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 completed several GE graduate level courses including the GE "A Course" while performing conceptual design, power flow, stability, trouble shooting and protection studies for GE's largest paper, chemical, and petroleum clients.

In 1970 Mr. Clark joined Power Technologies, Inc. (PTI) where he served large industrial clients as well as electric utility clients. His transmission planning work included all voltage levels and all available techniques for maximizing transfer capability including reclosing, series capacitors and reactors, shunt compensation, braking resistors, unit tripping, stabilizers, fast valve actuation, high performance excitation systems and special protection schemes.

Mr. Clark's involvement in industrial plant system studies gave him the background to help solve the industry need for better load models for first-swing, oscillatory and voltage stability analysis. He developed stability models for induction motor dynamics, discharge lighting, magnetic saturation, and the effects of manual and automatic load controls such as thermostats. These models are now widely used. He also recognized the industry's growing exposure to voltage collapse and developed VQ analysis and other methods for the analysis of voltage security. He was first to recommend undervoltage load shedding as a solution to voltage collapse and to recommend criteria to reduce the risk of voltage collapse. He was an invited speaker at the first joint NSF/IEEE/EPRI Conference on Voltage Stability in 1988 and has made subsequent presentations at WSCC, IEEE, and EPRI events.

He has investigated a number of 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 Short Courses on System Dynamics, HVDC, and Static Var Systems and taught portions of the two-year Power Technology Course. He created the PTI Voltage Stability Course in 1985 and presented it to 1000 students world-wide. He wrote sections of 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 Life Senior Member of IEEE and has presented or published 40 papers and articles. Mr. Clark retired from PTI in 1996 and is now an independent consultant. In 1997 he was selected by BPA to serve on the Blue Ribbon Panel assembled to review the two 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," expert witness assignments, the design of a country-wide remedial action scheme for Taiwan, assistance to wind farm owners on wind farm interconnection issues, and engineer and operator training assignments. In 2003 he prepared a text on the voltage stability and reactive power planning problem that is the basis for his ongoing seminars on this subject.

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. “Assessment of Voltage Stability Margins,” a report to the IEEE PES Task Force on Voltage Stability, August 19, 1988.
17. "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.
18. "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.
19. "Long-Term Disturbance Monitoring for Improved System Analysis," IEEE Computer Applications in Power, Volume 2, No. 2, April 1989, (co-author, S.J. Balser).
20. "Analysis and Solutions for Bulk System Voltage Instability," IEEE Computer Applications in Power, Volume 2, No. 3, July 1989, (co-author, G.C. Brownell).
21. "Voltage Stability of Power Systems: Concepts, Analytical Tools, and Industry Experience," Chaptere 3, IEEE PES, 1990, 90TH0358-2-PWR (co-authors Charles Concordia, Walter Lachs).
22. "New Challenge: Voltage Stability," IEEE Power Engineering Review, Volume 10, No. 4, April 1990.
23. “Load Characteristics,” Presented at the WSCC Stability Seminar, April, 1990, Los Angeles.
24. "Load Modeling for System Dynamic Performance," special publication of the IEEE PES Working Group on Load Modeling, September, 1991 (co-authors).
25. “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).
26. "Experience with Dynamic System Monitors to Enhance System Stability Analysis," IEEE PES Summer Meeting, Long Beach, 1991 (co-authors, R.K. Gupta, C. Loutan, D.R. Sutphin).
27. "The Voltage Collapse Phenomenon," 1991 Minnesota Power Systems Conference Proceedings, University of Minnesota, October, 1-3, 1991.
28. "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.

29. “Voltage Stability: Load Modeling, Solutions, and Criteria,” Presented at the WSCC Stability Seminar, June 3, 1992, Los Angeles.
30. “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).
31. “Suggested Techniques for Voltage Stability Analysis,” Chapter 2, Step by Step Power Flow Methods, IEEE Special Publication, 93TH0620-5PWR, and Summer Meeting Panel Session, July 21, 1993.
32. “Technical and Economic Evaluation of Utility Battery Energy Storage Applications,” Fourth International Conference, Batteries for Energy Storage, Sept. 27 – Oct. 1, 1993, Berlin, Germany (co-author H.W. Zaininger).
33. "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.
34. “Minimizing the Cost of Voltage Stability," Presented at PTI Hospitality Suite at 1994 Summer Power Meeting.
35. "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).
36. “Criteria and Countermeasures for Voltage Collapse,” Report prepared by the International Conference on Large High Voltage Electric Systems, (CIGRE) Task Force 38.02.12, June, 1995 (multiple co-authors).
37. “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 (co-author, Paul Smith).
38. "The Grid in Transition FACTS or Fiction,” IEEE Power & Energy Magazine, October, 2003, (co-authors, FP deMello, ND Reppen, RJ Ringlee).
39. “It’s Time to Challenge Conventional Wisdom,” Transmission & Distribution World, pp 62-64, October, 2004.
40. “Defense Plan Against Extreme Contingencies,” Technical Brochure by CIGRE Task Force C2.02.24, April 2007 (multiple co-authors).
41. "Softening the Blow of Disturbances,” IEEE Power & Energy Magazine, Jan/Feb 2008, (co-authors).
42. “Grid Shunt Reactive Power Compensation,” Publication 1015998, November 2008, Sponsored by the Electric Power Research Institute, Palo Alto, CA.

