UPEC 2001
12~14 September 2001, University of Wales Swansea, UK

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The 36th Universities Power Engineering Conference (UPEC 2001), was held 12~14 September 2001 in the Faraday Building at the University of Wales Swansea, UK. It excelled previous conferences by the quality of the presentations, the technical content of the papers, the number of delegates attending and the number of countries represented. As in the past, it had a broad theme, covering all aspects of electrical power engineering, and was attended by academics, research workers, and members of the power service and manufacturing organisations. During the sessions, 192 papers from roughly 40 countries were debated. A plenary session, 32 technical sessions, and a closing session were held, with all technical papers being presented orally in four groups of parallel sessions. The high standard of the papers, presentations, and technical discussions was particularly gratifying.

Held annually, UPEC provides a forum for the exchange of ideas among practising engineers from the universities, consultants, and in the manufacturing and supply industries. The first full conference was held at the University of Glasgow, UK, in 1967, following an inaugural meeting in Newcastle. Last year the conference was held at Queen's University, Belfast, Northern Ireland, UK. The thirty-seventh (2002) conference is to be hosted by Staffordshire University, Stafford, England, UK, while the venue for the 2003 conference will be Thessaloniki, Greece. The working language at all meetings is English.

This year the technical sponsors were IEEE PES, IEE; and industrial sponsors included Axonics Ltd., International Rectifier, Morganite Electrical Carbon Ltd., Swansea City Council, Welsh Development Agency, and Western Power Division.

The conference was Residential lasting 3 full days with accommodation provided in the Halls of Residence on the main campus or 4-star hotel accommodation about 2 miles away.

1. OPENING SESSION

Dr M S Khanniche, Chairman of the Organising Committee, welcomed participants to the conference, to Swansea, and to Wales and to the UK. He said that over 300 abstracts were received from all five continents and 192 papers would be presented orally in four parallel groups of sessions. One-page summaries of each paper were contained in the Abstract Records. The full conference papers were published on CD-ROM.

Dr Khanniche thanked the institutions and the companies supporting the conference. Contributions of members of the International Steering Committee and the Local Organizing Committee, the reviewers, and the session chairpersons were highly appreciated.

Professor Tony Davies, Pro Vice-Chancellor of the University, gave the Welcome Address. He was responsible for Personnel functions. He welcomed participants to the Meeting and thanked the sponsors. He said his research interest were in modern computation methods for ionisation physics that had brought extensive collaboration with the Keynote Speaker Emeritus Professor R. T. Waters.

This conference review article was prepared by T. J. Hammons, Chair of the UKRI Section Power Engineering Chapter; Chair of the UKRI Section; and Chair of International Practices for Energy Development and Power Generation; University of Glasgow, United Kingdom.

They have presented joint papers at UPEC. He welcomed delegates and wished the Conference success, reflecting that he had taken part in previous Meetings.

2. PLENARY ADDRESS

This followed the Opening Remarks and was on University Power Engineering Education in the UK. It was delivered by Emeritus Professor R. T. Waters, Cardiff School of Engineering, Electrical Engineering Division, University of Wales, Cardiff, Wales, U.K.

At the outset he discussed Education and Research in Electrical Power Engineering. He said that the importance of the role played by UPEC is best illustrated by the content of its papers in areas of the technology that did not exist in the sixties at the first UPEC. It would have been impossible for us then to predict the present-day scale of the research and development in these areas. Many of them of course depend upon computer-based design, data acquisition and control engineering, and are driven by modern demands for improved reliability and economic operation.

UPEC will always remain a university-driven series, with a primary emphasis on scientific and engineering principles and the provision of valuable experience for young researchers, but its relevance to vital areas of our infrastructure is clear. It will continue to contribute to innovation and the establishment of international standards and guidelines.

Education and research in the UK, like the major changes occurring in the electricity supply industry, are undergoing significant reappraisal. I aim to provide a short up-to-date report on university teaching and research in high-voltage power engineering.

2.1 Status of Power Engineering

The future demand on our technology is unremitting. The Department of Energy 1998 Survey anticipates a global doubling of annual electric power demand between 1995-2020, from 11.8 million GWh to 23.1 million GWh. This represents a steady 40% increase over 25 years in developed countries (EU, USA, and Japan), but a staggering 300% increase in Asia, Africa and Central and South America. As far as transmission and distribution systems alone are concerned, this will represent an annual investment of about 60 thousand million dollars.

As far as electrical engineering education in the UK is concerned, the mid-1970s saw a limit to the expansion of electrical power engineering teaching in the UK. This limit was a reflection not only of competition from the technical revolution in electronic and control engineering, but in the UK at least was also the result of two other causes. A rationalisation of the heavy manufacturing base and a slowing of electricity demand had significant effects on career opportunities. The years between 1978 to 1984 showed a reduction of IEE chartered power engineers from 18,000 to 15,000.

More recent evidence points towards resurgence in the electrical power industry in the UK, resulting from greater competition and added value, the privatisation of the electricity supply industry and the re-organisation of production in the European Community. It will be the task of our power engineering education and training to respond adequately to this process.

2.2 University Staffing

Until 1992, degree courses in Electrical and Electronic Engineering were conducted in 34 autonomous university institutions financed through University Funding Council and in 28 polytechnics monitored by the Council for National Academic Awards. All these institutions are now of university status which are funded by a common Higher Education Funding Council, with an increasing element of competition for governmental financial support. The more successful institutions attract over 50% of their funding from other sources. Table 1 shows a list of institutions offering these degree courses, classified in terms of the numbers of full-time academic staff active in research as well as teaching.

