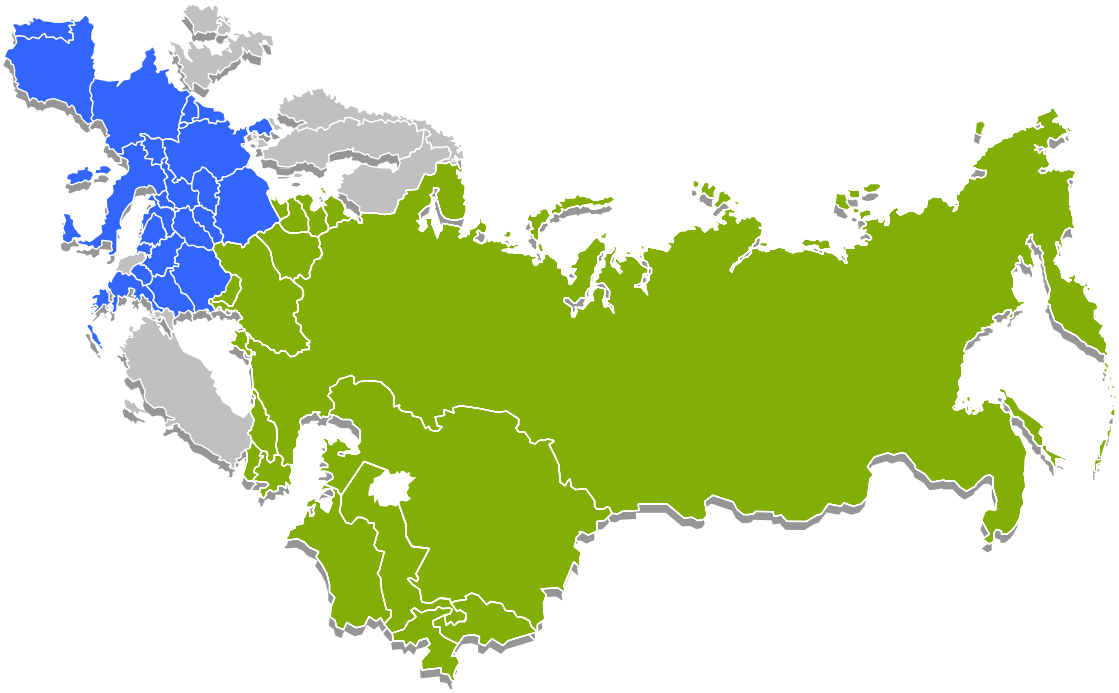
# Feasibility Study:

# Synchronous Interconnection of the IPS/UPS with the UCTE



## Summary of Investigations and Conclusions

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## Introduction

At the beginning of 2002, the Electric Power Council of the Commonwealth of Independent States (EPC CIS) expressed its interest in a synchronous interconnection with the power systems of the CIS countries and the Baltic States (IPS/UPS) to the power systems of the members of the Union for the Co-ordination of Transmission of Electricity (UCTE).

Therefore, the UCTE decided to conduct a Pre-feasibility Study in order to analyse the steady state load-flow [1]. After this was completed in 2003, the UCTE and the EPC CIS's Commission on Operational and Technological Coordination (COTC) agreed to launch a detailed feasibility study on the synchronous interconnection of the power systems concerned. The project was carried out in close co-operation with a UCTE consortium and a group of companies from the IPS/UPS. A geographical overview including some key figures about the different synchronous systems in Europe is given in Figure 1.

