UCTE

LOAD-FLOW ANALYSIS WITH RESPECT TO A POSSIBLE SYNCHRONOUS INTERCONNECTION OF NETWORKS OF UCTE AND IPS/UPS

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Content

1 Background and Objectives of the Study

2 Network Model and Methodology

3 Load-flow Calculation

4 Evaluation of Primary Control

5 Conclusion

1. Background and Objectives of the Study

The Electric Power Council of the Commonwealth of Independent States (EPC-CIS of Russia) has started an initiative within the framework of the Energy Dialogue between EU and Russia concerning a possible future synchronous interconnection of UCTE and IPS/UPS electrical power systems.

As a first step the UCTE Steering Committee took the decision to carry out a Pre-Feasibility Study in order to investigate the possible power exchanges between IPS/UPS and UCTE, which could be realized by the UCTE system from the load-flow point of view.

The main objectives of the study are to give answers to the following questions:

- What is the performance of the existing transmission network (380 kV and 220 kV) of UCTE for long distance transmission of electrical energy taking account of existing bottlenecks, i.e. the level of acceptable inflow?
- What are roughly the effects on the UCTE system in case of an interconnection of both systems (e.g. effects on system security and transfer capacities given from the today's market, excluding stability aspects)?

The results shall be used as a solid basis for the definition of the further approach towards a co-operation between the two large systems. This is in order to realize the access to a common market by the systems of UCTE and IPS/UPS as well.

2. Network Model and Methodology

2.1 Network Topology

For UCTE, a complete transmission network for the year 2005 was set up. A detailed network of IPS/UPS has not been included, because the pre-feasibility study is focussed on the UCTE grid. Therefore, an equivalent of the 750 kV grid of IPS/UPS was used including the stationary primary control function of IPS/UPS, Figure 1.

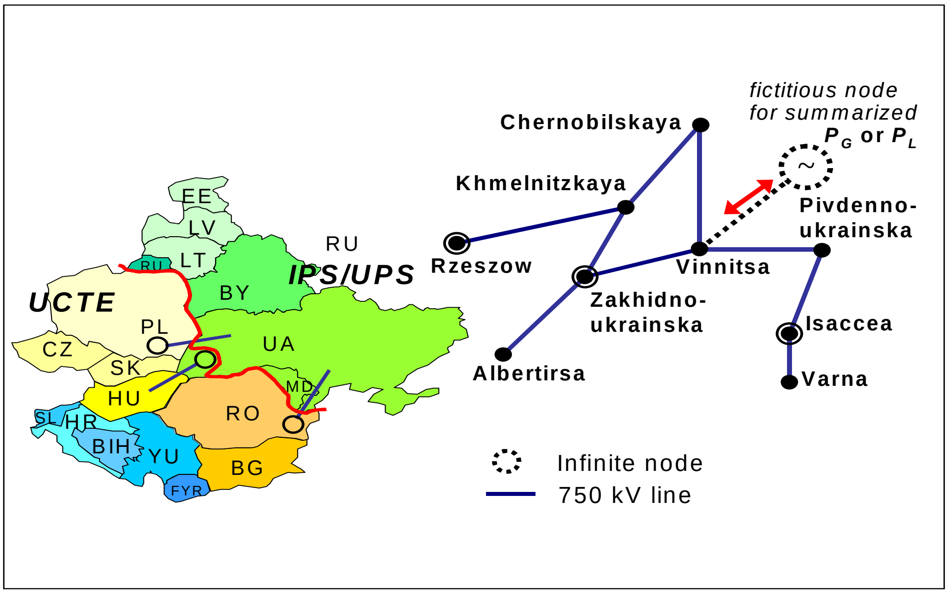

Figure 1: Simplified IPS/UPS model for checking load-flows within the UCTE system

2.2 Existing Congestion within the UCTE Power System

Transmission congestions of different importance exist in different locations of the UCTE interconnected power systems and have to be considered in the context of future load-flow scenarios. The congestions can be identified based on transmission network configuration and experience gained so far from daily operation of UCTE power systems. However, since the topic is considered here at European level one should deal only with major transmission bottlenecks of significant importance in Europe.

