-6, 1987.

8. "Voltage Control and Reactive Supply Problems," IEEE Tutorial Course: REACTIVE POWER: BASICS, PROBLEMS AND SOLUTIONS, Publication 87 EH0262-6-PWR, presented at the IEEE-PES Summer Meeting, San Francisco, CA, July 12-17, 1987, and the Winter Meeting, New York, NY, 1988.

9. "Dynamic Aspects of Excitation Systems and Power System Stabilizers," presented at the Symposium on Electrical Operational Planning, Rio de Janeiro, August 17-21, 1987, (co-authors, F.P. de Mello and L.N. Hannett).

10. "Reactive Compensation in Power Systems," presented at the Symposium on Electrical Operational Planning, Rio de Janeiro, August 17-21, 1987, (co-author, D.N. Ewart).

11. "Microprocessor Based Load Shedding for the Pulp and Paper Industry," TAPPI Annual Meeting, New Orleans, LA, September 1987, and TAPPI JOURNAL, December, 1987.

12. "Industrial and Cogeneration Protection Problems Requiring Simulations," IEEE Transactions on Industry Applications, Vol. 25, No. 4, July/Aug. 1989 (co-author, J.W. Feltes).

13. "The Case for Asynchronous Interconnection of China's Electrical Systems," presented at the Joint IEEE/CSEE Conference on High Voltage Transmission Systems in China, Beijing, The Peoples' Republic of China, October 17-22, 1987, (co-author, L.O. Barthold).

14. "Load Modeling for Power Flow and Stability Studies," presented at the 1988 WSCC Stability Seminar, Rosemead, CA, April 5-7, 1988.

15. "Voltage Control and Reactive Supply Problems," presented at the 1988 WSCC Stability Seminar, Rosemead, CA, April 5-7, 1988.

16. "Voltage Control Practices in North America," IEEE/NSF/EPRI Conference: Bulk Power System Voltage Phenomena--Voltage Stability and Security, Potosi, Missouri, September 19-24, 1988, Proceedings: EPRI Publication EL-6183.

17. "Experience with Load Models in the Simulation of Dynamic Phenomena," Panel on Load Modeling Impact on System Dynamic Performance, IEEE-PES Winter Meeting, New York, NY, January 30 - February 3, 1989.

18. "Long-Term Disturbance Monitoring for Improved System Analysis," IEEE Computer Applications in Power, Volume 2, No. 2, April 1989, (co-author, S.J. Balser).

19. "Analysis and Solutions for Bulk System Voltage Instability," IEEE Computer Applications in Power, Volume 2, No. 3, July 1989, (co-author, G.C. Brownell).

20. "Voltage Stability of Power Systems: Concepts, Analytical Tools, and Industry Experience," Special Publication of the System Dynamic Performance Subcommittee of the Power System Engineering Committee of the IEEE PES, 1990, 90TH0358-2-PWR (co-author).1. "New Challenge: Voltage Stability," IEEE Power Engineering Review, Volume 10, No. 4, April 1990.

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21. “New Challeng: Voltage Stability,” IEEE Power Engineering Review, Volume 10, No.4, April 1990.

22. "Load Modelling for System Dynamic Performance," special publication of the IEEE PES Working Group on Load Modeling, September, 1991 (co-authors).

23. “Load Representation for Dynamic Performance Analysis,” Paper by the IEEE Task Force on Load Representation for Dynamic Peformance, Presented at the IEEE Winter Meeting, January 26-30, 1992, New York, NY (co-authors).

24. "Experience with Dynamic System Monitoring to Enhance System Stability Analysis," IEEE PES Summer Meeting, Long ly, 1991 (co-authors, R.K. Gupta, C. Loutan, D.R. Sutphin).

25. "The Voltage Collapse Phenomenon," 1991 Minnesota Power Systems Conference Proceedings, University of Minnesota, October, 1-3, 1991.

26. "Voltage Stability: Criteria, Planning Tools, Load Modeling," EPRI/NERC Forum on Operational and Planning Aspects of Voltage Stability, Breckenridge, Colorado, September 14 and 15, 1992.

27. “Voltage Stability: Load Modeling, Solutions, and Criteria,” Presented at the WSCC Stability Seminar, June 3, 1992, Los Angeles.