Table 1. Number of UK University Research Academics in Electrical and Electronic Engineering

Southampton, Manchester (UMIST)	>50
Imperial College, Surrey, Sheffield. Glasgow, Strathclyde	>40
Loughborough, Bradford, Essex, Salford, Cardiff, Edinburgh	>30
UC(London), Queens (Belfast). Bath, Birmingham, Leeds, Liverpool, Bangor, Brunel, Hull, Kent, Manchester, Newcastle, Nottingham, Heriot-Watt, Swansea, Portsmouth, Glamorgan	>20
Bristol, Kings (London), Queen Mary, York, Aston, City, Plymouth, South Bank. Ulster, Coventry, De Montfort, East Anglia, Keele, John Moores, Staffs, Royal Gordon, Huddersfield, Trent, Sunderland, Westminster, Glasgow Caledonian	>10
Manchester Metropolitan, Reading, Hallam, Brighton, Greenwich, Teeside, Bolton, Central Lancs, Dundee Institute, Napier, Paisley	5-10
TOTAL	1400

Academics in Oxford, Cambridge and Durham are additional to this table.

This healthy staff population should easily maintain the graduation rate, provided that the student intake is sufficient. However, significant difficulties are arising in reaching training targets in electrical and electronic engineering and its sister disciplines.

2.3 Future Manpower Requirements for Electrical Power Engineers

He continued by saying we can try to estimate the graduation rate in electrical power engineering that is needed. The Institution of Electrical Engineers conducts an annual survey of Fellows, Members and Associate Members who are practicing in the United Kingdom and Ireland. We know the occupational spread of the 60,000 practicing electrical and electronic engineers. Just over 17,000 (28%) are estimated to be presently active in electrical power engineering (see Table 2).

Table 2 Employment of Electrical and Electronic Engineers as a Percentage of IEE Membership

Employment Area	Total	Power Engineers
Electricity supply and distribution	9%	8%
Building and transport	15%	7%
Power engineering manufacture	4%	4%
Processing industries	10%	4%
Defense and miscellaneous	10%	2%
University and other education	10%	1.5%
Electronics, computing and Telecommunications	30%	0.5%
Control and software	12%	1%
	100%	28%

Of the 1400 who are active in university research (Table 1), fewer than 300 can be estimated to be electric power engineering specialists, and about 100 to have a direct interest in power systems. For example in my own specialty there are probably about 20 high voltage engineering specialists in UK universities at this time, a dangerously low population for the skills, capital investment and widespread applications associated with the subject.

We can also look at activity in power engineering as reflected in the membership of the Divisions of the IEE. Most power engineers are involved with the Power and/or Science, Education and Technology Divisions, which together represent about 30% of the IEE membership strength. As we can see, these Divisions promote professional activities of direct relevance to UPEC (Table 3):

Table 3 IEE Professional Activities in Electrical Power Engineering

Transmission and distribution plant
Power cables and overhead lines
Industrial applications and processes
New concepts in energy distribution and utilization
Materials science and technology
Discharges and applications
Non-destructive testing and evaluation
Electromagnetic compatibility
Education and training

So to sum up the required graduation rate, the 17,000 practicing engineers in electrical power engineering will be subject to an annual wastage rate of about -6% per annum, so that the training of 1000 graduates per annum in power engineering is needed to maintain the status quo. This requirement was probably just satisfied in the United Kingdom until ten years ago (Table 4), when there were annually 5800 graduates in Electrical and Electronic Engineering, of which about one in six studied electrical power engineering in the final year.

Table 4 Graduate Output in Electrical Power Engineering (1991)

Practicing UK Electrical Power Engineers	17,000	UG students electrical & electronic eng.	22,000
Annual Wastage Rate	-6%	Graduation rate	6,000/annum
Replacement Requirement	1,000/annum	Electrical power graduates	1,000/annum

However, the electrical and electronic engineering student intake has declined in recent years, as can be deduced from examination of the annual general statistics published by the UK university admissions authority UCAS (Table 5).

Table 5 Student Intake in Engineering (1997–2000)

Subject		1997	1998	1999	2000
Electrical & Electronic eng.	UK	3,439	3,113	3,151	3,071
	Non-UK	1,333	1,134	1,158	1,096
Civil eng.	UK	2,247			1,850
	Non-UK	1,151			1,099
Mechanical eng.	UK	3,789			3,539
	Non-UK	1,511			926
All engineering	UK	20,495	19,488	18,994	18,180
	Non-UK	8,313	7,051	6,460	5,729
All subjects	UK	331,257	323,763	328,810	330,300
	Non-UK	38,622	36,986	38,074	36,542

The graduation rate in electrical and electronic engineering will thus fall from the needed 6000/annum to less than 3000/annum for UK students. Table 5 confirms also the 2001 British Association Science Festival report from the Institution of Civil Engineers that civil engineering graduates have declined in a decade from 4500/annum to 1700/annum.

The UCAS figures for 2000 also interestingly show that the overall engineering intake of 24,000 students compares with 46,000 into social studies and 50,000 into business courses.