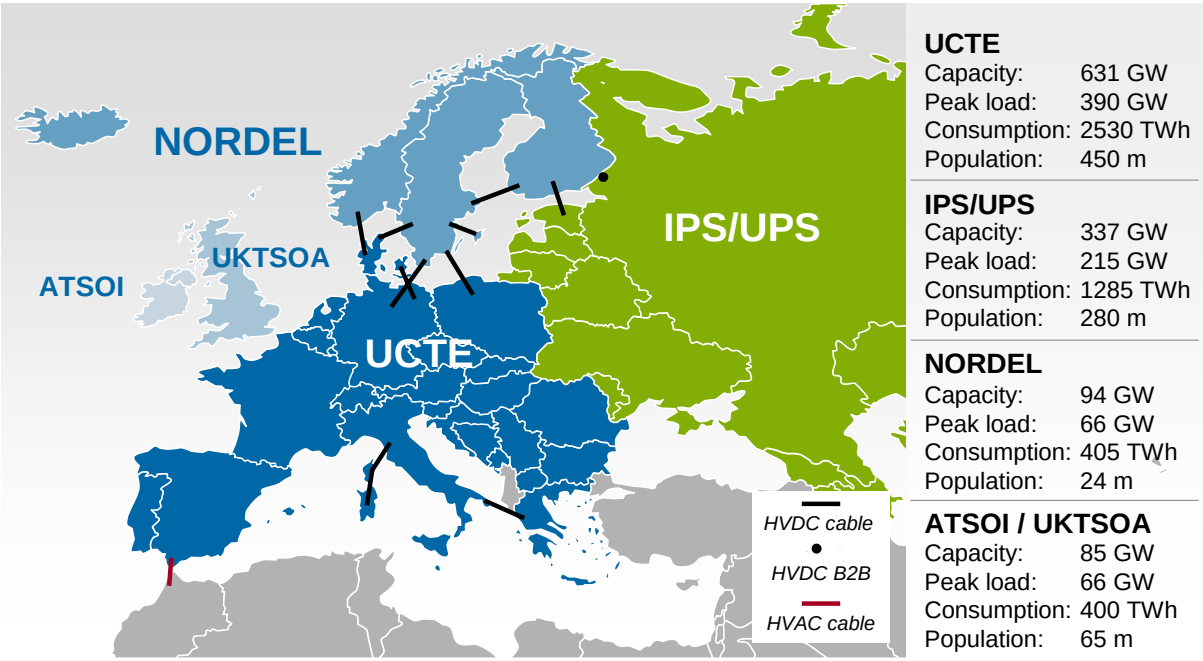


*Figure 1: Synchronous Systems in Europe*

The Feasibility Study is designed to answer three major questions:

- Is a synchronous interconnection of the IPS/UPS and the UCTE possible?
- What measures have to be taken in both systems?
- What are the associated costs?

The study is unique in its ambitions and scope. There is not an existing electricity system anywhere in the world at present which spans more than 10 time zones and that has different network structures, load characteristics and various generation patterns. More than 700 million people on two continents are served by the systems under investigation.

Although endeavours have previously been undertaken to examine the feasibility of an interconnection, the present study is unprecedented in regard to the resources employed and the advanced investigation methods and technologies applied. It is the first time that the

dynamic behaviour of synchronously coupled systems has been investigated by using a merged dynamic study model of the UCTE and the IPS/UPS.

The Final Report provides an overview of the work performed during the period from April 2005 to April 2008, as well as presenting the findings and results of this study. A number of recommendations on further possible activities are also given in the report. The results of the project can be used as a basis for any further decision making by the stakeholders concerned in system development on either side.

## Scope of Work

The main objectives of the study were to investigate the technical, operational, organisational and legal feasibility for an East-West synchronous interconnection of the transmission systems. It was also charged with identifying the necessary measures and associated costs involved in the implementation of the entire systems. The project work is a combination of analyses and power system simulations for two synchronously coupled systems without enforcing regulations and standards of one system on the other. The initial priority for investigation was and is to maintain the current level of system security and reliability in the systems concerned. This presented a major challenge for the experts from both the IPS/UPS and the UCTE.