28. “Application of Adjustable Speed Doubly Fed Machines in Pumped Storage and Conventional Hydro Electric Plants,” Presented at the American Power Conference, 55th Annual Meeting, April 13, 14, 15, 1993, Chicago Illinois, (Co-authors Jan Stein, Roy Nakata, Peter Donalek).

29. "Voltage Stability and other Considerations in the Application of Field Current Limiters," Panel Session on Excitation System Limiter Application and Modeling, 1994 Summer Power Meeting.

30. "Minimizing the Cost of Voltage Stability," Presented at PTI Hospitality Suite at 1994 Summer Power Meeting.

31. "FACTS Applications," Special publication of the FACTS Application Working Group of the IEEE Power Engineering Society, Dec., 1995, PES Publication 96TP116-0, (multiple co-authors).

32. “Impact of Increasing Wind Generation on the Transmission System in the Republic of Ireland,” Symposium – Neptun; Impact of DSM, IRP and Distributed Generation on Power Systems, September 18-19, 1997.

33. “Principles and Applications of Current-Modulated HVDC Transmission Systems,” Panel Session on “FACTS/Power Electronics Applications to Improve Power System Performance, New Orleans, October 9-12, 2005.

Articles written for Power Technology:

34. “Improve Stability Studies with Dynamic Load Models,” 1975.
35. “An Improved Load Model for Stability Studies,” 1978.
36. “Complex Dynamic Simulation Used in Selecting Protection Scheme,” 1980.
37. “Conventional Power Flow and Stability Analysis Applied to the Long-Term Simulation Problem,” 1982.
38. “Voltage Support in Heavily Loaded EHV Systems,” 1984.
39. “Performance Characteristics of Series Compensation and Shunt Var Support,” 1984.
40. “An Expanded Role for Back-to-Back DC Converters?” 1985.
41. “Protection of Cogeneration and Industrial Generation,” 1985.
42. “HVDC - Its Effect on System Performance and Existing AC System Capability,” 1985.
43. “Dynamic Stability,” 1987, Co-author F.P. de Mello.
44. “Voltage Stability Analysis Requires Accurate QV Curves,” 1990.
45. “Hydro Plant Model Sets Record,” 1991.
46. “Motor Starters Affect Angular Stability,” 1991.
47. “Dynamic Load Models from DSM Recordings,” 1992.
48. “Excitation Limiter Performance Is Critical to Voltage Security,” 1995.
49. “A New Ball Game,” 1996. (Reliability impact of independently owned generation)

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Reactive Planning and Voltage Collapse Experience

While performing planning studies for the greater Sao Paulo area in 1973, Mr. Clark recognized the potential for low voltages, motor stalling, and system break-up for certain contingencies. He coined the term "voltage collapse" and proceeded to confirm the problem through simulations using detailed load models. He developed QV curve analysis to help define reactive requirements. Two large synchronous condensers were installed to reduce risk of voltage collapse. Mr. Clark also recommended the first ever use of undervoltage load shedding. This was a landmark effort in that it defined the nature of the voltage collapse problem, provided terminology and tools to address it, and developed solutions. Shortly after this effort Mr. Clark was instrumental in PTI's development of the industry's first long-term simulation capability for the study of the "slow dynamics" of voltage collapse.

Mr. Clark went on to conduct numerous reactive planning and voltage collapse studies. He refined the concept of undervoltage load shedding and demonstrated its effectiveness in several long-term simulation studies for clients facing voltage collapse problems. He contributed to all early IEEE tutorials and working group efforts to define the voltage collapse problem and it's analysis and solutions. He was a frequent speaker at EPRI, NSF and WSCC Seminars on the Voltage Collapse problem.

In 1986 Mr. Clark prepared the PTI "Voltage Course" which covered reactive planning and in particular the nature of the voltage collapse problem and it's analysis and solutions. This course reached more than 1000 students in several dozen countries.

In 1991 Mr. Clark helped Central Power and Light understand an incident on their system (Corpus Christie and southward) that involved "transient voltage collapse" wherein motors slow sufficiently during a fault that the system is unable to re-accelerate them. This same effort also revealed a traditional voltage collapse problem in the Brownsville area near the Mexican border.

In addition to his early IEEE contributions, Mr. Clark has written articles on the voltage collapse problem and on voltage criteria requirements. He has regularly advised clients that voltage problems will be overlooked if studies are limited to the contingencies normally associated with thermal and angular stability criteria.