2.4 Research in UK Universities

In addition to the total undergraduate population in Electrical and Electronic Engineering, academic staff are also responsible for supervising 3,000 Masters and Doctoral students. The student/staff ratio is increasing annually, which could have negative implications for research opportunities in universities. The estimated prospective output of 600 graduates annually in electrical power engineering is trained in fewer than half of the 60 universities. Some of these centers, however, are among the largest in the country. Postgraduate degree teaching is confined to a few universities.

The overall success of UK universities in attracting research grants is shown in Table 6. In real terms government funding is static, whereas external research funding is increasing at about 10% per annum.

Table 6 **Financial Support of Electrical and Electronic Engineering in UK Universities**

Staff and General	£80m
Equipment	£11m
Research Grants and Contracts	£100m

As part of this funding, the government enables the Engineering Research Council (EPSRC) to provide annually (for competitive bidding) about M£32 for university power engineering research (Table 7).

Table 7. **EPSRC Portfolio 2001**

Total Funding	7000 Projects	£1432m
Subjects include		
IT and Computer Science		235
Materials		79
Chemistry		153
Manufacturing		132
Engineering and Physical Science (Includes Electric Power Engineering)		79
Electric Power Engineering:		
Motors and Drives		6.6
Generation (conventional)		4.1
Generation (renewable)		14.5
Power System Management , Protection Contol and Plant		6.5
	Total	31.7

5 HV Engineering

He then said that for his own area of research in high voltage engineering the traditional strength of UK university research in fundamental physical processes has been largely replaced by more directed programs (Table 8). Particular strength is shown in materials and testing, but the programs are impressively diverse.

Table 8 **High Voltage Research**

University	Research Area

Cardiff	1/ Electric field measurement 2/ Polluted insulators and insulator design 3/ Atmospheric breakdown tests and modeling 4/ Breakdown statistics and measurements 5/ Surge arrester characterization 6/ Very fast transients, pulse sharpening 7/ Earthing characteristics for transient currents
Dublin	1/Insulation tests and fault location in distribution transformers 2/Insulation coordination
Leicester	1/ Individual water tree growth 2/ Inception and inhibition of water trees 3/ Electrode design and physical processes in precipitators
Liverpool	1/ Optical diagnostic techniques 2/ Fast transients in GIS 3/ Plasma processing
Manchester	1/ Mechanical causes of treeing in solid resins 2/ High temperature testing of solid insulation 3/ Water treeing in solid and liquid insulation 4/ Surface breakdown 5/ Ultrasonic NDT
UMIST	1/ Ablative rubber for cable insulation 2/ Transient breakdown of machine insulation 3/ Generation of fast transients in switching 4/ Surface breakdown phenomena 5/ Live-line working
Southampton	1/ Defects and ageing in polyethylene for dc and ac cables 2/ Charge trapping and transport in polymers 3/ Limitation of sheath voltages and currents in cross-bonded cables
Strathclyde	1/ Wide band field measurement in GIS 2/ Charge trapping, transport and water treeing in polymers 3/ Surface charging and damage in SF6 and vacuum 4/ Breakdown in contaminated vacuum 5/ Remote monitoring of GIS 6/ Fast transient breakdown of GIS 7/ Lightning and aircraft 8/ Pulsed ozonisers 9/ Triggered high-pressure switches for pulsed power 10/Applications of pulsed power in food processing and NDT

2.6 Future Prospects

In both teaching and research it will be necessary to maintain an effective capability within the university system to address those issues which will be critical to the medium and long term development of the electricity industry in the UK (Table 9):

Table 9 Priority Research and Development Areas

(i) Reliability and Life of Devices and Systems;

E.g. New dielectric and magnetic materials,
On-site testing and monitoring,
Risk assessment and asset management,
Aging studies on plant and materials.

(ii) Environmental Issues;

E.g. Options for generation and pollution control,
E.m.c. sources and testing,
Safety and earthing
Gas-insulated substations and lines.

(iii) Long Term Strategy and Emerging Technologies;

E.g. Neural networks and condition monitoring,
High-voltage power electronic devices,
Sensors development,
Digital data acquisition and processing.

As well as these domestic priorities, the mutual interest of both advanced and developing countries in extending the generation, distribution and utilization of power to meet the projected demand will guarantee the future of our branch of engineering. UPEC will continue its valuable contribution.

3. DISTINGUISHED LECTURER ADDRESS

This address was on FACTS and was presented in the afternoon of the first day by Rambabu Adapa, IEEE PES Distinguished Lecturer, EPRI, Palo Alto, CA. USA. He gave an in-depth account with examples of EPRI's FACTS System Studies.

He began by saying transmission systems are becoming increasingly stressed because of growing demand and because of restrictions on building new lines. However, most high voltage transmission systems are operating below their thermal rating due to such constraints as stability limits. EPRI is pioneering FACTS technology to make it possible to load lines at least for some contingencies up to their thermal limits without compromising system reliability. To understand what is required of the FACTS controllers, EPRI has initiated several FACTS system studies with various utilities. These utilities include Southern Company Services, Florida Power & Light, New York Power Authority, Minnesota Power, Commonwealth Edison, Tennessee Valley Authority, Public Service Electric & Gas, San Diego Gas & Electric, Western Area Power Administration, ENEL (Italy), and PPGC (Poland). He then summarized findings of these studies. He also gave a brief description of the EPRI's software packages, which are being used in these studies.

