Development of UCTE and Reconnection of 1st and 2nd Pan-European Synchronous Zones

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Abstract: - Size and features of European electric power systems, like any other in the world, is subject to changes. The reason is of technical nature – increased work safety, as well as economic – the possibility of electricity trading i.e. increased production optimization. The consumption of electricity is increased every year by 1% to, in some cases, even 4%, which additionally makes the issue of meeting electricity needs more complex. The processes of expanding and connecting electric power systems are very complex and depend on the political, technical and economic environment. Until 1991 UCPTE (from the year 2000 UCTE) had operated in a synchronous manner in accordance with the political environment of that period. Consequently to changes caused by democratic process of the former USSR break-up and the war in the region of former Yugoslavia, two UCTE synchronous zones were created. In the early 2000 preconditions for connecting the aforementioned areas in one common electric power system were created. The UCTE Steering Committee decided in its Brussels meeting in early 2002 to set up an Executive Team with the main goal of organizing and implementing the above mentioned project. The following, as main leaders, were assigned: the Croatian representative, today HEP-TSO and the representative from the Czech Republic, ČEPS-TSO. The reconnection was carried out on October 10, 2004 along with a huge number of preparatory and expert as well as scientific papers and challenges in the total period of five years. The reconnection results are extremely positive and affirmative.

Key words: - Executive team for reconnection, Reconnection, Synchronous zone, UCTE

1 Introduction
The Union for the Coordination of Production and Transmission of Electricity (UCPTE) – the association for operating the European transmission system is an organization which was founded after the WW2 by Austria, Belgium, France, Germany, Italy, Luxembourg, Netherlands and Switzerland. The main goal for creating the common system was to increase security; i.e. in case of a disturbance the systems will provide mutual support in order to prevent damage which could lead to a system breakdown. It is a known fact that a break-up in electricity supply causes enormous economically negative consequences. According to some analyses, the price or damage caused by one non-delivered kWh reaches up to 50 times higher values. Expanding or increasing tendencies follow the establishment of such a system. UCPTE was joined by former YU in 1974. This work manner continued until the war in former Yugoslavia, when the outage of the 400 kV overhead line Ernestinovo – Mladost on September 26, 1991 caused the system to separate following the line through Bosnia and Herzegovina therefore creating a second synchronous system to which Romania and Bulgaria were also connected.

The main reason for the UCPTE separation was the destruction of the TS Ernestinovo, the key 400/110 kV substation with accompanying lines, during the war aggression against the Republic of Croatia. The accompanying lines were: 400 kV TS Ernestinovo – TS Tumbri, TS Ernestinovo – TS Mladost and TS Ernestinovo – TS Ugljevik overhead lines. In 1992 during the war aggression against Bosnia and Herzegovina, 400/110 kV Mostar substation with accompanying lines was destroyed. In 2001 the Lisbon Memorandum of Understanding (MoU) was signed in Portugal [1] between the Union for the Coordination of Transmission of Electricity (UCTE), the national power company of Croatia "Hrvatska elektroprivreda" (HEP), the Joint Power Co-ordination Center (ZEKČ) – BIH and Electric Power Industry of Serbia (EPS) – SRJ for the purpose of conducting necessary reconnection activities. Financing for the construction of necessary infrastructure was provided during 2002. HEP secured a loan from Croatian Bank for Reconstruction and Development for financing the construction of key transmission facilities:
Ernestinovo and Žerjavinec substations with their accompanying lines. ZEKC with its electric power companies- founders (Bosnia and Herzegovina) and the Power III Program financing (World Bank, EBRD, EIB) completed the rehabilitation of Mostar substation and key transmission facilities in August 2004.

The UCTE Executive Team as the Project Manager of the UCTE reconnection was in charge of all activities (the coordination of all required reconnection activities).

The main goal was to prepare the signing and implementation of resynchronization procedures as well as to draft all necessary documentation through the final Multilateral Re-synchronization Program and to conduct the reconnection. After having agreed on all issues in a meeting held in Sarajevo in late August 2004, the UCTE Steering Committee approved the project realization from the National Dispatch Center on December 10, 2004.

2 Review of the UCTE development and the situation prior to reconnection

Electrification of the continental (pan-european) Europe started from smaller areas [2] which were steadily expanding paralelly with simultaneous rise and voltage levels. The long history of their interconnection started in 1920s (for exploiting the Alps hydroenergy). It was intensified in 1949, the process which has been undergoing until today. Mesh national networks have grown into cross-border ones in order to increase system security and achieve commercial exchange between (integrated) power utilities. This long process has been monitored by UCPTE from 1951 when it was founded by power utilities representatives from the before-mentioned eight countries. It has also been carried out in accordance with strict technical rules which have gradually been compiled not only for the operation of synchronously interconnected systems but also for the nearly standardized interconnection development process.

