

# Approximate Model of European Interconnected System as a Benchmark System to Study Effects of Cross-Border Trades

Qiong Zhou and Janusz W. Bialek

**Abstract**—Research into transmission pricing and congestion management in interconnected power systems, such as those found in USA and Europe, requires an appropriate benchmark system to test different methodologies. Creation of a realistic benchmark system is difficult as utilities are often unwilling to disclose details of their own systems because of commercial sensitivity and security reasons. This paper presents development of an approximate model of a European interconnected system which could be used to study the effects of cross-border trades. In creating the load-flow model, only publicly available information was used. Comparison of simulation results conducted on the test system with the published cross-border flows and power transfer distribution factors showed a very good correlation, exceeding 90%.

**Index Terms**—Interconnected power systems.

## I. INTRODUCTION

**L**IBERALIZATION of electricity supply industry has created many new challenges for the research community. New problems and new terms appeared which were unknown until late 80s, e.g., transmission pricing and congestion management. In the world of vertically integrated monopolistic utilities, transmission pricing and congestion management used to be internalized and did not require explicit treatment and pricing. Even in the case of large interconnected power systems, like those found in Europe or USA, whenever a trade crossing borders of control areas had to be accounted for, approximate approaches were sufficient, usually based on the contract paths concept. In USA, such trades are known as interarea trades while in Europe a term cross-border trades is usually used. This paper is looking at the problem from the European perspective so we will use the latter term.

The explosion in the number and magnitude of cross-border trades in the 90s has brought the problems of cross-border transmission pricing and congestion management to the fore. A proper solution is required not only in order to achieve efficient markets but also to maintain system security. This last point was made painfully clear recently as the widespread blackouts in US/Canada and Europe in the August/September of 2003 can be largely attributed to cross-border trades [1].

In Europe, Florence Regulatory Forum [2], organized by European Commission, has succeeded in bringing together dif-

ferent stakeholders (member States, regulators, system operators, consumer associations, power exchanges, brokers etc.) to discuss and build some consensus on the multitude of problems hindering the aim of achieving internal electricity market (IEM). Despite publishing a number of documents outlining technical problems and possible solutions to the questions of transmission pricing and congestion management, the progress has been slow which is not surprising taking into account the number and diverse interests of all the stakeholders.

Academic community has recognized the problems created by cross-border trades a long time ago as signified by a large number of papers published on that topic. However the lack of publicly available load flow model of the European interconnected system makes it impossible to test and compare different proposed approaches. Often very simplified, or even radial, models of the interconnected network are used which do not address the problem of parallel (or loop) flows, i.e., flows outside the main contract paths.

The research published in this paper has been spurred by the recognition of that problem. We have tried to test our congestion management ideas on an approximate model of Europe. We have contacted the Union for Coordination of Transmission of Electricity (UCTE) and all European utilities but almost all of them, with a few notable exceptions, refused to share any information whatsoever citing commercial sensitivity or security reasons. The former excuse is debatable as transparency is one of the main pre-requisites for an efficient market. For example British electricity market is one of the oldest and most developed in the world yet all three British transmission utilities (National Grid, ScottishPower and Scottish Hydro-Electric Transmission) publish annual Seven-Year Statements with detailed models of their transmission networks and typical load and generation profiles. Detailed, although not current, load flow models of USA transmission networks have also been published. On the other hand security concerns are quite understandable in view of recent terrorist attacks.

To fill this gap, and help in the development of IEM in Europe, we have decided to develop an approximate load flow model of so-called 1st synchronous UCTE region using only publicly available sources of information. Our aim was to create a research tool which would replicate main physical characteristics of the real network without pretending to be an accurate model. This way we would address security and commercial sensitivity concerns. Although there are many models of systems of different sizes available, we feel there is no model of a standard *interconnected* network of a reasonable size available, with clearly

Manuscript received June 21, 2004. Paper no. TPWRS-00332-2004.

The authors are with the School of Engineering and Electronics, University of Edinburgh, Edinburgh EH9 3JL, Scotland (e-mail: q.zhou@ed.ac.uk; Janusz.Bialek@ed.ac.uk).