The demands of the twenty first century, with increased growth and interconnection of power grids, he continued, will stretch existing delivery systems to their limits and create new requirements for flow control, system stability, and capacity enhancement. FACTS, based on advanced solid -state controllers, incorporate the capabilities that will be needed. FACTS controllers offer tremendous speed, precision, and reliability improvements over the mechanical switching devices they will replace. FACTS controllers allow loading of the transmission lines to their thermal limits, without compromising reliability, which is possible because most high-voltage transmission lines have substantial margins in their thermal capacity.

Before making any decisions on a new technology such as FACTS, system study is the first step that is undertaken by the electric utilities to perform both technical and economic evaluations. In this regard, EPRI has been in the forefront by initiating more than fifteen system studies with different utilities to evaluate possible application of FACTS controllers. Electric utility industry-wide accepted computer software is needed to perform these system studies. EPRI has developed the most comprehensive packages such as PSAPAC (Power System Analysis Package) and EMTP (Electro-

Magnetic Transients Program) with detailed models for FACTS controllers. EPRI's software has been used by many utilities while performing these system studies.

3.1 Power System Analysis Tools

He then said today, reliable operation of power system is being challenged as power systems must withstand more stress than ever before, and some systems are pushed close to stability limits almost daily. Power system stability is crucial to reliability. EPRI has developed a suite of programs called Power System Analysis Package (PSAPAC) for static and dynamic analysis of power systems. PSAPAC can model large and small systems under the full range of normal and transient conditions. With these programs, utilities can calculate system limits and determine safe loading and operating procedures for systems operating under stressed conditions.

PSAPAC consists of data preparation programs such as dynamic reduction and load synthesis; static analysis programs such as power flow and transmission transfer limit; and dynamic stability programs such as transient stability, small signal stability, and voltage stability. The nine programs that make up PSAPAC share common data files, representing the static and dynamic power system data. In addition, the programs can convert static network data from BPA, PTI, WSCC, IEEE, and EPRI power flows and PTI's dynamic generator plant data. An overview of each PSAPAC program is now given:

- ❖ Dynamic Reduction (DYNRED) Program identifies groups of coherent machines and aggregates these machines into one or more equivalent machines per group.
- ❖ Load Synthesis (LOADSYN) Program models loads on the network for static and dynamic simulation.
- ❖ Interactive Power Flow (IPFLOW) Program consists of tools for steady state analysis of voltage and power flow conditions for various loads, contingencies, and generation dispatches.
- ❖ Transfer Limit (TLIM) Program calculates rapidly the real power flows and transmission line transfer limits for various contingencies, loads, and generation dispatches.
- ❖ DIRECT stability analysis software is intended to complement the traditional time-domain stability analysis programs for first-swing transient stability analysis. The direct method of transient stability analysis is based on the evaluation of system transient energy function (TEF).
- ❖ Long-Term Stability Program (LTSP) is a time-domain simulation program for simulating the long-term dynamics of a large power system after a disturbance. Detailed conventional and nuclear turbine models are provided to give accurate long-term simulation.
- ❖ Voltage Stability (VSTAB) Program provides information on the proximity to, and mechanisms of, voltage instability.
- ❖ Extended Transient Midterm Stability Program (ETMSP) is a time-domain simulation program for transient and midterm stability analysis of large systems.
- ❖ Small Signal Stability Program (SSSP) package consists of two programs: Multi-Area Small-Signal (MASS) stability program for determining the stability of small-signal disturbances in small power systems; and Program for Eigenvalue Analysis of Large Systems (PEALS). The SSSP package can aid the analysis of both local plant mode oscillations and inter-area oscillations in interconnected power systems.

EPRI's ETMSP and SSSP programs, he continued, could model a number of FACTS devices, which are presently considered feasible and are being studied by North American and foreign utilities. These FACTS devices include: Static VAR Compensator (SVC), Thyristor Controlled

Series Compensators (TCSC), Thyristor Controlled Phase Angle Regulator/Tap Changer (TCPAR/TC), Thyristor Controlled Braking Resistor (TCBR), Static Compensator (STATCOM), Unified Power Flow Controller (UPFC), and Convertible Static Compensator (CSC). FACTS modeling is done by means of user defined models. The enhancement of PSAPAC programs with the models of FACTS devices will allow power system engineers to optimize design parameters while analyzing the use and effects of FACTS devices in large electric power systems.

High-speed electromagnetic transients are often the controlling factor in the design and operation of a power system. EPRI in cooperation with the Development Coordination Group (DCG) has developed the EMTP program to assist utilities in the analysis of design and operating problems. Given EMTP's ability to predict the strength and frequency of transients on transmission networks, utilities can often reduce equipment costs by avoiding unnecessarily conservative designs. Of equal importance, the program can be used to determine the cause of equipment failures after they occur so that mitigating steps can be taken to prevent problem recurrence. FACTS device models with controls can be modeled using the EMTP for evaluating the performance of these devices, as well as control system design. SVC and TCSC models are implemented and extensively tested using EMTP. Other FACTS device models can be easily implemented using the component models in EMTP.

3.2 FACTS System Studies

He went on to describe several FACTS System Studies to investigate benefits of applying FACTS technologies for increased power transfers that have been initiated by EPRI.

