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Feasibility Aspects of a Synchronous Coupling of the IPS/UPS with the UCTE

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SUMMARY

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[1] (UCTE).

After UCTE completed a Pre-feasibility Study [1] analysing the steady state load-flow 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 by a UCTE consortium and a group of companies from the IPS/UPS between 2005 and 2008.

The Feasibility Study was 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?

Extensive investigations of the systems were carried out dealing with steady state analysis, system dynamics, power system control, operation and organisation as well as the analysis of legal framework.

The system simulations confirmed the necessity of the transmission network re-enforcements mainly dedicated to the IPS/UPS interface area. Further, a higher potential risk for the dynamic stability of the interconnected systems compared to the current performance of both systems had been identified.

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[1] Since 1 July the European Network of Transmission System Operators for Electricity (ENTSO-E) replaces all former TSO associations in Europe (ATSOI, BALTSO, NORDEL, ETSO, UCTE, UKTSOA), and continues and consolidates their work. The former UCTE region is now represented within ENTSO-E through its Regional Group Continental Europe.

Additionally, further efforts for the adaptation and harmonisation of existing defence and restoration plans in both synchronous areas would be necessary.

Besides these technical issues, the need for interzonal, bilateral and multilateral agreements is substantial in order to setup a legal basis for a future reliable market platform with the focus on necessary organisational and operational issues under the framework of EU-market requirements and standards.

The investigations point out that even if a synchronous coupling appears viable, it must be considered as a long-term option. The study results underline the overall complexity of a synchronous coupling first in the context of system security and reliability but also from the point of view of operability of the underlying electricity markets. Additionally, the study considers the evidence of non-synchronous system coupling possibilities by high voltage direct current (HVDC) technology, e.g. by back-to-back links. This worldwide used technique in large transmission systems may result beside its technical and economic advantages in a more cost-effective and thus “easier to realise” perspective for merging the electricity systems.

At the end of 2008 the project partners worked out a documentation of the study results. The "Summary of Investigations and Conclusions", endorsed by the study partners, is available at www.ucte-ipsups.org.

KEYWORDS

Feasibility study, European transmission system development, system coupling, synchronous interconnection, system stability

INTRODUCTION

The main objectives of the study were to investigate the technical, operational, organisational and legal feasibility for an East-West synchronous coupling 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 was a combination of analyses and power system simulations for two synchronously coupled systems without enforcing technical standards and regulations of one system on the other. The initial priority for the investigation was to maintain the current level of system security and reliability in the systems concerned. An overview about the European and the IPS/UPS transmission systems including their key figures for 2008 is given in Figure 1.

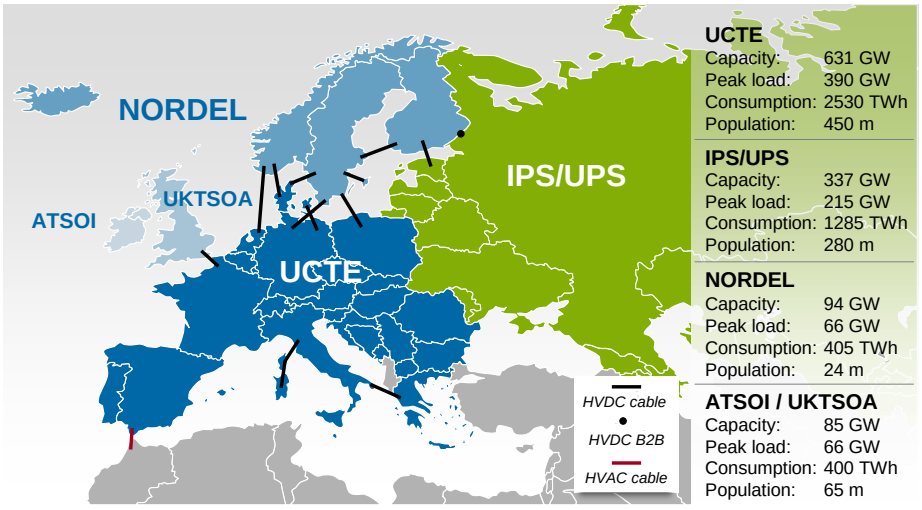

Figure 1: Synchronous systems in Europe and key figures (2008)

The study was 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, 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.