The most important reasons for these major transmission congestions are the following:

- natural geographical barriers making it extremely difficult to build transmission interconnections (e.g. water reservoirs),
- historical background of transmission systems´ development
- changing of the market situation (liberalization), which leads to new additional load-flows over long distances,
- feeding of wind power generation; its dramatic development makes the load-flow much more volatile than in the past,
- environmental issues preventing further expansion

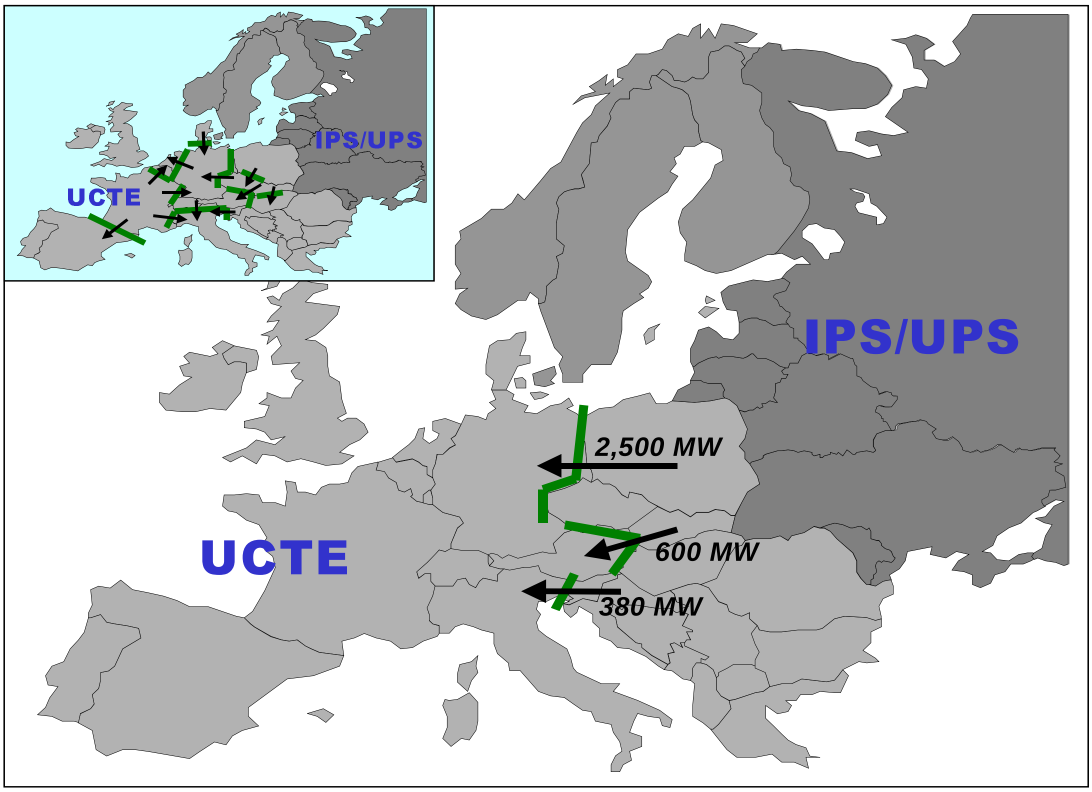

Figure 2: Presently existing bottlenecks with NTC values for East-West direction (including other major congestions within UCTE with arrows showing directions)

Figure 2 shows the existing major bottlenecks in the UCTE power systems. It has to be mentioned that the future development on this issue is very uncertain. On the one hand, the affected TSOs endeavour to remove existing bottlenecks and avoid new ones. On the other hand, the usage of the grid by the market is increasing and a dramatic development of wind power generation can be foreseen in several countries.

2.3 Scheduled Power Exchanges between Control Areas

The base case for the load-flow analysis was developed from the January 2002 UCTE snap-shot concerning the 1st synchronous zone. For the 2nd zone the programmed exchange within this zone was superimposed by an export of 500 MW from the 1st to the 2nd synchronous zone.

Further at selected profiles within UCTE, which probably have the greatest importance in the context of power transfers between IPS/UPS and UCTE, the monitored power flows of the recent history were evaluated. In this context, the border profile between Germany and the Czech Republic/Poland is a very important grid section. Figure 3 shows the regularly updated NTC values for this section, which are published by the responsible TSOs as guaranteed transmission capacities provided to the market. The monitored power flows show their almost full usage by the market participants. It is obvious that on these borders there are no more transmission capacities, what has to be considered as a representative network condition.

By taking these observations into account, the assumed pattern of generation and system load - including the scheduled power exchanges among the control areas - represents the typical usage of the transmission capacities of UCTE. It is a realistic starting point for investigation of further potential of the UCTE network.