Blackout Analysis Experience

Mr. Clark's successful career in the planning of reliable transmission systems has been in part the result of first-hand experience with system failures. His investigations of blackouts and major disturbances have equipped him to prepare effective reliability criteria and ensure that those criteria are adequately applied.

WSCC 1996. Mr. Clark was appointed to the Blue Ribbon Panel formed to examine the two 1996 events that caused WSCC break-up and widespread loss of load. He was one of three experts on the panel with reactive planning and voltage stability experience. He prepared a dissenting opinion letter which was published with the Panel Report.

Southern California 1996. One of the two 1996 WSCC-wide events cascaded into angular instability and voltage collapse in a large area of Southern California. Mr. Clark investigated these events and their impact on large industrial customers.

Hawaii 1992. Line outages resulted in unexpected generating plant responses and blackout. Governor overspeed protection caused power swings and voltage regulators on manual control allowed voltage to collapse. Mr. Clark recommended tests and operating practices to reduce the risk of such surprises in the future.

Saudi Arabia 1990. Angular instability that caused blackout was traced to inadequate protection of EHV lines.

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Central America 1996. In a study to improve reliability in six of the seven countries of Central America, Mr. Clark reviewed recent disturbances and guided the development of system upgrades and an interconnection to improve reliability and economic operation.

New Jersey 1974. A medium voltage substation burn-down resulted in extended outages to area customers. Mr. Clark examined the substation physical and protection design and found unprotected bus sections. Major protection updating was required to ensure detection of all faults.

New York City 1977. Mr. Clark assisted the New York Public service commission in its analysis. His operator interviews and related work revealed several important issues that were overlooked by other investigators. He prepared the NY Power Commission's list of questions for Consolidated Edison, and assisted in the analysis of the response. He subsequently supervised analytical work conducted by Consolidated Edison to improve reliability.

Venezuela 1978. A country-wide blackout occurred during a visit by US President Carter. Mr. Clark was a member of a two-man team that spent one month reviewing all Venezuelan planning and operating practices. The team prepared a document that included 23 specific recommendations that would reduce the likelihood of future major outages. President Perez of Venezuela ordered the utilities to implement all 23 recommendations.

St. Johns Newfoundland 1985. System experience and the prospect of greatly increased imports lead to analysis of major disturbances and future reliability. Mr. Clark conducted these analyses and prepared both new planning and operating criteria for the Province and an application guide for the new criteria. He prepared similar criteria for Norway.

USA Northeast 2003. Assistance to certain entities in the Northeasts subsequent to this event. Includes advice and training of engineering and operations personel.

Testimony Experience

In addition to the experience covered in the biography, Mr. Clark has provided expert witness services on occasions as listed below:

Deposition on causes of failure of protection to prevent energization and destruction of the generator of a 400 MW thermal plant during maintenance. Litigation was between the plant owner (Utah Power and Light) and the architect/Engineer responsible for plant and switchyard design.

Etensive testimony on the technical feasibility of planning and operating a 1400 km HVDC transmission system extending from the Churchill Falls plant on the Quebec-Newfoundland border to St. Johns Newfoundland. Testimony addressed steady state and dynamic performance of the line and receiving system. Newfoundland would receive up to 50% of its power from this line. Testimony was on behalf of Newfound Labrador Hydro in action against Hydro Quebec.

Testimony before the Wisconsin Public Service Commission on behalf of Wisconsin P&L and Exxon on the limitations to use of shunt capacitors and static var controllers to extend the capacity of an existing 115 kV system and thereby delay the need for a 345 kV line.

Extensive testimony before the Utah Public Service Commission on behalf of the Utah Association of Municipal Power Cooperatives. UAMPS wished to construct a transmission line from Central Utah to Southwest Utah and Nevada. The testimony focused on the greater ability of the Associations proposed line to serve Southwest Utah reliably and without jeopardizing stability of the greater Utah system as compared to a line proposed by Utah Power and Light.

Testimony before the United States Federal Energy Commission Staff on behalf of Dayton Power and Light in a dispute between DP&L and the City of Piqua over extent and type of interconnection that is

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needed to improve reliability of power supply to Piqua. Effort included visits to substations and lines, review of Piqua and DP&L operating practices, staff quality, and other factors affecting interconnected operation.

Depositions, testimony, and rebuttal testimony before FERC and the Texas Utility Commission in support of the merger of Central and Southwest and El Paso Electric Company.