Digital Object Identifier 10.1109/TPWRS.2005.846178

defined borders of utilities. Such model could be used to validate and benchmark different methodologies for assessing the effects of cross-border trades and we would hope that our model could form a first step in developing such a tool. This paper shows how such a model has been developed using publicly available information and validated against actual UCTE cross-border flows and power transfer distribution factors (PTDFs).

## II. FORMING LOAD FLOW MODEL FROM PUBLIC DATA

### A. European Network

The extra high voltages (EHV) of European transmission network consists of several voltage levels: 380-kV or 400-kV (standard in UCTE, GB and NORDEL—Organization for Nordic Electric Power Co-operation) and nonstandard voltage levels varying from 220 kV or 225 kV to 300 kV [3]. 750 kV is applied only in Hungary for one line [4].

UCTE has 21 member countries. Due to the war in the Balkans in the 90 s, the UCTE area is divided into two synchronous areas, which were re-connected via the asynchronous dc link between Greece and Italy [4]. This paper deals with so-called “1st synchronous UCTE region” composed of 18 continental European countries: Portugal (P), Spain (E), France (F), Belgium (B), Luxemburg (LX), Switzerland (CH), Italy (I), Netherlands (NL), Germany (D), Denmark west (DK), Czech Republic (CZ), Slovakia (SK), Poland (PL), Austria (A), Hungary (H), Slovenia (SV), Croatia (CRT) and part of Bosnia and Herzegovina (BIH). Different market mechanisms, regulatory rules and geographic structures exist in all the member countries.

Recently the AC connection has been extended to Northern Africa. The 1st synchronous UCTE region is also connected with UKTSOA (United Kingdom Transmission System Operators Association) and NORDEL via dc connections.

### B. Classification of Data

The data needed to build up the load flow model can be divided into the following categories:

- transmission network data;
- power plant locations, fuel types and capacities;
- load center locations and capacities.

For the reason of simplicity, we have used dc power flow model so the network information required included reactance, voltage levels and topologies of transmission lines.

### C. Collecting Public Data

As mentioned in the Introduction, UCTE and most of member Transmission System Operators (TSOs) refused to make available load flow models of their networks. However, some information was publicly available such as

- national generation, peak load, power flow exchange and cross-border lines information on UCTE website [www.ucte.org](http://www.ucte.org);
- generation/substation description list from websites of individual TSOs;
- geographic information of population and industry from publicly available websites;

- technical reports from European Commission website concerning cross-border information.

### D. Transmission Network Data Collection

Transmission network is the backbone of the load flow model and creating a model of the transmission network took most of time. Although the electrical parameters of transmission lines are generally not available to the public, they can be estimated from the lengths and voltage levels of the lines, because typical reactance values per kilometer for overhead lines are widely used by electrical engineers, given the voltage level and operating frequency. We have assumed that for single circuit 220-kV and 380-kV lines, the typical reactance values are 0.31 ohm/km and 0.28 ohm/km at 50 Hz [5].

Transmission network maps are available from the websites of some TSOs, therefore both the reactance and the connection were roughly given. UCTE also published its transmission network map [6], giving the voltage level, number of circuits of each EHV line, as well as its geographic location.

Transmission capacity limits between the countries were obtained from [7], and the thermal limits of tie-lines were obtained from UCTE yearbook [8].

The following assumptions were used in building up the model.

- 1) Only those lines with voltage levels above and including 220 kV are taken into consideration. This assumption is generally accepted for transmission network carrying bulk energy. Although there are a number of tie-lines operating at 110 kV, they have relatively small capacities and play a less important role in power interactions.
- 2) The resistance and shunt admittance were ignored, because we only consider dc power flow method. Some long distance transmission lines may have series capacitors installed but they were also ignored.
- 3) All the circuit breakers on the map are assumed to be closed under normal operation in order to make full utilization of the whole network. In fact, they can be open, depending on the operation modes. For example, the 220-kV line between Belgium and Luxembourg does not tend to be energised. This makes all the power flows deviate from the actual values due to the loop flow effect.

### E. Creating Database Using GIS

One of the most time-consuming tasks was extracting the transmission line lengths and their connections from the paper map. As the UCTE network consists of over a thousand buses, a database was needed to store and manage all the related information. To facilitate this task, Geographic Information System (GIS) software was used. Details of that task are described in [9].