Articles written for the PTI newsletter; Power Technology:

1. “Improve Stability Studies with Dynamic Load Models,” 1975.
2. “An Improved Load Model for Stability Studies,” 1978.
3. “Complex Dynamic Simulation Used in Selecting Protection Scheme,” 1980.
4. “Conventional Power Flow and Stability Analysis Applied to the Long-Term Simulation Problem,” 1982.
5. “Voltage Support in Heavily Loaded EHV Systems,” 1984.
6. “Performance Characteristics of Series Compensation and Shunt Var Support,” 1984.
7. “An Expanded Role for Back-to-Back DC Converters?” 1985.
8. “Protection of Cogeneration and Industrial Generation,” 1985.
9. “HVDC - Its Effect on System Performance and Existing AC System Capability,” 1985.
10. “Dynamic Stability,” 1987, co-author F.P. de Mello.
11. “Voltage Stability Analysis Requires Accurate QV Curves,” 1990.
12. “Hydro Plant Model Sets Record,” 1991.
13. “Motor Starters Affect Angular Stability,” 1991.
14. “Dynamic Load Models from DSM Recordings,” 1992.
15. “Excitation Limiter Performance Is Critical to Voltage Security,” 1995.
16. “A New Ball Game,” 1996. (Reliability impact of independently owned generation).

Blackout Analysis Experience

Mr. Clark's successful career in the planning of reliable transmission systems has been in part the result of his investigations of major system disturbances and blackouts.

WSCC 1996. Mr. Clark was appointed to the Blue Ribbon Panel formed to examine the two 1996 events that caused break-up and widespread loss of load across the eleven western states. He was one of three reactive planning and voltage stability experts on the Panel. He prepared a dissenting opinion letter which was published with the Panel's 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 voltage collapse and blackout. Plant design and operating practice upgrades were required to improve reliability.

Saudi Arabia 1993. Angular instability that caused a blackout was traced to inadequate coordination of underfrequency load shedding and generator underfrequency protection.

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 planning criteria and an interconnection to improve reliability and economic operation.

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

New York City 1977. Mr. Clark assisted the New York Public Service Commission staff in its analysis. His interviews and related work revealed several important elements of the failure that were overlooked by other investigators. He subsequently supervised Con Ed's analytical studies (conducted by PTI) to define protection and operating practices that would reduce the risk of future similar events and reduce restoration time.

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. Key elements were use of out-of-step blocking without the requisite out-of-step protection and voltage collapse triggered by a large pumping station. The team prepared 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.

Texas 1991. A fault triggered widespread loss of load in the south of Texas. The cause was identified as transient voltage collapse in two areas, one involving industrial load and the other air conditioning load. A high risk of "slow dyanamic" voltage collapse was also uncovered.

WSCC 1980. Mr. Clark assisted in an analysis of major WSCC outages from a ten year period to identify conditions and events most likely to lead to blackouts. Protection was found to cause or be a contributing factor in more than half of all outages.

Major US City 199X. Mr. Clark reviewed four evaluations prepared by others and found that each had overlooked a significant weakness. The weakness created a high blackout risk.

WSCC 1970-1980. Mr. Clark co-authored an analysis of major WSCC outages from a ten year period to identify conditions and events likely to lead to blackouts. Protection was found to cause or be a contributing factor in more than half of the outages.

Taiwan 1999. Mr. Clark was not involved in the early investigation of this blackout. However, he researched this blackout as a senior member of a team that developed a computer-based country-wide high speed remedial action scheme to reduce the risk of blackouts.

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 consequent system break-up for certain contingencies. He coined the term "voltage collapse" and proceeded to confirm the problem through simulations containing 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 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 1978 Mr. Clark planned the first "high-speed emergency shunt capacitor banks." He guided simulations to define a voltage collapse problem in the Minnesota Iron Range and devised a control scheme that would energize three emergency banks within 0.75 seconds following line or generator trips that could cause an immediate voltage collapse.

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 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. This work resulted in adding series capacitors, emergency shunt capacitor banks, and a special control scheme on an HVDC back-to-back tie to Mexico.

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.

Testimony Experience

In addition to the experience covered in the biography, Mr. Clark has provided expert witness services 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.

Extensive 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 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.

Report and testimony preparation and a deposition for a client facing a class action lawsuit.

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 of protection equipment 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 responsible for relay selection and settings in the 250 MW isolated power system (240 V through 13.8 kV) of the Amerada Hess refinery in the Virgin Islands, and assisted Amerada Hess for over 20 years.

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 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 were traced to relay problems, one at 69 and one at 230 kV. Problems included wiring errors and inappropriate relay settings.

Mr. Clark assisted UP&L in the assessment of the risk of instability of the Intermountain Power Project power plant and the impact instability would have on WSCC and the UP&L customers. A backup protection scheme was developed to separate the plant from the Utah grid promptly following failure of the HVDC line.

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.