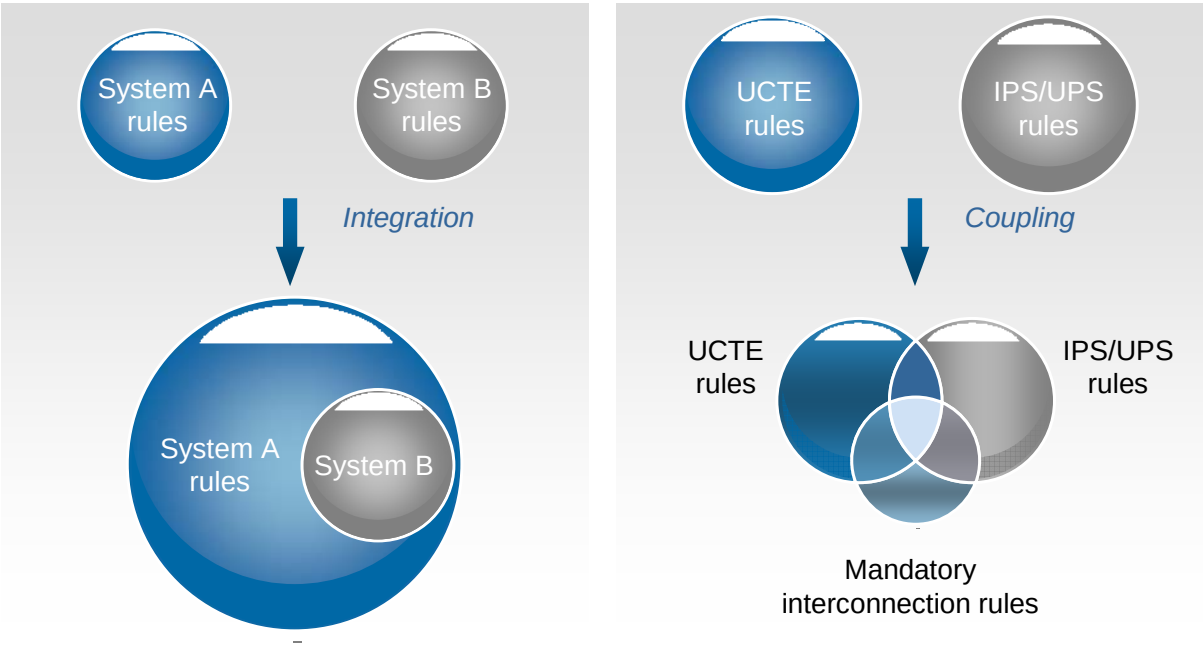


*Figure 2: Principles of system integration and system coupling*

All power system extensions in the UCTE grid have up to now been based on two principles. The individual Transmission System Operators (TSOs) are committed to these. They require the adherence to a common set of standards for operating the interconnection and its development, as well as upholding the rules of the common electricity market. In applying these principles, relatively small power systems were connected to the UCTE in a step by step procedure by adopting the UCTE standards in their entirety for the operation and reliability of such systems.

However, the marginal conditions for the present feasibility study are quite different from those applied to all former system interconnections. Contrary to the standardised UCTE *system integration* analysis procedures, this study has investigated the *system coupling* of two large electrical power systems, both having different regulations, standards and operating philosophies. Figure 2 illustrates the different principles of system integration and system coupling.

The two synchronous areas have been operated independently using different operating procedures and regulations for some considerable length of time. Therefore, the feasibility of the synchronous interconnection has not only to be defined in terms of the compatibility of technical performance, but also that of organisation and management within a consistent legal framework in order to ensure a secure and reliable interconnection. A mandatory set of technical, organisational and legal requirements needs to be defined in order to avoid any negative influence of one system on the other. However, the technical standards and internal regulating of each system will, as far as possible, remain unchanged providing that they do not have any negative impact on system security.

## Project Organisation

Two consortia were established in order to carry out the study:

The UCTE-Consortium responsible for the project consisted of 11 TSOs from 9 countries, namely: E.ON Netz GmbH (Germany) – acting as the Consortium leader, ELIA System Operator S.A. (Belgium), MAVIR Hungarian Power System Operator Company (Hungary), Electricita Sistemen Operator EAD (Bulgaria), PSE-Operator S.A. (Poland), Red Electrica de Espana S.A. (Spain), Reseau de Transport d'Electricite (France), RWE Transportnetz Strom GmbH (Germany), Slovenska elektrizacna prenosova sustava, a.s. (Slovak Republic), National Power Grid Company “Transelectrica” (Romania) and Vattenfall Europe Transmission GmbH (Germany).