When digitising the map, some groups of electrically closely connected buses were merged into one equivalent bus. It was necessary to do so because too-short transmission lines in the network might cause ill-conditioning in power flow calculation.

### III. NODAL AND BRANCH DATA

#### A. Generation Data

Power plant fuel types and capacities are related closely to their outputs, and therefore influence power flows. These data are commercially sensitive because they can reflect the marginal generation costs of the generators.

Since up-to-date information is not accessible, we had to turn to historic information published before the deregulation of electricity industry. As the historic data about capacities and fuel types has not changed greatly in UCTE over the past twenty years, power flow calculation based on the historic information can still reflect the present real network. European fossil thermal power plants database [10], published 12 years ago, is available on the Internet, and it was used in the work.

The difficulties with obtaining generation lists varied with TSOs in different countries. We have used mainly generator lists obtained from some TSOs and generator lists available on the websites of some power producers (member links of [www.eu-electric.org](http://www.eu-electric.org)). If the above two resources failed for a certain country, or the generator lists were incomplete, a list of European fossil plants (including their installed capacity and type of fuel) [10] and a list of nuclear plants [11] were used as the last resort, because these two lists are not up-to-date ones.

Generators in our model are simply classified as hydraulic, fossil thermal or nuclear ones, so that no sensitive information is included. This classification is also available from UCTE map.

To run a load flow, one needs the actual outputs of power plants which could be obtained from a dispatch program. Running dispatch for every country was simply not feasible so we have taken an approximate assumption that actual outputs of power plants are proportional to their installed capacities. This is equivalent to scaling down proportionally outputs of all the plants in a given country. This obviously is not generally the case, but it can give a rough estimation of the power flow trend. The proportional scaling assumption can be easily relaxed, even without using detailed cost information, by assuming that certain types of plants are base load and other are peaking. Then peak load plants could be scaled down more, especially for off peak load conditions.

Each power plant is related to a bus in the UCTE map, and the bus can be retrieved from the GIS database, where the bus record is labeled with its ID number. Considering the fact that all the power plants are identified by their names (which are names of their places in most cases) in every generation list, one of the necessary tasks was to relate the names of the plants with the ID of the buses. Putting the names in the database enables us to check and upgrade the database easily in the future. The installed capacities of the plants can also be entered into the database by the plant names. Detailed description of the database can be found in [12].

Besides capacity information, cost curve information is also needed to run optimal power flow (OPF) and to get the close-to-reality power flows. Although the true cost curves are confidential, a typical cost curve can be used for each specific type of generator.

#### B. Demand Data

Load center locations and capacities also have important influence on the power flows. Unfortunately there is no sufficient public information about loading of particular substations. To estimate the load level, we have assumed that demand levels are related closely to local population and industry.

The total demand of each UCTE member country is available in UCTE website. This total demand level was further distributed among all load buses according to local population. This approach was based on the following two rules.

- 1) The demand from households in a certain area is proportional to the population in that area.
- 2) The demand from industrial users in an area can be roughly reflected by the population there too, because population follows employment.

The website [www.world-gazetteer.com](http://www.world-gazetteer.com) gives population of all the administration areas (e.g., provinces) in each country, thus the total demand of a country was distributed into groups of demands by administration areas. Further division of regional load into substation loads by population was not attempted. Instead the load buses were assumed to share equally the regional load.

In order to check the viability of that approach, a comparison with actual demand distribution was attempted using Italy as an example. Actual area consumption list was available from the Italian TSO website ([www.grtn.it](http://www.grtn.it)), and the area population list was taken from [www.world-gazetteer.com](http://www.world-gazetteer.com) as year 2002 data. The result is shown in Table I and Fig. 1. Clearly pattern of population is closely related to the pattern of electricity consumption as signified by the correlation factor of 91%. Although such strong correlation might not stand in all the other countries, the proposed method can still reflect the load distribution trend.

Similar to generation buses, the demand buses are also associated with names of places and that information is stored in the database. For some countries the substation list was unavailable and estimation has to be made on the demand levels.