In the years to come the UCPTE membership was expanded by representatives from 4 more countries (ex Yugoslavia, Greece, Portugal and Spain) following the years of parallel operation between their systems and UCPTE, while the western part of the Danish system remained only the associate member and the Albanian in parallel operations. During the previous decade UCPTE on several occasions experienced even deeper changes.

During the 1991 aggression against Croatia (and against Bosnia and Herzegovina in 1992), destruction of key substations Ernestinovo (followed by Mostar 4) and parts of 400 kV overhead lines led to the separation of the UCPTE synchronous area into two parts, so-called zones. Soon after, during 1993, the parallel operation of the islandic system of Serbia, Montenegro, Macedonia, Greece and a part of BIH (called 2nd synchronous zone) was joined first by the Romanian and consequently by the Bulgarian systems. This operation was initially called the trial one only to become permanent after having obtained the UCPTE preliminary licence in 1995. However, regular testings and trial operation didn't commence until 1997 after setting up the competent UCTE Technical Committee/Bulgaria – Romania and defining an appropriate group of concrete preconditions for accession into the full membership. This procedure is being successfully completed this year only with 2nd synchronous zone although it was originally planned to conduct testings including the entire UCTE synchronous system. Founding of CENTREL in 1992 by power utilities of the Czech Republic, Hungary, Poland and Slovakia, the significant part of former CDO (Central Dispatch Organization) started with intensive technical, organizational and financial preparations in order to fulfill conditions for the synchronous connection with UCPTE, which followed in late 1995 (which caused the expansion of the UCTE synchronous area in the biggest extent so far) so that CENTREL members joined the UCPTE associate membership.

Since the remotest western part of the Ukrainian network around Burštin region is significantly linked with these systems, the procedure for its synchronous connection with UCPTE was set in motion (and formally successfully completed in 2003 following the period of testings and trial operations as well as an affirmative report by the appropriate UCTE-CENTREL/Ukraine Technical Committee).

Radical changes of the European electric power system provoked by the EU Directive 96/92/EC on the common rules for the internal market in electricity [3] have left their mark within UCPTE as well. Amendments to the Articles of Association of 1997 and 1999 introduced, among others, changes in membership (legal instead of physical entities), working language (English instead of French and German) and operational focus (focus on transmission network). The letter 'P' was removed from the name (along with all the activities connected with the generation, which were transferred to EURELECTRIC, a UNIPEDE's successor).

In order to achieve a better adjustment to the changed environment, but also retain the continuity of existing successful performance, the 'old' UCTE was dissolved in May 2001 on its 50th anniversary and the 'new' UCTE was set up by 33 founders from 20 European countries (Fig.1).
Brussels was elected the head office and the new Articles of Association were adopted. This is a process of creating one of the biggest synchronous systems in the world, which safely and reliably supplies 400 million people with about 2200 TWh per year (13.2% of which are cross-border energy flows i.e. 11.5% taking only those within UCTE under consideration), peak load of 344 GW and 200,000 km of lines with more than 510 GW installed capacity in power plants (Fig. 2).

Fig. 1 Development of UCTE and other electric power systems

3 Course of preparations, organization and reconnection preconditions

After signing the Memorandum of Understanding in Lisbon, the activities relating to the reconnection project commenced. After long discussions and meetings, the UCTE Steering Committee founded the Executive Team in Zagreb in 2002. with its fundamental goal to prepare and carry out the project of connecting or electrical linking of then existing two European synchronous zones. Project leaders were representatives of the Croatian and Czechian TSOs. The study made by UCTE under the direction of German power utility (so-called DVG study) [4] represented a good preparatory ground. The main downside of the study was the absence of Ernestinovo substation due to a belief that Croatia would not be able to prepare its network infrastructure for some time in future. Therefore, the plan, according to that study, was the reconnection but not including the Ernestinovo substation and by-passing Croatia. After several meetings and uncertain situations Croatia earned the trust of the UCTE Steering Committee and it was given short deadlines to rehabilitate its system, which meant: the construction of two new 400 kV substations, reconstruction of all accompanying overhead lines as well as the construction of the new ones within the Croatian network topology. The deadline was June 2004.
Terms for the construction and the preparation of the Croatian network were heavily controlled and continuously reported to the UCTE Steering Committee. The project success also depended on the development of infrastructural reconstruction in BIH. Through the Power III Program employees of Bosnian power utility managed to reconstruct 400/110 kV Mostar substation on time as well as accompanying overhead lines 400 kV line Mostar – Sarajevo was a particular problem, but thanks to everybody's dedication what seemed almost impossible was achieved, which represented a significant contribution of BIH experts to this project.