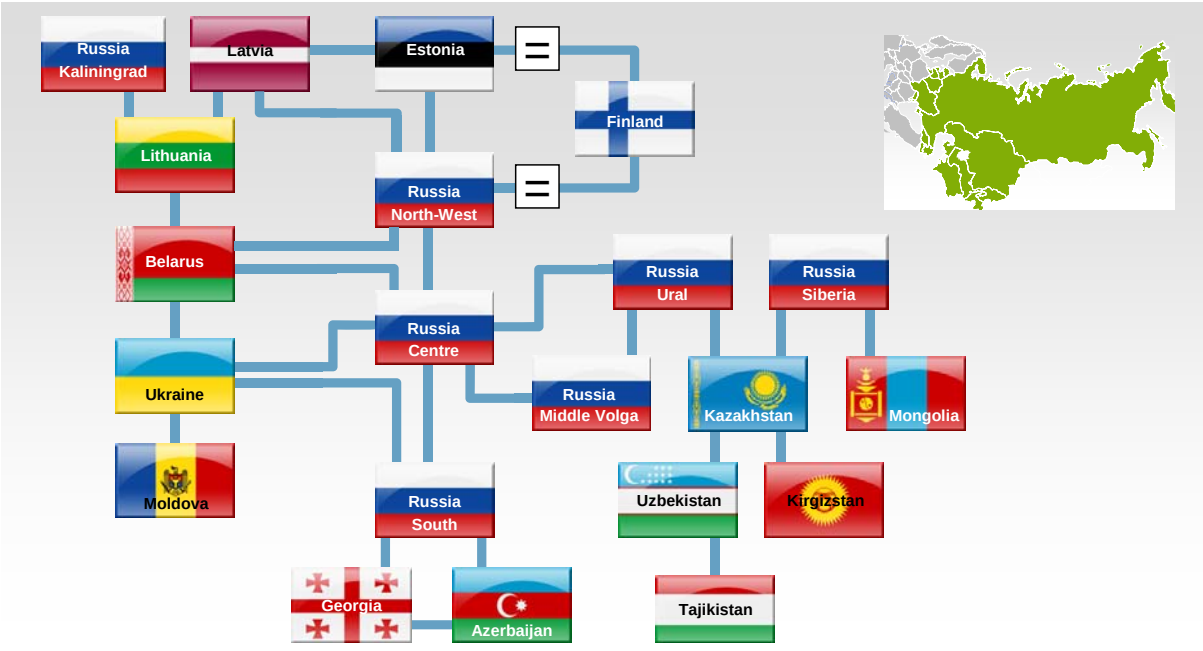


*Figure 3: Structure and member countries of the IPS/UPS*

On the IPS/UPS-side, a group of 8 companies established a joint agreement for the project: Belenergo (Belarus), Eesti Energia (Estonia), KEGOC (Kazakhstan), Latvenergo (Latvia), Lietuvos Energia AB (Lithuania), Ukrenergo (Ukraine), Moldelectrica (Moldova) and the System Operator - Central Dispatch Organisation for the Unified Energy System of Russia (RAO UES). The latter having the leading function for the Eastern European partners. An overview about the structure and the member countries of the IPS/UPS is given in Figure 3.

The 3-year investigation was inaugurated in April 2005 by the signing of a Cooperation Agreement between both parties. The project is of significant importance in furthering progress on electricity issues. The European Commission, whose policy is to promote the creation of an open electricity market in Europe, is displaying considerable interest in the results of the study. The work of the UCTE consortium is co-financed by the Trans European Network (DG-TREN) programme run by the European Commission.