### IV. POWER FLOW CALCULATION USING POWER WORLD SIMULATOR

The methodology described in the previous section was used to develop an approximate model of UCTE system containing 1254 buses and 378 generators. The system data was prepared initially in IEEE CF text file [13]. As CF format does not support many of power system features like generator cost curves and multiple generators/loads in the same bus, the IEEE CF files are normally used only for inputting data instead of storing system descriptions. Further modifications on the testing network were done using PowerWorld simulator after loading the CF file. Therefore, the final network data are stored in PowerWorld format (\*.pwb) [18]. The advantage of PowerWorld is that it provides one-line diagram editor, which allows editing the network graphically. PowerWorld uses \*.pwb file to store the one-line diagram information. Version 9 of PowerWorld was used as it supports dc loadflow. It is impossible to produce ac loadflow of European network due to uncertainties about required voltage levels, reactive power sources and sinks etc. Data files are available for downloading at [12] in the formats of PowerWorld files and IEEE CF files, as well as Microsoft Access

TABLE I  
CORRELATION BETWEEN POPULATION AND ELECTRICITY DEMAND

Region	Population 1000s	Consumption (TWh)	Population %	Consumption %
Abruzzo	1243	6106	2.2	2.2
Basilicata	595	2352	1.1	0.8
Calabria	1992	4582	3.5	1.6
Campania	5648	14674	10.0	5.3
Emilia-Romagna	3957	23177	7.0	8.3
Friuli-Venezia Giulia	1179	8677	2.1	3.1
Lazio	4972	19642	8.8	7.0
Liguria	1560	6256	2.8	2.2
Lombardia	8915	59584	15.8	21.3
Marche	1463	6354	2.6	2.3
Molise	316	1256	0.6	0.4
Piemonte	4163	25095	7.4	9.0
Puglia	3980	15756	7.1	5.6
Sardegna	1598	10698	2.8	3.8
Sicilia	4862	17392	8.6	6.2
Toscana	3458	18594	6.1	6.7
Trentino-Alto Adige	936	5173	1.7	1.9
Umbria	815	5407	1.4	1.9
Valle d'Aosta	119	820	0.2	0.3
Veneto	4487	27725	8.0	9.9
Total	56260.6	279320	100	100

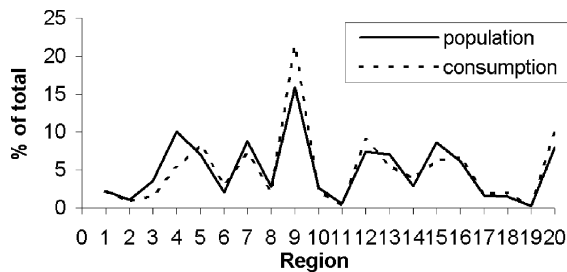


Fig. 1. Regional population and electricity consumption in Italy as percent of national totals.

databases. The cross-border transmission line capacity limits are also included in the Microsoft Access databases.

A. Simulation Cases and Results

Fig. 2 shows the whole UCTE network and an enhanced part of the Switzerland–Italy border area with power flows calculated for winter peak operation. The network has 17 areas and 28 cross-border interfaces. For the countries outside the UCTE 1st synchronised area, fictitious generator/load buses were put at the borders to simulate the power imports/exports.

The zoomed-in Italy–Switzerland interface area is interesting as it is where the Italian blackout of September 2003 started. Power flow directions are indicated by the arrows along the transmission lines. The pie charts on the cross-border lines show power flows as percentages of transmission limits. Clearly several cross-border lines are running near their limits.