3.2.1 Scoping Studies

Initially, two scoping studies of FACTS were sponsored by EPRI to investigate the possibility of using high speed thyristor based control of HVAC power system elements to enhance the carrying capacity of existing transmission circuits without compromising reliability. One scoping study was performed by PTI and GE performed a second. Study systems representative of existing power systems were developed. The studies were conducted to evaluate the economic and technical issues of loading transmission lines to their thermal limits. Both multi-line corridor and long radial interconnection scenarios were considered. The issues addressed were transient and dynamic stability, loop flow control, power flow control, reactive support and voltage stability. The devices studied included fast acting phase shifters, rapidly adjustable network impedance devices, thyristor control braking resistors, and static VAR compensators.

Using models of realistic power systems, transmission corridors where increased power transfer would be beneficial were identified. Appropriate locations for FACTS devices were identified, workable control systems were developed, and device designs were refined to increase power transfer while maintaining original stability margins.

The study results indicate that FACTS devices have the potential to significantly increase system stability margins., thereby increasing the loading capability of existing transmission corridors. Economic evaluations of the applications considered in these studies show that the FACTS devices are attractive, when compared with other methods of achieving the same system performance.

3.2.2 FACTS Requirements on the Southern Electric System

The objective of this study was to investigate FACTS controller requirements by studying FACTS applications for the Southern Electric System (SES)/TVA interface and the SES/Florida Peninsula (FP) interface. These two interfaces were modeled in sufficient detail using EPRI's load flow and stability programs (ETMSP) with various FACTS options and under several contingencies.

The study was extended to include economic considerations and engineering aspects of FACTS technologies. The major conclusions of this study are:

- The interchange transfer capability from TVA to SES and from SES to FP can be increased through the use of FACTS devices.
- 230 kV and 161 kV FACTS devices on the SES/TVA interface appeared to be cost competitive with conventional improvements.
- A new 500 kV interconnection between TVA and SES is cost competitive with 500 kV FACTS devices.
- A combination of conventional and FACTS devices may offer a cost-effective solution for increasing the transfer capability on the SES/FP interface.
- Static VAR compensation and shunt compensation were found to be more effective at the midpoint of some 500 kV lines as opposed to the terminal ends.
- The cost per unit of transfer capability added on the SES/FP interface is generally higher than on the TVA!/ES interface.

3.2.3 FACTS Requirements on the Florida Power & Light Co. System

This study was limited to FACTS applications of series or shunt compensation, which would provide for an increase of 500 MW in first contingency total transfer capability from SES to Florida Power & Light (FPL). FPL performed steady state and dynamic stability assessment studies on the SES/FPL interface using two different system configurations. The main difference between the two configurations is the addition of a third 500 kV line in the West Coast connecting Florida to the SES.

The first contingency total transfer capability from SES to FPL can be increased by 500 MW by providing series compensation on selected 500 kV lines. Series compensation is found to be cost effective compared to shunt compensation or to building new 500 kV transmission line. Further, the results indicate that thyristor control applications could be beneficial in improving system performance. Studies on shunt compensation showed a voltage collapse point in the operating range that makes this option unacceptable.

3.2.4 Application of TCSC in New York State

FACTS show promise for better utilization and control of the existing New York State transmission system. In this study, the application of TCSC to the New York State 345 kV network was considered. Conventional and optimal power flow studies identified the minimum cost combinations of the series and shunt compensation required to control flow and voltage at increased power transfers. For example, the increase of power transfer from 2850 MW to 3200 MW on Central East interface could be achieved by 510 MVAR of shunt capacitors, 880 MVAR of SVC, 2437 MVAR of fixed series capacitors, and 533 MVAR of TCSC.

Fundamental frequency dynamic studies identified control requirements for stability enhancements. Interactions between TCSC and SVC controls were investigated at higher bandwidths. Results showed good performance and no control interaction between the Fraser SVC and the Edic-Fraser TCSC with reactance control alone. However, a control interaction exists between the voltage-input power swing damping control (PSDC) of the TCSC, the series compensated ac system resonances, and the SVC control. It was concluded that the successful application of TCSC with shunt compensation would be capable of controlling power flow in the New York 345 kV system with increased transfers without exceeding existing thermal and dynamic stability limits. TCSC would also obviate operational restrictions brought about by lack of dynamic stability during generator and SVC outages.

Results of the electromagnetic studies showed that increasing transfers by application of TCSCs will not significantly affect the electric and magnetic fields produced by the circuits involved.

Facing a bottleneck in its transmission system that hampered interstate electricity transfer, the New York Power Authority (NYPA) teamed with EPRI to install a convertible Static Compensator (CSC) to increase power flow by 240 MWs. This latest FACTS device entered service in April 2001.

3.2.5 TCPAR at Minnesota Power

This study was to investigate the technical feasibility and evaluate the benefits of applying a thyristor controlled phase angle regulator in the planned 115 kV interconnection of Minnesota Power and Ontario Hydro. The two systems (Minnesota Power and Ontario Hydro systems) are weakly interconnected and share very little synchronizing torque. Because of this, the phase angle across the interconnection can vary wildly, as mush as 220 degrees from summer to winter and with over a 100 degrees variation in a 24-hour period. In order to maintain a power schedule across such an interconnection, direct control of power flow is required. The only two options, which can give the necessary control, are phase angle regulators and HVDC. The relative cost of HVDC to phase angle regulators is approximately 5 to 1 for this application. The impact of introducing a thyristor controlled phase angle regulator (TCPAR) in series with the conventional phase angle regulator installation was studied.