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

STUDY PREREQUISITES AND INTERFACE DESIGN

The initial activities involved analysing the technical, organisational and legal status of the IPS/UPS. A review of existing transmission system studies [1, 2, 3, 4, 5] was performed as an initial step prior to the technical and organisational investigations.

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. Some 26 measurement devices were installed in the IPS/UPS up to April 2008. Around 50 measurement devices are currently installed in the UCTE synchronously operating systems.

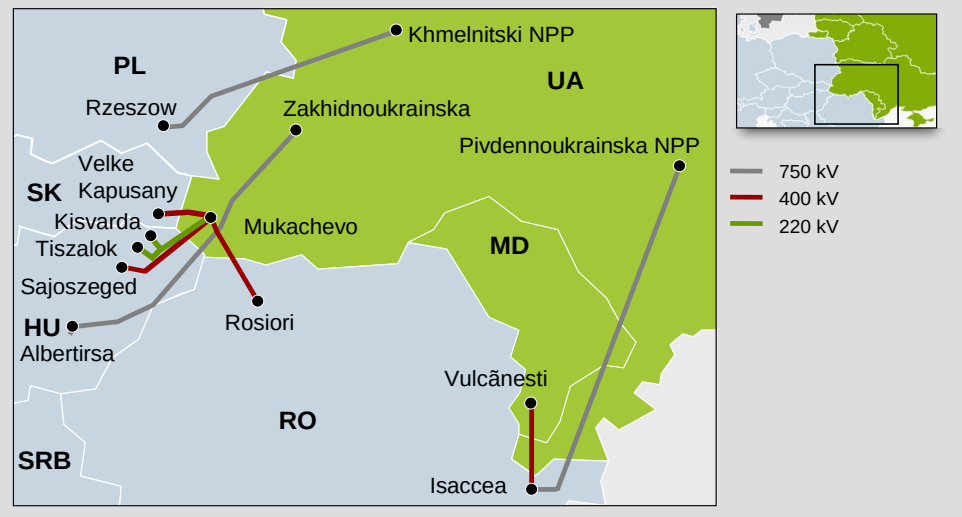

Figure 2: Interface tie lines under consideration

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 2: Eight links connect Ukraine with its Western neighbours and one 400 kV line links the transmission system of Moldova with Romania. The transmission lines and the power systems 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 make a synchronous coupling between the UCTE and the IPS/UPS possible.

STEADY STATE LOAD FLOW ANALYSIS

The models for the steady state and load flow analyses reflect the planning status in 2008 for both synchronous areas. 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. 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.

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.

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.

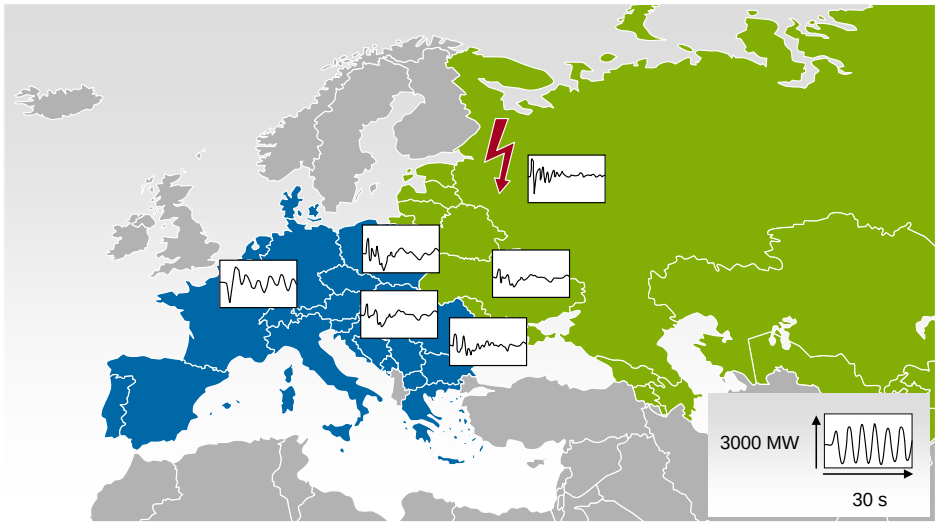

Figure 3: Profiles of wide-area power oscillations after a severe disturbance in the IPS/UPS

The results of the model analyses showed that the synchronous coupling causes structural based oscillations. Figure 3 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.