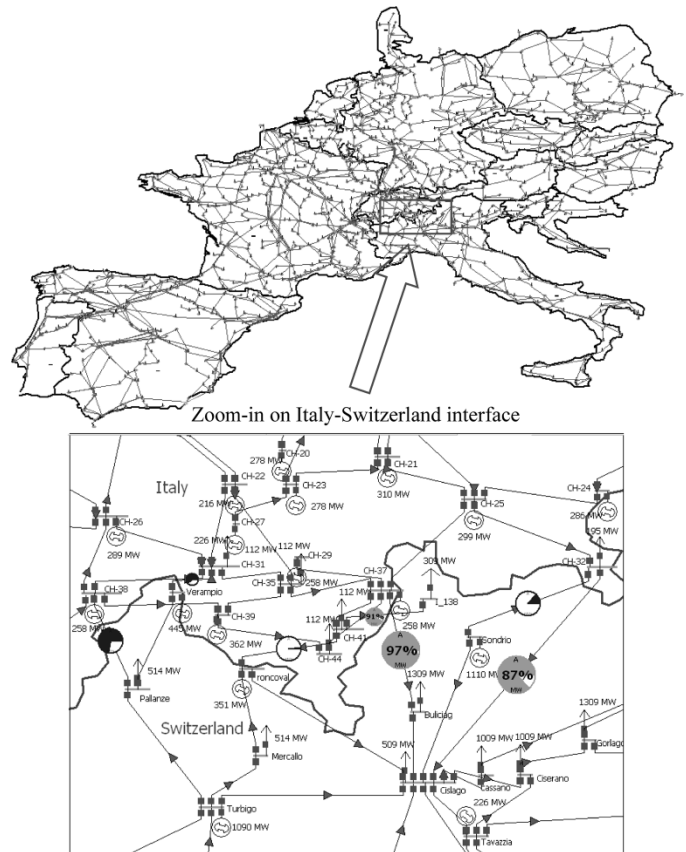


Fig. 2. UCTE network with enhanced Switzerland–Italy interface—winter peak 2002.

In order to validate the developed model, the calculated flows were compared with actual cross-border power flows. The following three real scenarios were used to check the model:

- 1) UCTE 16 January year 2002 11 am—winter peak load [14];
- 2) UCTE 16 January year 2002 3 am—winter valley load [14];
- 3) UCTE 21 August year 2002 11 am—summer peak load [15].

Among those scenarios, the 2002 winter peak load scenario was the most important because it has the highest demand and thus is interesting for congestion management studies. Generations and demands together with total cross-border exchanges for winter peak load are shown in Fig. 3. For example 9491/9407 for Switzerland (CH) means that internal generation of Switzerland was 9491 MW while internal demand was 9407. The numbers next to links between any two countries refer to the actual cross-border flow and, in brackets, the difference with respect to the calculated one. For example 2086(−65) for the D–NL link means that the actual cross border exchange was 2086 MW but the load flow result using the approximate network representation was  $2086 - 65 = 2021$  MW. The results are quite good as the correlation factor between the actual and modeled cross-border exchanges was about 90% which is quite satisfactory.

It should be noted that UCTE data show only total cross-border exchanges between countries without breaking them down into individual tie-lines. Hence a link between any two countries, which is shown as a single connection in

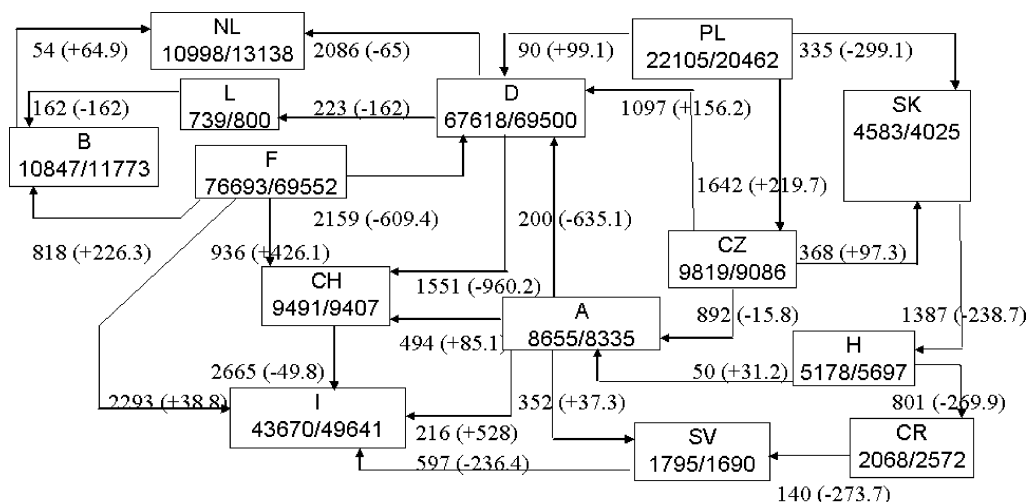


Fig. 3. Winter 2002 peak cross-border flows in UCTE network and the differences between the actual and simulated cross-border exchanges.

Fig. 3, in fact may consist of a number of tie-lines. Sometimes power may even flow in opposite directions in different tie-lines linking any two countries.