Results of the initial investigation and system studies indicate that a single-tank, single-core TCPAR design with a minimum number of thyristors would provide acceptable transient performance at minimum cost. Improvement in system transient response due to TCPAR control would provide an additional 50 MW of transfer capability between Minnesota Power and Ontario Hydro and would increase stability on parallel corridors.

3.2.6 FACTS Requirements on the Commonwealth Edison’s Power System

The first part of this study was to investigate the technical feasibility of applying FACTS devices to improve the stability of the Byron nuclear plant of the Commonwealth Edison (CE). The stability limitation, as identified by CE, is loss of synchronism under certain second local transmission contingencies, with both Byron units operating at full capacity during light system load levels.

The identified stability limitation can be solved by the addition of a 345 kV circuit. However, a new circuit may not be a feasible solution. Using EPRI’s ETMSP program, the conventional remedies such as installing two-cycle circuit breakers and digital relays, high gain electronic exciters (static exciters), or fixed capacitors were studied. Using the same computer program, the FACTS solutions such as a breaking resistor at Byron, fast switched shunt capacitors, and switched series capacitors were evaluated.

Two cycle circuit breakers and digital relays resulted in a first-swing stable case, but the post-contingency voltage dip was unacceptable. Static exciters did not result in a first-swing stable system. High levels of fixed series capacitors represented a possible solution but introduced unacceptable power circulation through neighboring systems. FACTS solutions with braking resistors and shunt capacitors proved viable. Fast-switched capacitors with static exciters, as well as switched series capacitors, produced a first-swing stable case.

The second part of this study was to investigate the technical feasibility of applying FACTS devices to improve voltage stability and power quality at CE’s Schaumburg substation. CE identified the Schaumburg substation, which operates under stressed conditions in a fast load-growth area, as a likely site for low voltages and a possible cause of voltage collapse.

3.2.7 FACTS Requirements on the TVA system

To improve first swing stability of TVA's Cumberland thermal power plant, both FACTS and conventional solutions were studied. The stability limitation, as identified by TVA, is loss of synchronism under certain double transmission contingencies, with both Cumberland cross compound generating units operating at full capacity.

The Cumberland plant stability limitation can be eliminated by either conventional solutions or by FACTS solutions. When synchronism is maintained by use of corrective measures, a transient voltage-dip may follow fault clearing. However, by providing series compensation on the Cumberland-Marshall line both stability and voltage-dip problems can be eliminated. Either a mechanically or thyristor-switched braking resistor can also solve both stability and voltage-dip problems. Changes to the Cumberland 500 kV switchyard can prevent first swing instability due to breaker failure. Shunt compensation alone was found to be impractical as a solution to the stability problem.

3.2.8 Static Phase Shifter in ENEL Network

This study investigates the technical and economic feasibility of applying a static phase shifter in the ENEL (Italian) 380 kV transmission system. In a single contingency condition, the utility experiences overloads on one critical interface. To alleviate this problem, the considered solutions include static phase shifter (SPS), mechanical phase shifter, and addition of a 60 km 380 kV line section.

The investigation indicated that an SPS with +1- 9 degrees of regulation would maintain power flow under the first contingency within prescribed limits on the overloaded line without degrading system security. Since the ENEL system did not exhibit stability problems, a slower acting mechanical phase shifter would suffice. The study also showed that a new 60 km 380 kV line would allow the 750 MW import with reduced losses. Preliminary estimates indicate that the annual levelized cost of a conventional phase shifter is 70% higher than the new line, while the SPS is four times higher.

3.2.9 FACTS Assessment Study to increase the Arizona-California Transfer Capability

This study, which is being completed by San Diego Gas & Electric, focuses on the effectiveness of increasing the Arizona-California power transfer capability with FACTS devices. Arizona-California intertie is composed of 500 kV transmission lines from West of the Colorado River (WOR) to the East of the Colorado River (EOR) with conventional series compensation. The application of various FACTS devices such as SVC, TCSC, STATCON, Thyristor Controlled Reactor (TCR) were studied using EPRI's ETMSP program. The issues considered for this study include:

- EOR and Southern California Import (SCIT) stability enhancement
- EOR and WOR thermal limitation enhancement
- System voltage collapse mitigation
- Loop flow mitigation in the Mexican transmission system
- More efficient utilization of existing series compensation
- Spinning reserve.

3.2.10 FACTS Requirements on the Entergy System

The Entergy system includes, as part of its service area, the cities of New Orleans, Baton Rouge, and vicinity in the southern end of its network. There is sufficient local generation available in this sub-region to meet its normal load demand. However, under certain operating conditions, it is necessary to transfer power into this region from northern generation. Under such operating conditions, the Amite South Interface (ASI) becomes a critical interface for reliability and economic operation of the Entergy system. The Conway-Bagatelle 230 kV line under contingency of the Willow GlenWaterford 500 kV line limits the import capability of this interface. Various FACTS devices including series reactors and phase angle regulators are considered in this study to alleviate the ASI interface limitations. This study is being completed.

3.2.11 FACTS Requirements on the Public Service Electric and Gas System

The use of TCSC for SSR mitigation is studied for Public Service Electric and Gas Co's system. This study also looked at other FACTS device applications for PSE&G's system. This study is in progress.