The Terms of Reference (ToR) included a detailed description of the scope of work and the study procedure was prepared before the actual start of the project. The project work was generally divided into three phases:

1. Data acquisition and system modelling;
2. Verification and simulation;
3. Assessment and results.

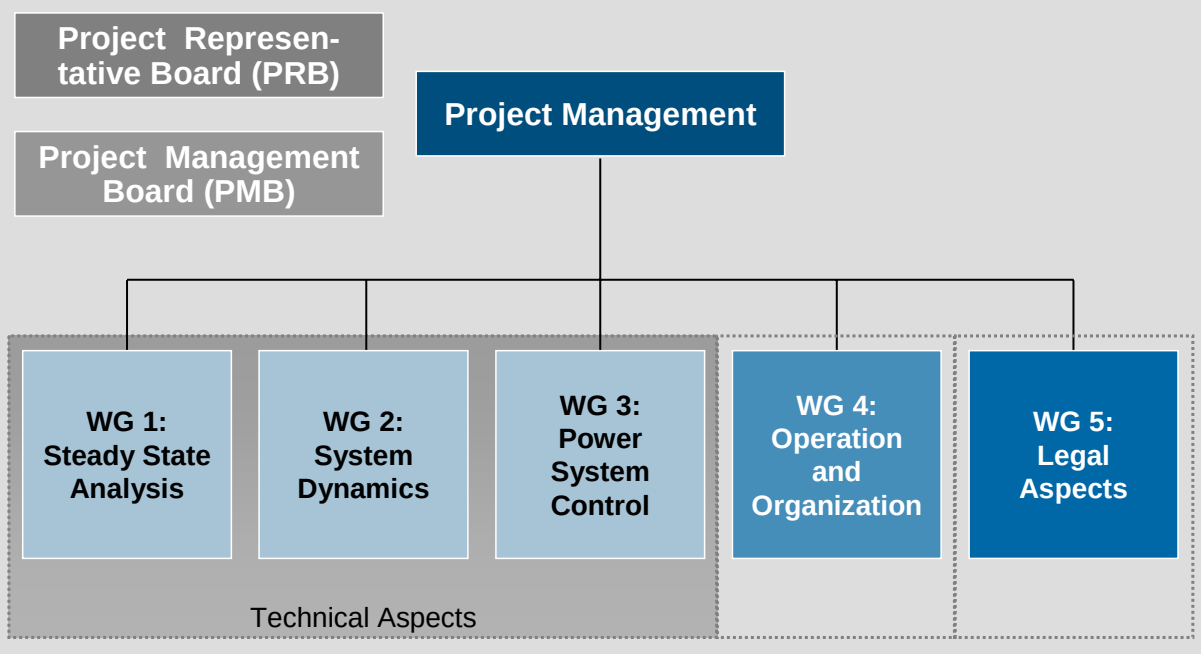


*Figure 4: Organisational structure of the Feasibility Study*

The organisational structure of the project is shown in Figure 4. The study was performed at a working level by a group of experts from the UCTE and the IPS/UPS. Five working groups dealt with the sub-tasks of steady state analyses, system dynamics, power system control, operation and organisation, as well as the legal aspects. All internal and external UCTE activities were coordinated by the project management.

Further project entities were:

- A Project Representative Board (PRB) was responsible for the political communication and lobbying, and consisted of representatives from the European Parliament, European Commission, UCTE, EPC CIS, the Baltics, TSOs and IPS/UPS companies;
- A Project Management Board (PMB) was responsible for the steering of the project and deciding on major steps during the study. It also approved the progress and reports of the working groups. This joint board consisted of representatives from the UCTE and the IPS/UPS.

## Allocation of Information, Data and Modelling

In order to deliver qualified results from the analysis work, the data allocation and modelling were the key prerequisites for the power system simulations within the study. In this respect, the obligations of both sides for the provision of data and models were stipulated in the Cooperation Agreement signed by the UCTE and the IPS/UPS: It was a common understanding that the quality of the simulation results truly depended on the quality of the input data. Therefore, providing the necessary data and information was a *sine qua non* condition for the successful completion of this comprehensive study.