The main findings and results of the transient stability analyses are:

- 3-phase short circuits applied in the interface region, which were conceptually cleared, probably do not jeopardize the transient stability of the coupled systems.
- The analyses of more severe events revealed serious potential consequences for the synchronously coupled system of the IPS/UPS and the UCTE. These are in the first instance of a structural nature that needs both sophisticated countermeasures and further research in this respect.

Analyses were carried out following the disturbance in the UCTE on the 4th November, 2006 [10] under conditions of a synchronously coupled IPS/UPS grid. This showed that the coupling of the IPS/UPS and the UCTE might not ensure reliable support between the systems in such emergency situations. Instead, it could worsen the situation due to severe stability risks. The simulation demonstrated the technical drawbacks of very large synchronously interconnected systems when considering the survivability of the systems concerned in the event of major incidents.

Economical benefits that are mainly associated with the extension of power systems are to some extent countervailed by technical drawbacks. Priority has to be given to preventing the unabated propagation of disturbances and their consequences throughout the interconnected system.

POWER SYSTEM CONTROL ANALYSIS

The synchronous coupling of the two transmission systems leads to reduced frequency deviations after a large, sudden loss of power. This is a result of the so called “solidarity rule”, which means that power reserves are automatically activated by primary control within the whole synchronous area. The amount and distance of the related power flows increase in proportion to the capacity of the synchronous area and its geographical extension, respectively.

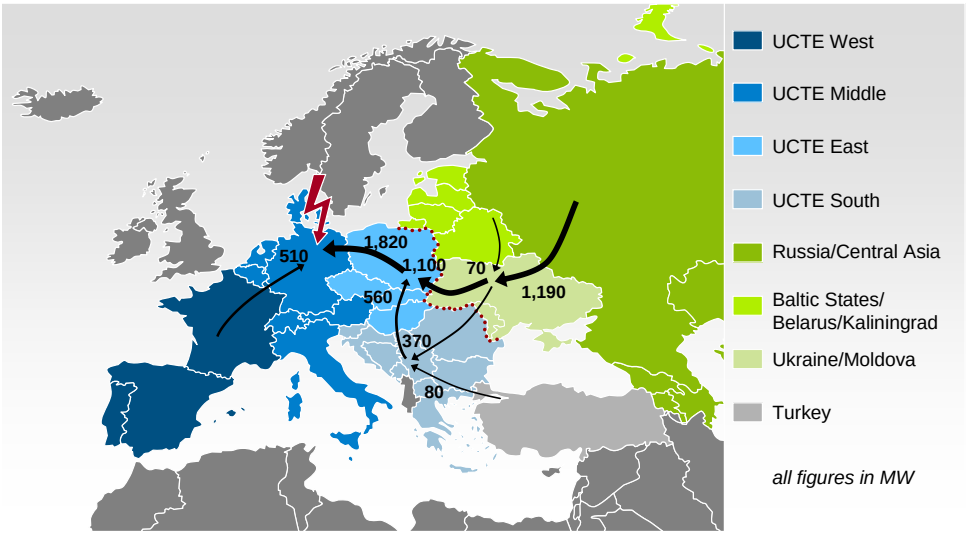

Figure 4: Control power flow after an outage of 3000 MW in UCTE

The installed power and the control reserve in both systems are in the same range. Figure 4 illustrates the distribution of the control power flow after a loss of 3000 MW generation capacity in Germany. In the case of a 3000 MW outage (the dimensioning amount of reserve power in the UCTE system), a ~1500 MW regulating power flow will cross the interface area. This flow has to be managed in a secure manner. Hence, free transfer capacity has to be maintained at any time in order to allow this regulating power to flow through the interface in both directions.

Therefore, a synchronous coupling of the UCTE and the IPS/UPS would require the consideration of an additional Control Power Flow Margin (CPFM) for determining the Available Transfer Capacities (ATC). The CPFM is not incorporated in the Transmission Reliability Margin (TRM) according to definitions applied in the UCTE at the present time. Thus, in order to respect system security, the required amount of CPFM has to be determined and the ATC has to be reduced correspondingly for the market across the IPS/UPS-UCTE interface.

OPERATION, ORGANISATION AND LEGAL ISSUES

The organisational aspects (i.e. operational procedures at the technical interface, the coordination of strategies and methods among the interface TSOs, etc.) were considered in the study as a bridge between the technical measures and their implementation, as well as for the necessary legal framework.