Testimony before ALJ and a Commissioner of the California Public Utilities Commission regarding use of the ISO generation meter multipliers (GMMs) for the purpose of quantifying loss savings associated with QF power deliveries.

Testimony on behalf of the CPUC's Office of Rate Payer Advocates concerning SDG&E's application for the 500 kV Valley-Rainbow project.

Protection Experience

Mr. Clark's protection experience includes a full year as a relay requisition engineer with General Electric in the medium voltage switchgear department in 1966. In that position he was responsible for preparation for protection equipment design to meet industrial and utility customer specifications. Responsibilities included assembling the necessary complement of relays, laying out the relay panels, and preparing elementary diagrams for the relays, batteries, and breaker trip and close circuits.

For three years (1967-1970) he worked as an application engineer in the GE Industrial Power Systems engineering unit in Schenectady. In this assignment he conducted system analysis and relay application and coordination studies for large paper mills, steel plants, and refineries. The protection studies included utility interconnection protection, coordination with utility relaying, etc.

Mr. Clark joined PTI in 1970, and for several years continued to conduct studies of industrial power systems with heavy emphasis on protective systems. He was solely responsible for relay selection and settings in the 200 MW isolated power system (240 V through 13.8 kV) of the Amerada Hess refinery in the Virgin Islands, and continues to consult with Amerada Hess today.

In the mid 1970's his responsibilities shifted to EHV planning. In transmission planning and design studies for clients in South America he was frequently responsible for recommending protective systems for special situations, including compatibility with existing protective systems, out-of-step blocking and tripping in systems subject to instability, overvoltage protection for systems subject to radial load rejection and self-excitation, comparison of reliability of blocking and unblocking directional comparison schemes where sympathetic line trip was a special problem, and others. One study required development of a detection scheme for impending self-excitation based on generator terminal overvoltage and negative field current relays.

Mr. Clark assisted the New York Public Service Commission in its investigation of the 1977 New York City blackout, including the role of protection in the cascading process. He identified 7 relay problems that contributed to the cascading or delayed restoration. In 1978 he was the coauthor of a report on a country-wide blackout in Venezuela. The report included 23 recommendations to reduce risk of future similar occurrences, six of which addressed relay problems that contributed to cascading and restoration problems.

In 1978 he investigated a major substation burndown that was traced to a fault that was in a gap between first zone protection zones, and which interrupted trip circuits of backup protection thereby preventing clearing.

In 1979 he conducted an extensive dynamics study to specify a protection system for the Guri 800 kV system in Venezuela. This coordinated protective system addressed stability and cascading problems with

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out-of-step block and trip relays, overvoltage relays, and a unit tripping scheme.

He conducted failure modes and effects analysis on a complete nuclear station auxiliary system, including protection, battery systems, and automatic controls for starting of diesels and emergency coolant drives.

Since 1983 he has conducted a number of cogeneration protection studies, including voltage levels from 480 volts through 138 kV. In 1985 he conducted a coordination study for the Electric Boat Division of General Dynamics facility in Connecticut. This study covered over 400 protective devices from 220 volts through 69 kV.

He analyzed the protective equipment and circuitry that failed to prevent catastrophic damage to a large generating unit when it was accidentally energized from the EHV system. He provided testimony during litigation that followed this incident.

In 1984 and 1985 he investigated two breaker failure disturbances for a midwest client, both traced to relay problems at 69 and 230 kV. Problems included wiring errors and inappropriate relay settings.

In 1986 Mr. Clark also investigated the protection problems that could result from the operation of two parallel 300 kV lines with existing shield wires removed. These lines are in an area where tower footing resistance ranges from 20 to over 250 ohms. Various relay options, including wave relays were considered.

In 1986 he also documented potential fault level, grounding, and protection problems associated with cogeneration on distribution systems for a client, and reviewed six planned cogeneration interconnections for the same client.

In 1987 he investigated a 1986 disturbance in the Orange and Rockland system and identified from oscillographs and simulations a number of relay problems including sympathetic trip and out-of-step tripping.

Mr. Clark prepared the Power Technology Course unit on protection and taught this unit for 17 years. His course notes for the unit are used in the graduate program at the University of Sao Paulo. He has written papers on industrial plant load shedding and on microprocessor based industrial load shedding. He co-authored a paper on interconnection protection problems associated with customer owned generation and system dynamics for the annual IEEE-IAS meeting in 1986.

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