The main reconnection precondition was zero exchange of energy on the D day. Organization and regulation hierarchy was set in a manner not to disturb the project implementation.

4 Static and dynamic analysis

4.1 Static analysis

Transit analysis and the analysis of capacity flows, short circuits and N-1 [5] was conducted within the DVG study but, as before mentioned, the project was carried out without the Ernestinovo substation so that results were only partially applicable. Therefore, analyses with domestic experts who succeeded in analytical presentation of key analysis that showed the possibility of reconnection with the present risk were carried out. Programs that were used were DAM from the Faculty of Electrical Engineering and Computing and PTI/PSS. Several models were developed depending on the expected network configuration, hydrological conditions and expected project realization date.

It was extremely difficult to decide which model is acceptable, the risk was huge. Empirical data and opinions by most experts were to start with the implementation on a significant condition to stop trading on that day i.e. to stop electricity exchange between TSOs [6] in the reconnection.

4.2 Dynamic analysis

Dynamic behaviour; angle analysis, voltage stabilities, frequency oscillations, changes of capacity flows in a short time period were analytically observed using several software programs during the preparation itself, but mostly during the DVG study.

During the reconnection the dynamic behaviour was observed by monitoring the response of the above stated parameters using the installed state-of-the-art WAMS (wide area monitoring system) equipment in several junction points in Switzerland, Croatia and Greece. ETRANS, the Swiss operator, helped significantly. Interarea electromechanical and frequency oscillations were observed. However, the system was maintained in a matter of few minutes and by further connection on lower 220 kV and 110 kV voltage levels reached the stability zone.

5 Harmonization of phase sequences

During the preparation for the historical reconnection event of 1st and 2nd UCTE synchronous zones (October 10, 2004), on September 25 2004 HEP performed final activities of technically and organizationally extremely complex project of harmonizing phase sequences on the Croatian and UCTE electric power system interface. HEP carried out detailed and comprehensive preparations and undertook all measures for the successful implementation of such a complex and risky project.

Specifically, it was about interfacing systems which encompass all connecting lines between the Croatian, Slovenian and Hungarian electric power systems. To put it more simply, as it is clearly shown in Fig. 3, to harmonize phase sequences on this interface meant to conduct an appropriate physical switch of phase conductors ('transposition') on most favourable points of each connecting line between the Croatian, Slovenian and Hungarian electric power systems. This problem has existed since 1943. For this reason the electric power systems of Croatia and BIH were at one point on that very day in island operation.

LEGEND: EES – electric power system; BIH – Bosnia and Herzegovina; H – Hungary; HR – Croatia; SLO – Slovenia

Fig. 3 The interface between the Croatian and UCTE (Slovenian and Hungarian) electric power systems before (left) and after (right) harmonizing phase sequences
6 Implementation of reconnection

On the very day of the reconnection, October 10 2004, the key steps were the following:

- Preparation: all interconnecting overhead lines ready for operational use and idle [7].
- The command to Bucurest to take over the frequency regulation in 2nd synchronous zone (Romania regulates the frequency, Greece, Bulgaria and EKC only the exchange).
- The command to Budapest to discontinue the pluralistic CENTREX regulation and to assume the regulation by itself.
- 9:34 after fulfilling conditions \( \Delta U < 20 \text{kV} \); \( \alpha < 10^\circ \); 
  \( 0.03 \text{ Hz} < \fr1 - \fr2 < 0.05 \text{ Hz} \) in Arad substation, Sandorfalva overhead line was connected (RESYNCHRONIZATION was carried out).
- 9:41 Subotica overhead line connected to Sandorfalva substation.
- Command to all synchronous zone block 2 controllers to restore the LFC regulation mode.
- 9:58 Podgorica overhead line connected to Trebinje substation;
  - Prior to the resynchronization, this overhead line had the biggest voltage difference (over 60 kV) which activated all compensation equipment in Croatia, the operating compensation generator in BIH was CHE Čapljina, and in Montenegro the aluminium factory was put out of operation for a few minutes in order to raise voltage.
- 10:07 Rosiori overhead line connected to Mukačev substation.
- 10:20 Mladost overhead line connected to Ernestinovo substation.
- 10:58 220 kV Trebinje – Peručica, 220 kV Višegrad – Požega and 110 kV Trebinje – Herceg Novi overhead lines connected.
- 11:00 – Main coordinators announced the successful completion of the reconnection.