### B. Model Modifications

Although the correlation factor of about 90% between the actual and modeled cross-border exchanges was quite good an attempt was made to improve it. Considering the assumption that all nodal injections are proportional to their installed capacities, which is far from the reality, further modifications can be made to bring the testing network closer to the real system. Possible changes on the model can be

- increasing/decreasing the generation at certain locations within generation limit;
- increasing/ decreasing the load at certain place to make it fit the local population more precisely.

Basically these increases and decreases on the nodal injections were done manually to make the cross-border exchanges closer to the real values. When making modifications, care has to be taken to recognize the influence of transit power flows in order to avoid unnecessary adjustments as explained below.

Transit power flows can be easily detected. For example, Croatia (CR, on the bottom right of the map) is connected with both Hungary (H) and Slovenia (SV), and power flow deviations on the interfaces (H → CR and CR → SV) are -66.1 MW and -69.9 MW, respectively. Inspection of the map leads to a conclusion that the deviations are caused by the transit power from Hungary to Slovenia. Thus, instead of adjusting nodal injections within Croatia, one should adjust the injections in Hungary or Slovenia in order to reduce the power flow deviations.

The adjustment in Slovenia can be done using the following procedure:

- 1) Find all the interfaces and their power flow deviations. Slovenia has three interfaces, they are: A → SV (48.2 MW), SV → I (-21.9 MW) and CRT → SV (-69.9 MW).
- 2) Find the border buses (Slovenia side) of the interfaces, and change their injections to reduce power flow deviations.

In order to keep the total generation/demand within Slovenia unchanged, after the adjustments in step 2, the unbalanced generation/demand should be balanced by the other generators or loads in this country.

Similar adjustment work can be done for other countries. As the UCTE network is highly meshed, the existence of loop flows makes it impossible to achieve 100% similarity by simply adjusting the nodal injections. Final results are shown in Fig. 4 and plotted in Fig. 5. The correlation factor between the actual and simulated cross-border exchanges was increased to 99.28%.

The 2002 winter night and summer cases were then used in order to check whether the model network is still valid under different scenarios. Cross-border power flows for each scenario were obtained simply by scaling down the generation/demand values in all the countries from the values in case 1 to those in case 2 and 3. The resulting correlation factors between the actual and calculated cross-border flows for the scenarios 2 and 3 were also quite high and equal to 97.34% and 94.72%, respectively. Thus the model network seems to be suitable for analysing UCTE network performance in terms of cross-border power flows at different loading levels.

### V. VALIDATION OF PTDF VALUES

The basic tool for congestion management is Power Transfer Distribution Factor (PTDF) which assesses sensitivity of a given line flow to the changes in nodal generations and demands. PTDF factors are used to measure the impacts of a commercial transaction on the physical power flows in the critical transmission lines/ or interfaces. Based on the values of PTDFs, transactions are curtailed and increased in order to relieve lines overloads. Due to the phenomenon of loop flows in a meshed network, PTDF calculation requires the full network information.

In order to test the applicability of the UCTE network model under various dispatch conditions, the published PTDF values were compared with the calculated ones. Although not all PTDF values are publicly available, some of the PTDFs in the UCTE network were obtained from European Commission reports [7] and [16]. As our study was focused on the cross-border congestions, we were interested only in the values of PTDFs on