3.2.12 TCPAR Study at Western Area Power Administration

This study focussed on retrofitting an existing phase shifting transformer with thyristor switches. Early portions of the study focused on an interface between Arizona and California that can be limited due to inter-area oscillations for disturbances on four parallel 500 kV lines. By using the power modulation capabilities of TCPAR, the power transfer level can be increased by about 200 MW. The study progressed to include an evaluation of the controller design with the addition of new lines to be in service by 1996. These transmission additions eased the transfer capability but reduced the incremental benefit of TCPAR control. However, under contingency conditions where a SVC or line was out of service, the transfer could be increased by 150 MW or 200 MW respectively.

3.2.13 Application of FACTS Technology to the Polish Power Grid

This study focused on assessing the feasibility for applications of Flexible AC Transmission Systems (FACTS) technology on the Polish national transmission system. The study concluded that FACTS devices would be effective in damping inter-area oscillations to which the Polish power system is vulnerable.

Just as in the United States, the electric power industry in Europe is undergoing restructuring changes. In eastern European countries, national grids are becoming interconnected via the Union for the Coordination of Transmission of Electricity (UCTE). In Poland, the Polish Power Grid Company (PPGC) has observed an increase in certain grid conditions such as poorly damped inter-area oscillations since interconnection. Furthermore, the Polish grid previously experienced a voltage collapse and continues to experience load flow control limitations. For these reasons, the company undertook analyses to identify appropriate solutions, including the location, size, and control strategy for installing FACTS devices as well as conventional devices.

The objectives of this study were (i) to investigate the technical feasibility of FACTS applications on the Polish transmission system, and (ii) to identify potential benefits of FACTS applications.

Team members first conducted in-depth reviews of prior research results and had discussions with PPGC planners and operators. They identified five specific locations within the Polish power system as potential locations for FACTS devices. Subsequently, the project team conducted extensive steady state, dynamic, and economic analyses, initially establishing base cases for year 2000 and year 2010 system conditions. They assessed four FACTS devices for specific sites: static compensator (STATCOM), static synchronous series compensator (SSSC), Thyristor Controlled

Phase-Shifting Transformer (TCPST), and Unified Power Flow Controller (UPFC). To conduct these analyses, the team used applications from EPRI's Power System Analysis Package 5.0 (PSAPAC), and Real and Reactive Power Optimization for Planning and Scheduling Program 2.0(ROPES).

The project team concluded that the FACTS devices studied would be valuable in resolving specific planning and operations issues encountered on the Polish grid, such as enhancing damping of inter-area oscillations between the north and south. It was also demonstrated that the conventional techniques studied in the project could solve these problems. The report also notes that the need for a FACTS device to improve the systems dynamic performance depends, in part, on the future role of the Polish grid in the European electricity market. The knowledge gained in this project, including developing expertise in the area of FACTS technology, will be valuable in the future should PPGC decide to implement FACTS. With the knowledge gained in the project, planners will be able to provide the necessary specifications for a FACTS device.

3.3 <u>Conclusions</u>

Adapa concluded by saying that FACTS technologies are offering competitive solutions to today's power systems in terms of increased power transfers, improved system damping, and better system control. The application of FACTS devices are very much system dependent. The simulation of detailed power system models as well as FACTS device models in a production grade program such as ETMSP was found to be necessary to evaluate the complete benefits of FACTS technologies. It is important to consider both technical and economic considerations while evaluating FACTS options.

4. TECHNICAL PAPER SESSIONS

Topics debated in the four parallel groups of technical sessions on the first day included: power system operation and control, power electronics, high voltage engineering, power system protection, power system analysis and transients, electrical machines, renewable energy sources, FACTS and HVDC, Power Generation, Electrical machines and drives, transmission and distribution, and power quality.

On the second day, there were further parallel groups of sessions on: power system operation and control, power electronics, high voltage engineering, power system protection; renewable energy sources, and power quality, and new sessions on power system analysis, and power electronics and transformers.

Topics debated in parallel groups of technical paper sessions on the third day included: third sessions on power system operations and control, power electronics, electrical machines, and power system protection; second sessions on transmission and distribution, power system analysis and transmission, electrical machines, and power generation; and sessions on power system protection and transmission and transients, power engineering education and utilisation, flexible ac transmission, and power utilisation.

5. OTHER CONFERENCE HIGHLIGHTS

Highlights of the conference included:

- Welcome Buffet Supper in Angels at the main Refectory, Fulton House Main University Campus on the Tuesday before the Conference where the Café West Bar in Fulton House was open for bar service.

- Buffet and Civic Reception at the Maritime and Industrial Museum on the Wednesday evening which consisted of a drinks reception and finger buffet, at which participants were welcomed to Swansea by the Deputy Lord Mayor Councillor June Burtonshaw.
- Conference Banquet in Angels, Fulton House Main University Campus, at which the welcome address was given by the Lord Mayor of the City of Swansea Robert Francis Davies and where the guest speaker was Martin Rees of Bluebird Technologies.

There was also a sponsor's exhibition which both delegates and accompanying persons visited.

6. VISITS

Also arranged were technical and tourist visits to:

❖ CORUS Packaging Plus at Trostre in Llanelli, a supplier of light gauge steel for packaging and non-packaging applications, based in Ijmuiden, Netherlands, with other production plants in the Netherlands, South Wales, Norway and Belgium.

❖ Cardiff Barrage and Cardiff Bay, where for many years Cardiff Docklands (Tiger Bay/Shirley Bassey country) lay derelict, but construction of the Cardiff Barrage changed the tidal estuary into a permanent waterfront attraction.