The investigations have considered the system control structure in the IPS/UPS: The overall frequency control function being carried out by the Russian system operator, while other systems are operated by means of agreed power balances with or without the correction of frequency deviations. The key proposal from the organisational and operational viewpoint was to apply the UCTE control block structure to the IPS/UPS, where the IPS/UPS is wholly acting as one single control block. Therefore, legally binding commitments need to be prepared and agreed upon with all operators involved that can provide adequate solutions to these issues. These include such issues as inter-area cooperation agreements with the TSOs, legal rules covering system reserves, as well as specific contracts with generators in regard to power system stability, etcetera.

The proposed contractual framework is “multi layered” as it offers several contractual “layers”, namely:

- An “Interzonal Agreement” (IZA) aimed at addressing the needs on a global level for the whole synchronous interconnection; and
- A series of “Bi- and/or Multilateral Agreement” (BLA/MLA) designed to address the legal needs of the interface (e.g. at a local level).

ALLOCATION OF INVESTMENTS

As an initial step, the necessary investments for refurbishing the existing equipment and interface lines have been identified. It has to be borne in mind that even if the lines and substations already exist, they have not been in operation for several years since the disconnection of the former CENTREL countries, as well as those in Romania and Bulgaria. The necessary refurbishments of the interface lines are estimated at a total sum of € 280m, of which € 180m is dedicated to the refurbishments in the IPS/UPS interface countries. In order to improve the congested areas in the UCTE, results from a probabilistic analysis have estimated that the necessary investments in the UCTE amount to € 240m. Additionally, the synchronous coupling requires an exchange of operational data between both synchronous blocks. Therefore, additional communication equipment has to be installed and the protection schemes have to be partially updated. These measures have been estimated to come to some € 14m.

Although no specific system simulations were carried out by means of DC coupling of the IPS/UPS with the UCTE, the investments for DC coupling have been roughly estimated for comparison reasons. The specific investment costs estimated for a back-to-back link are in the range of € 12.5m per 100 MW. Typical unit sizes for conventional HVDC back-to-back links vary between 600 and 1000 MW. Assuming that three back-to-back stations of 600 MW each would be placed at the interface the investment for these stations – not considering costs for network improvements – would amount to € 225m.

RECOMMENDATIONS ON FURTHER STUDIES

The study reveals the need for further investigations into the IPS/UPS in order to refine and endorse the recognized measures and requirements. Major areas identified for further studies are:

- The verification of the IPS/UPS dynamic performance by means of observations being carried out over a longer period.
- The analyses of emergency situations in the IPS/UPS caused by severe disturbances that have not been experienced by the system up to now. It is recommended that a simulation model is prepared which sequentially simulates the control automatics and functions after severe disturbances, as well as any necessary restoration measures.
- The analyses of technical and organisational aspects within the IPS/UPS based on the assumption that several control blocks may eventually operate in the IPS/UPS, compared with the single control block status at the present time.

FEASIBILITY ASSESSMENT AND CONCLUSIONS

The findings and results of this study essentially confirm the conclusions arrived at in previous projects. However, the 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.

The transfer capacities across the interface in the steady state analyses indicated that the potential power exchanges between the UCTE and the IPS/UPS are limited. This is mainly due to the internal congestions in the systems concerned. Therefore, a synchronous coupling would require investments in the transmission grids on both sides of the interface in order to maintain the transfer capacities available to the present markets in the two synchronous areas. Additional transmission system investment will be necessary to ensure any significant increases in power exchanges.

The performed dynamic stability analyses underlined the sensitivity to inter-area power oscillations within the synchronously coupled system structure. While ordinary operational disturbances can be withstood by both the coupled and uncoupled systems, severe disturbances lead to wide-area oscillations in the coupled systems. This could lead to the reduction in system security. The necessary countermeasures require investments both in the generation and transmission sectors.

Although the conclusions indicate that a synchronous coupling appears technically viable, it must be considered as a long-term option, to be achieved by implementing a number of technical, operational and organisational measures, as well as by establishing the legal framework that was identified during the investigation. As the implementation phase for carrying out the identified measures and conditions is recognized as a long process, a synchronous coupling should be considered as a long term perspective. In order to achieve a joint, world-largest electricity market platform between the UCTE and the IPS/UPS synchronous areas, the construction of asynchronous links may also be considered for system coupling. This certainly deserves further consideration and investigation by the stakeholders concerned.

ACKNOWLEDGEMENTS

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