The sequence of connecting interconnection lines is shown in Fig. 4.

As no problems in system operation were observed by TSOs involved in the process during the test run commencing on October 31 2004, the test run, which was not approved for commercial contracts between former 1st and 2nd UCTE synchronous zone, was rated successful.

For the period between November 1 2004 and the end of 2004, UCTE issued the recommendation regarding the gradual increase of trade volume directed from the former 2nd UCTE zone towards the former 1st UCTE zone (monthly increase by 30% to complete NTC values).

7 Post-reconnection technical and economic analysis

The electric power system of each area is a very complex dynamic system in technical terms which can be faced with one of the following states: stationary (normal) operating state, transient operating state, emergency operating state or outage.

Apart from maintaining the conditions for the safe operation of an electric power system, the operational cost-effectiveness (total costs) which optimally must be lowest possible is taken into consideration.

The operation of interconnected electric power systems enhances, in general terms, technical possibilities required for safe system operation by using increased flexibility of the regulation connected system by interlinked (interconnected) lines.

In more accurate terms, the parallel connection of two or more electric power systems achieves a bigger stability and operational availability of connected systems. For executing such a task previous theoretical and experimental research is required, which is to show the manner in which each system individually and jointly as a whole will dynamically behave during parallel connection [8]. The first UCTE synchronous zone was conducted from the two main control centres: Brauwieler (Germany) and Laufenburg (Switzerland). The Croatian electric power system was coordinated from the Laufenburg coordination center. The second synchronous
zone was, apart from connected countries, joined by Romania and Bulgaria. The process of UCTE reconnection was graded a high-risk because it was the first time the two big synchronous systems were connected, lacking similar prior experience and threatened by both systems' complete breakdown. The Executive Team, founded by the UCTE Steering Committee's decision, was given a task to prepare and carry out the reconnection of the UCTE synchronous zones. Following 2-year-long preparations the reconnection was successfully led and conducted from the National Dispatch Center in Zagreb on October 10, 2004 with the participation of all key transmission system operators. From the technical and economic point of view, the huge contribution of the reconnection to increased security of the UCTE system, increased electricity trading volume, electricity market opening and stimulating further development of internal EU electricity market was observed. TSOs are service providers for all market participants and as such significantly contribute to the development of electricity market preserving safety restrictions.

Since the reconnection enlarged the entire UCTE system, inter area oscillation in the connected UCTE system was expected and supported by measurement results. The reconnection has also created preconditions for enabling the remote-distance electricity trade via the integrated ITC (inter TSO compensation) mechanism. The rise in the total electricity trading volume also resulted in a gradual increase of trading schedules by TSOs in order to secure a continual safe system operation.

Positive technical effects for the Croatian electric power system are in broad terms the following: increased reliability of electricity supply to customers (more supply routes, availability of the entire 400 kV network ...), increased system security and disturbance resistance, increased electricity transmission, decreased share of technical losses in electricity transmission and improved voltage conditions. Positive economic effects of the Croatian electric power system can also be identified: increased revenues and savings for several reasons (e.g. due to decreased technical losses achieved savings of about 1/5 of investment in a reconstructed 400/110 kV Ernestinovo substation), doubled total cross-border electricity trading volume in Croatia (import, export, transit). The need (and costs) for the reactive power compensation in the Croatian transmission network for the purpose of improving total voltage conditions was reduced after the reconnection, the need for additional generation of reactive power was decreased as well as the need to invest into compensation equipment. Insulation stress in HV facilities was decreased due to an improvement of voltage conditions with a positive long-term effect regarding the expected equipment life time which lessened the congestion possibilities on cross-border lines by redistributing incoming electricity flows into the Croatian electric power system onto reconnection connected lines. Total net transmission capacity (NTC) on the interface has been increased by approximately 500 MW, which enabled the electricity trading intensification. Circular flows from Hungary towards Slovenia have remained almost unchanged. New circular flows between Serbia, Croatia and BIH have appeared. However, previously mentioned technical positive effects for the Croatian electric power system can be expanded in broad terms onto the connected UCTE system.

8 Conclusion

Summarizing, it could be said that the frequency stability (reduced number and quantity of frequency deviation) was increased in the connected UCTE system, the compulsory primary reserve in accordance with the UCTE rules was decreased, the required value of the regulation constant Kr was reduced, emergency support by neighbouring TSOs in case of an outage was increased. Positive effects of the UCTE system in economic terms could be summarized into increased capability of operational optimization with reduced total costs, increased total electricity trading volume (access to cheap surplus in the former 2nd UCTE zone) and the contribution to the development of the regional electricity market and EU IEM (Internal Electricity Market).

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