The initial activities that followed the beginning of the project in April 2005, involved analysing the then current technical, organisational and legal status of the IPS/UPS. The *Questionnaire on Data Acquisition for IPS/UPS* was agreed among the parties in June 2005. The questionnaire was based on earlier data allocation procedures that had been used in similar UCTE investigations. It consisted of a specification for the necessary input data on steady state and dynamic system simulations, as well as data for power system control, system operation and organisational aspects. A similar acquisition procedure for network data was applied within the UCTE. These procedures were so determined to ensure that the analyses were carried out under the required quality standards. The legal marginal conditions were issued in a separate legal questionnaire.

It evolved during the study procedure that the acquisition of data was the most complex matter entailed in this work. Although a certain amount of information was provided, it did not entirely meet the volume of the information required. Consequently, a compromise was arrived at, that enabled the necessary input and accuracy of data to be supplied in time for the analyses to be carried out. However, for the purpose of achieving the provisions laid down in the ToR, the UCTE and the IPS/UPS made plausible assumptions where necessary or used data gained by experience or information from relevant literature.

Based on the current separate synchronous areas, models for the power system simulations were prepared by the UCTE and the IPS/UPS, respectively. Both parties were responsible for their respective model preparation and for their individual validation procedures. These were carried out by an interactive comparison of real measurements and system simulations. After the setting up of the individual models, they were merged in order to create joint simulation models for evaluating the impact of a possible synchronous coupling. The UCTE and the IPS/UPS focussed their analyses on their individual synchronous systems in line with their knowledge and skills.

The simulation models were prepared using the best available information that could provide a detailed representation of the system structure in the interface area. In cases where data was

not available or not permitted due to (e.g. legal restrictions) equivalent models were subsequently used and validated.

## Analysis, Findings and Results

A review of existing transmission system studies [1, 2, 3, 4, 5] was performed in each of the individual working groups as an initial step prior to the technical and organisational investigations. The IPS/UPS gave a general overview of their principle structure, key figures and the global operational control behaviour. This was presented in an *IPS/UPS System Survey* which was finalised in February 2006.

In parallel to the data acquisition process, the installation of a Wide Area Measurement System (WAMS) – similar to the one operating in the UCTE – was initiated in the IPS/UPS synchronous area [6]. This transient measurement system was a prerequisite for the validation of the dynamic simulation models. One was able from early 2007, to observe the dynamic system behaviour of the whole synchronous IPS/UPS area and receive measurements, for example, following disturbances in the grid. Some 26 measurement devices had been installed in the IPS/UPS up to April 2008. Around 50 measurement devices are currently installed in the UCTE synchronously operating systems.

In order to define the necessary technical specifications, a *Technical Glossary* was prepared which was also used as a basis for common communication within the study.