❖ Tour of Gower Peninsular, which was the first designated 'area of outstanding natual beauty' in Britain, where the coach stopped at beach and cliff locations.

❖ Aberdulais Falls, where the story spans over 400 years--starting with the first manufacture of copper in 1584, later followed by iron smelting and corn milling. A tin-plate works was built around 1830 and the remains of this industrial period is still seen today. Many artists were inspired to paint here, one of the most famous being J M W Turner who painted The Mill at Aberdulais in 1795. In 1991 the National Trust built a HydroElectric Scheme and a Waterwheel.

7. AFTER DINNER SPEECH

Martin Rees, Director of the Bluebird Project gave an entertaining talk about what is involved in achieving the Water and Land Speed Record during the past several decades.

He joined the conference for dinner direct from the historic burial of Donald Campbell at Coniston (who died in an attempt on the Water Speed Record many decades ago) that very day (12 September 2001).

He described his personal feelings in coming to the project and reviewed the long history of land and water speed record attempts. The involvement of the Campbell family in record attempts is world renowned and continuing currently with electric cars through Donald Wales, grandson of Sir Malcolm Campbell and nephew of Donald Campbell, and the Bluebird Project. He described how in 2000 the group undertook a long project at Pendine Sands in West Wales and successfully claimed the UK Electric Vehicle Land Speed Record. Now plans are afoot to travel to Bonneville Salt Flats to secure the World Record.

The Bluebird project has a strong commercial arm that aims to finance the very expensive process of record beating.

More information about record attempts is on the web-site at: www.bluebird.wales.com
Martin Rees can be contacted at: Martin@bluebird.wales.com

8. CONFERENCE PROCEEDINGS

All technical papers were incorporated in the UPEC 2001 Proceedings CD-ROM that was distributed to delegates at the conference. The Abstract Records (212 pages), also distributed to delegates, contains one-page hard copy summaries of each paper. Abstracts of the UPEC 2001 can also be found on the UPEC 2001 home Page: http://eepe.swan.ac.uk/upec/

UPEC 2001 Proceedings (CD-ROM, Abstracts, and Conference Literature) may be purchased for £100 (sterling), until supplies are exhausted, from Dr M S Khanniche, UPEC 2001 Conference Chairman, Department of Electrical Engineering, University of Wales Swansea, Singleton Park, Swansea SA2 8PP, UK, Tel: +44 1792 295421, Fax: +44 1792 295 441, E-mail: M.S.Khanniche@swansea.ac.uk, UPEC World Wide Web: http://eepe.swan.ac.uk/UPEC/

9. AWARDS

Prizes were awarded for the Best Technical Paper and for the Best Technical Presentation by a Young Engineer.

The recipient of the Best Paper Prize was P J Moore and D L Hickery of Bath University, for their paper entitled HVAC Measurements by Corona Analysis. The paper was presented in a Session on High Voltage Engineering

The recipient of the Best Technical Presentation by a Young Engineer prize was Nanette Teo of Aberdeen University, who was actually a substitute presenter. Her presentation was entitled: Improvement of Automatic Voltage Control of On-load Tap-changer Transformer. She presented it in a session on Distribution Systems with Embedded Generators.

10. CONFERENCE WRAP-UP

Papers were well thought out and benefited from the 15 minutes allowed for presentation and discussion of each paper. The general level of the discussions was extraordinarily high and stimulating. Of particular note was the high standard of the presentations by the younger members of the profession. The pleasure the participants experienced in meeting colleagues with similar interests from so many countries should be particularly noted

Gratitude is expressed to Dr M S Khanniche, UPEC 2001 Conference Chairman, Members of UPEC Steering Committee, and colleagues at University of Wales Swansea for the detailed organisation of the meeting.

11. UPEC 2002

In closing the conference, Dr M S Khanniche stated that the 37th UPEC will be organized by the School of Engineering and Advanced Technology, Staffordshire University, United Kingdom, and will be held at the University's Stafford Campus, September 9~11, 2002. It will be co-sponsored by IEEE PES, and IEE. It will be held on the main university campus. Its aim will be to provide engineers and academia with the opportunity to explore recent developments, current practices and future trends in power engineering, and young engineers and research students are especially invited to contribute. The conference will be accompanied by a Technical Exhibition that will give the opportunity to keep participants up-to-date on recent developments in Power Engineering. It will again have a broad theme covering all aspects of power engineering. The working language will be English. The majority of accepted papers are to be presented in oral sessions.

For more information on UPEC 2002, contact Dr Moofik Al-tai, Conference Chairman or Ms Dorota Wiernikowska (Conference Secretary), UPEC 2002, School of Engineering and Advanced Technology, Staffordshire University, PO Box 333, Beaconside, Stafford ST18 0DF, United Kingdom, Tel: +44 1785 353469, Fax: +44 1785 353552, E-mail: d.wiernikowska@staffs.ac.uk Website: www.staffs.ac.uk/upec2002

Abstracts are to be submitted by February 1, 2002, notification of acceptance of papers will be on March 18, 2002, and receipt of full papers will be May 20, 2002.

The conference closed with a unanimous vote of thanks to Dr Khanniche for organising a very successful event.

NOTE: The Renewable Energy Sources Revised Papers will be published in a special edition of "Revue Des Energies Renouvellables" Journal. Alger, Algeria. Dr M S Khanniche will contact the authors,