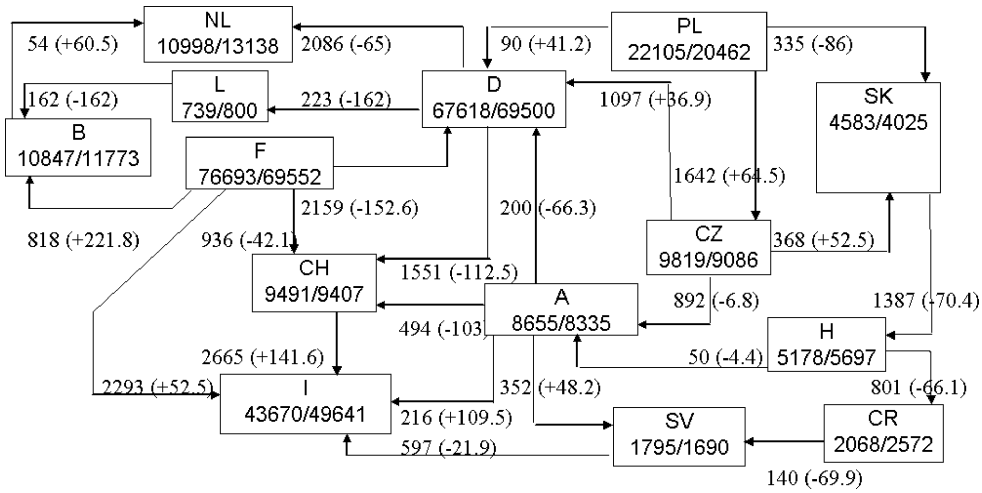


Fig. 4. Winter 2020 actual and simulated cross-border flows after modifications.

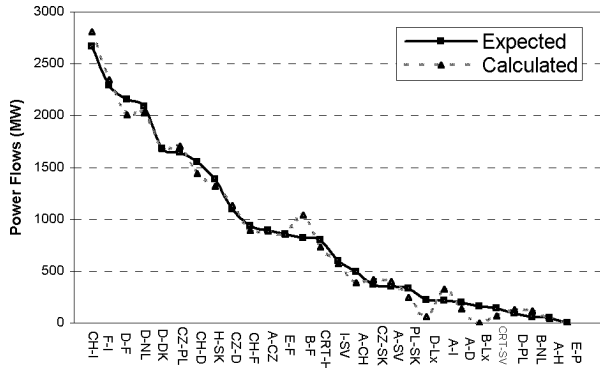


Fig. 5. Winter 2020 expected and calculated cross-border flows after modifications.

TABLE II  
PTDFs FOR BELGIUM-ITALY TRANSACTION [17]

	Expected PTDF (%)	Calculated PTDF (%)
NL-D	41	41.7
B-NL	41	41.7
B-F	59	58.3
F-D	6	8.8
F-CH	20	22.3
F-I	33	27.2
D-CH	28	17.8
CH-I	56	52.5
A-I	11	8.6
A-CH	8	12.3
D-CZ	3	5.4
CZ-A	3	3.6
D-A	16	24.2

cross-country interfaces rather than individual PTDFs for all internal lines within each country.

Tables II-IV give the PTDF factors (in percent) on the cross-border interfaces for the transactions from Belgium to Italy [17],

TABLE III  
PTDFs FOR FRANCE-NETHERLANDS TRANSACTION [16]

	Expected PTDF (%)	Calculated PTDF (%)
F-I	0	11.9
B-F	48	47
B-NL	48	47
CH-F	11	14.8
CH-I	0	-8.2
CH-D	11	-13.6
I-SV	0	-2.4
D-F	35	26.3
D-NL	52	53
A-CH	0	-9.3
A-D	0	9.7

North France to the Netherlands and France to Italy [16], respectively. The correlation factors are 97%, 91% and 95%, proving very good agreement between the expected and actually calculated values.

## VI. CONCLUSION

Research into transmission pricing and congestion management in interconnected power systems, such as those found in USA and Europe, requires an appropriate benchmark system to test different methodologies. Creation of such a benchmark system is difficult as utilities are often unwilling to disclose details of their own systems because of commercial sensitivity and security reasons. This paper has presented development of an approximate model of a European interconnected system which could be used to study the effects of cross-border trades. In creating the load-flow model, only publicly available information was used. Comparison of simulation results produced using the developed test system with published cross-border flows and PTDFs showed a very good correlation. For the cross-border

TABLE IV  
PTDFs FOR FRANCE-ITALY TRANSACTION [16]

	Expected PTDF (%)	Calculated PTDF (%)
F-I	38	37.2
B-F	15	11.1
B-NL	15	11.1
CH-F	25	32.4
CH-I	51	45.2
CH-D	21	7.1
I-SV	6	10
D-F	22	19.3
D-NL	-15	-11.1
D-PL	0	-2.1
A-CH	5	5.6
A-I	5	7.6
A-D	-12	-17
A-CZ	0	2.5
A-SV	6	5.1
CZ-D	0	-4.1
CZ-SK	0	3
H-SK	0	3.7
CRT-H	0	5
CRT-SV	0	5

flows, the correlation was well above 90%. For the PTDFs under the three published cross-border transactions, the correlation was between 90% and 97%. The results suggest that the developed system replicates well main characteristics of the European system and can be used as a benchmark for the research into effects of cross-border trades. The model data files can be downloaded from [12].