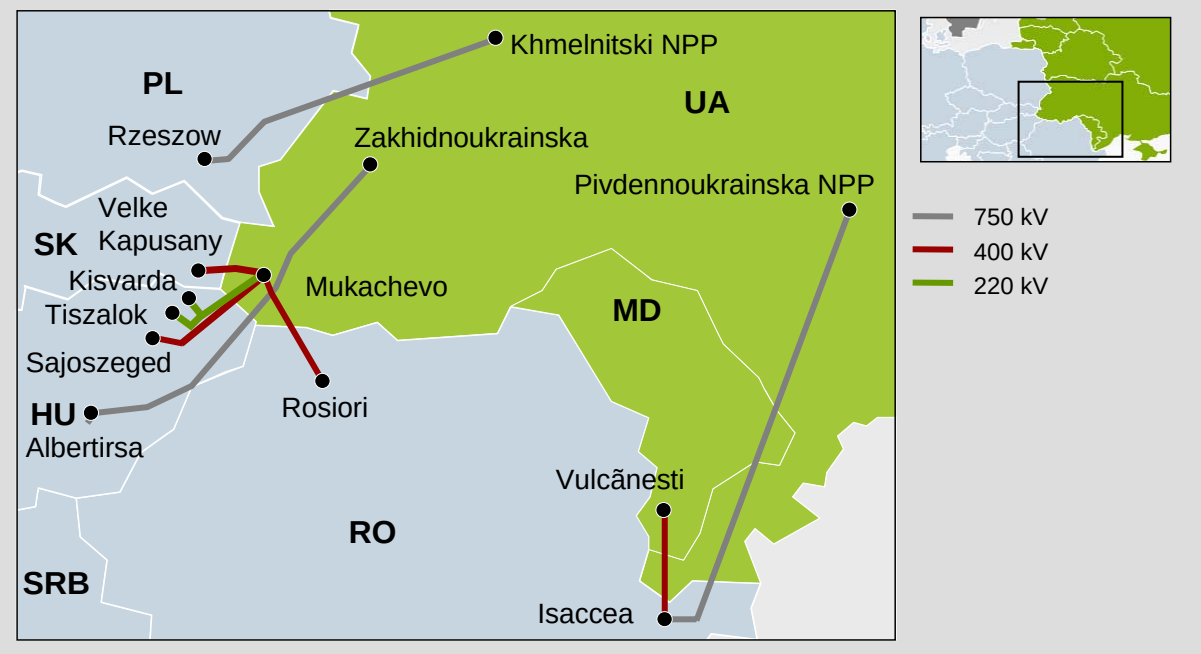


*Figure 5: Interface tie lines under consideration*

The nine tie lines (three of 750 kV, four of 400 kV and two of 220 kV) considered as being available for the coupling itself are shown in Figure 5: Eight links connect Ukraine with its Western neigbours and one 400 kV line links the transmission system of Moldova with Romania.

The transmission lines and the “MIR” power system were operated as an integral part of the IPS/UPS up to 1995, prior to Poland, Hungary, Slovakia and the Czech Republic being

synchronously interconnected to the UCTE. These lines need to be refurbished and partly reconstructed in order to have a synchronous coupling between the UCTE and the IPS/UPS.

Due to their independent development in the past, major differences in the system structure and operation philosophy exist between the UCTE and the IPS/UPS. The UCTE system is developed using the n-1 contigency as the planning criterion, whereas in the IPS/UPS, this criterion is met with the support of a set of operational actions mainly comprising of load and generation shedding.

The findings and results of this study essentially confirm the conclusions arrived at in previous projects. However, this study also enables the previous results to be updated and form a broader context covering the respective organisational and legal tasks, as well as the relevant frameworks. Consequently, an additional value of this project has been the setting-up of merged simulation models for the steady state and dynamic system simulations. The comprehensive dynamic studies conducted during the project have never previously been performed with such large simulation models. This underlines the fact that dynamic effects reveal the most limiting criteria for system extensions in preference to steady-state load flow limitations.

As to a possible synchronous coupling of the UCTE and the IPS/UPS, the findings and results as well as the impact of a synchronous coupling on the UCTE system can be summarized as follows:

**Results from Steady State Analysis**

The models for the steady state and load flow analyses reflect the planning status in 2008 for both synchronous areas. The results of the steady state load flow calculations are:

- The parties applied different methodologies and models for the load flow analyses in their particular synchronous areas depending on the variance in the planning and operational criteria. The calculations revealed that in most cases, the admissible power flows in the IPS/UPS are significantly higher than those limits identified in the UCTE.
- As the main load flow paths across the interface run through the Ukraine, the load flow distribution is very sensitive to the generation pattern in Ukraine and its direct Western neighbours.
- In most cases, the power transmission is limited due to the internal congested sections in each synchronous zone. Short distance power transfers between the systems in the interface zone reached a secure power transfer in the East West direction of about 1000 to 3000 MW. The calculated West-East transfer is limited to 1000 MW.
- The simulations clearly proved that in the synchronously coupled system structure, the capacities for long distance power transmissions are rather limited. In about 50% of the simulated long distance transmissions (e.g. Russia – Germany or Russia – Italy) the transferable capacity across the interface was less than the mandatory transfer capacity for the provision of control reserve. In order to guarantee system security in the UCTE after a synchronous coupling to the IPS/UPS, the UCTE grid must be improved or the present available capacity for the market in the UCTE needs to be reduced. A long-term analysis of market developments needs to be initially carried out in view of the requirement for a realistic allocation of the investments involved.

- The limited inter-system transfer capacities within the UCTE are caused by a high utilisation of the UCTE transmission systems. The available inter-system transfer capacities in the UCTE are also further reduced by the priority for renewable (wind) generation.

**Dynamic System Simulations**

The dynamic simulation models were individually set-up and validated for each synchronous area based on the load flow models. The UCTE dynamic model has been verified and developed over the last fifteen years and shows a good correspondence between real system measurements and simulation results [7, 8, 9]. The IPS/UPS dynamic model was initially set up for the purpose of this study. This model was verified against recordings of actual disturbances by a Wide Area Measurement System installed in the IPS/UPS during the period 2005-2007.

Both models were merged in order to study the impact of a synchronous coupling on small signal and transient stability.

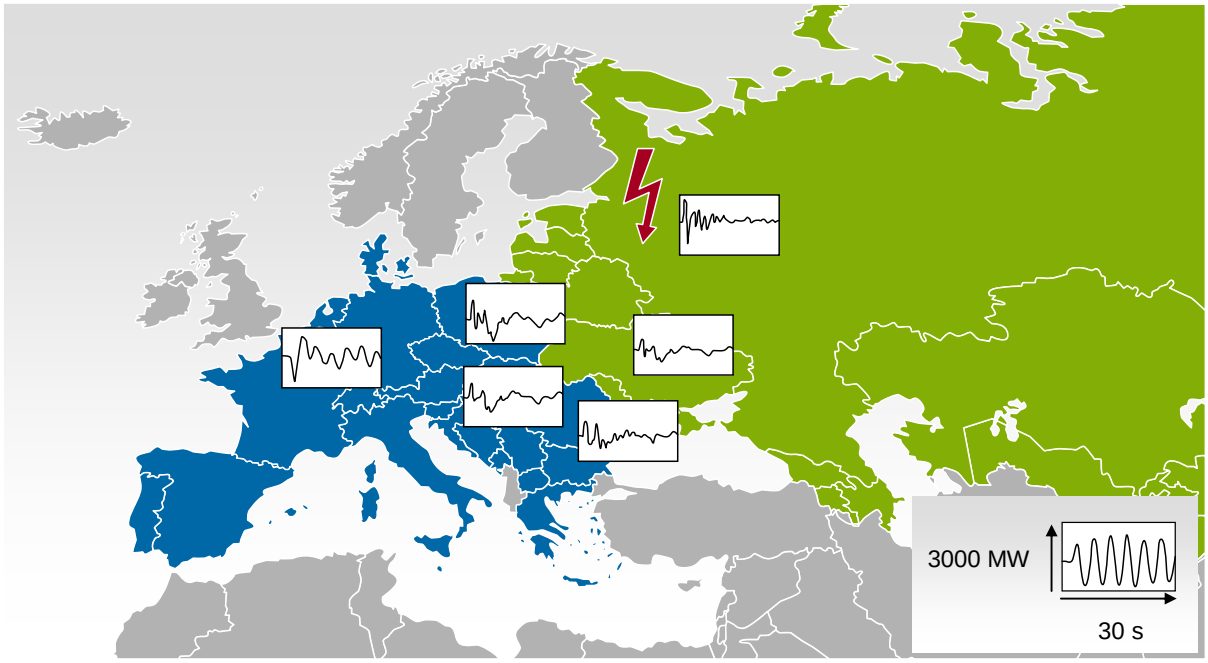


*Figure 6: Profiles of wide-area power oscillations after a severe disturbance in the IPS/UPS*

The results of the model analyses show that the synchronous coupling causes structural based oscillations. Figure 6 shows an example of the generated power oscillations in the synchronous coupled systems after a major disturbance in the North-Western part of the IPS/UPS. These oscillations create a new and poorly damped frequency mode of 0.07 Hz, and thus require special damping measures in the interconnected systems. The oscillations are of electromechanical origin, i.e. the rotors of the machines in the East part of the system oscillate against the rotors of the machines in the West. The final solution to adequate damping measures for the detected low frequency mode (e.g. voltage control or speed governor based) requires further development of the IPS/UPS dynamic model.