#### REFERENCES

- [1] J. W. Bialek, "Are blackouts contagious?," *Inst. Elect. Eng. Power Eng.*, vol. 17, no. 6, pp. 10–13, Dec. 2003.
- [2] . [Online]. Available: [http://europa.eu.int/comm/energy/electricity/florence/index\\_en.htm](http://europa.eu.int/comm/energy/electricity/florence/index_en.htm)
- [3] *Unit Costs of Constructing New Transmission Assets at 380 kV within the European Union*, ICF Consulting Ltd, Norway and Switzerland, 2002.

- [4] *UCTE Operation Handbook: Transforming UCTE Rules and Recommendations into Binding Security and Reliability Standards*, UCTE, 2003.
- [5] M. G. Say, *Electrical Engineer's Reference Book*, 13 ed. London, U.K.: Butterworth, 1973.
- [6] *UCTE Interconnected Network*, UCTE, 2001.
- [7] (2001) Analysis of Electricity Network Capacities and Identification of Congestion – Final Report. European Commission. [Online]. Available: [http://europa.eu.int/comm/energy/en/elec\\_single\\_market/index\\_en.html](http://europa.eu.int/comm/energy/en/elec_single_market/index_en.html)
- [8] UCTE Statistical Yearbook 2001: Transmission Lines and Inventory of Power Stations. UCTE. [Online]. Available: <http://www.ucte.org>
- [9] Q. Zhou, "Cross-Border Congestion Management in Electricity Power Markets," Ph.D. dissertation, Univ. of Durham, Durham, U.K., 2004.
- [10] The European Fossil-Fueled Power Station Database Used in the SEI CASM Model. Stockholm Environment Institute SEI, York. [Online]. Available: <http://www.sei.se/dload/1996/TEFFPSDUITSCM.pdf>
- [11] (1995) World List of Nuclear Power Plants. Comedition.com. [Online]. Available: <http://www.comedition.com/Science%20and%20Technology/NuclearTechnology/listofnuclearpowerplants.htm>
- [12] Univ. of Edinburgh. Bert Whittington Chair of Electrical Engineering. [Online]. Available: <http://webdb.ucs.ed.ac.uk/see/staff/staff.cfm?person=jbialek>
- [13] "Common data format for the exchange of solved load flow data," *IEEE Trans. Power App. Syst.*, vol. PAS-92, pp. 1916–1925, Nov./Dec. 1973.
- [14] Half-Yearly Report I/2002. UCTE. [Online]. Available: [www.ucte.org](http://www.ucte.org)
- [15] Half-Yearly Report II/2002. UCTE. [Online]. Available: [www.ucte.org](http://www.ucte.org)
- [16] H.-J. Haubrich and W. Fritz, *Study on Cross-Border Electricity Transmission Tariffs*. Aachen, Germany: European Commission, 1999.
- [17] *Net Transfer Capacities (NTC) and Available Transfer Capacities (ATC) in the Internal Market of Electricity in Europe (IEM) – Information for User*, ETSO, 2000.
- [18] . [Online]. Available: <http://www.powerworld.com>

**Qiong Zhou** received the B.Sc. degree in 1994 and the M.Sc. degree in 1997, both in electrical engineering, from Wuhan University of Hydraulic and Electrical Engineering (now Wuhan University), Wuhan, China, and the Ph.D. degree in 2004 from the University of Durham, Durham, U.K.

She was with the North China Electrical Power University, Beijing, China, from 1997 to 2000. She is currently a Research Associate with the University of Edinburgh. Her interests are in transmission and distribution network modeling.

**Janusz W. Bialek** received the M.Eng. degree in 1977 and the Ph.D. degree in 1981, both in electrical engineering, from Warsaw University of Technology, Warsaw, Poland

He was a Lecturer at Warsaw University of Technology from 1981 to 1989. From 1989 to 2002, he was with University of Durham, Durham, U.K., and currently, he holds the Bert Whittington Chair of Electrical Engineering at the University of Edinburgh, Edingurgh, U.K. His research interests are in the liberalization of the electricity power industry and in power system dynamics.