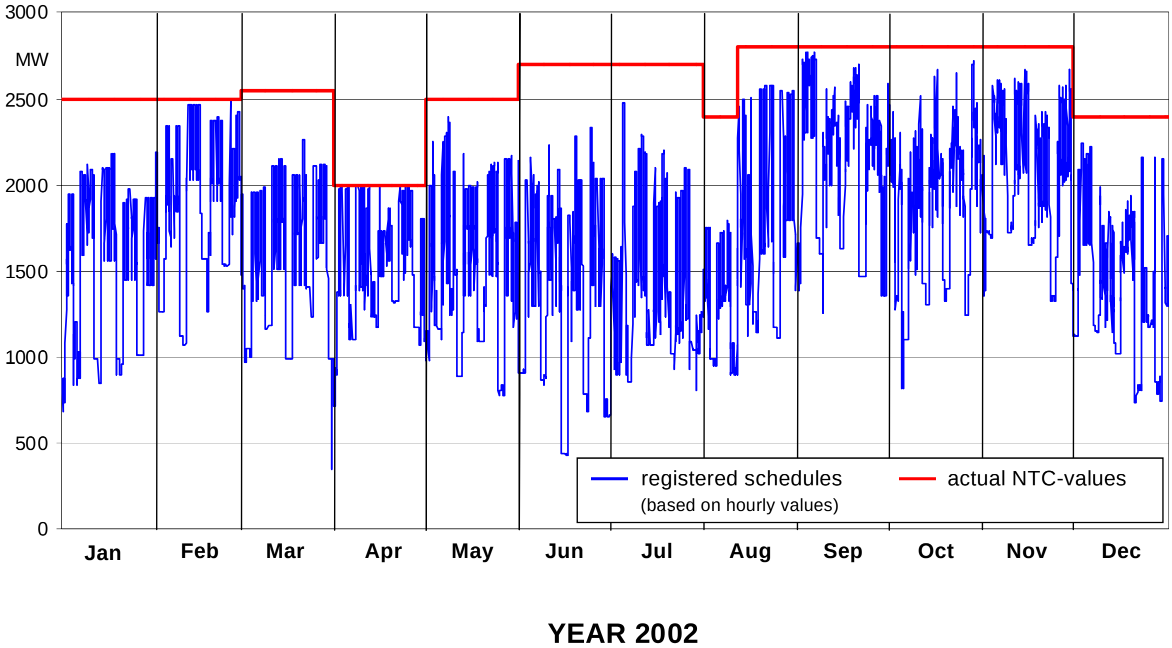

Figure 3: Official NTC values for the border *CZ+PL to G* and the recorded power exchange

2.4 Scenarios for Analysis of Transmission Capacities

The following scenarios have been investigated:

A Imports from IPS/UPS to UCTE
- A.1) Reduction of generation in all countries *(Case 2)*
- A.2) Reduction of generation in importing countries *(Case 3)*
- A.3) Reduction of generation in exporting countries (Case 4)

B Exports from UCTE to IPS/UPS
- B.1) Increase of generation in all UCTE counties *(Case 5)*
- B.2) Increase of generation in UCTE exporting countries *(Case 6)*

C Imports from IPS/UPS to the present 2nd synchronous zone
- C.1) Shutdown of two units in Kozloduy NPP *(Case 7)*
- C.2) Reduction of generation in all countries in the 2nd zone *(Case 8)*

D Generation outage in UCTE *(Case 1)*

In all cases, the generation of the relevant UCTE areas was decreased (import to UCTE) or increased (export to IPS/UPS). The generation was changed in proportion to the respective generation of each area. Based on these scenarios, the following aspects were analysed:

- additional loading of existing bottlenecks and identification of new ones resulting from the load-flow distribution taking account of (n-1) criterion.

  In this framework, and with regard to the limited study time, this aspect cannot be investigated completely with the necessary high number of variants, e.g. regarding the possible unit commitment and the network topology (maintenance). Therefore, the analysis was started with the above mentioned main variants enabling the development of existing and new bottlenecks in the UCTE to be estimated.

- identification of the “main corridors” of power flows caused by power exchanges between UCTE and IPS/UPS by the “distribution factor method”.

  In order to get a global survey of the usage of the UCTE grid in case of power exchanges between IPS/UPS and UCTE, the “main roads” of the power transfers have to be identified. For this purpose, the partial contribution of the transmission lines to the total power exchange was calculated by determining their distribution factors. This approach is very effective for identifying the “transfer corridors” in a meshed grid, (like the UCTE, power system), which may represent wide-area limiting factors for transfers, that cannot be overcome easily.

- Effect of primary control activated by IPS/UPS on the load-flow.

  The usage of the UCTE transmission system by the primary control power, activated by IPS/UPS in case of generation outages, has to be determined in order to estimate to what extent the TRM (Transmission Reliability Margin) values of the cross border transmission capacities have to be adapted to the new situation. This could possibly result in a reduction of certain NTC values (***N****et* ***T****ransfer* ***C****apacity*), which can be provided for the market.

3. Load-Flow Calculation

3.1 Base Case

The interconnection with IPS/UPS has a significant effect on the present picture of the load-flow situation in the eastern part of UCTE - even in the base case (without imports/exports from IPS/UPS). Figure 4 shows a loop flow (around 300 MW) resulting from the interconnection with IPS/UPS. The circuits between Poland and the Czech Republic/Slovakia are relieved, as the loop flow leads to a partial compensation of the highly loaded lines in north-south direction or even of the assumed load-flow of 500 MW from the 1st zone to the 2nd zone. However other congested lines may be additionally loaded: e.g. from Slovenia to Italy.

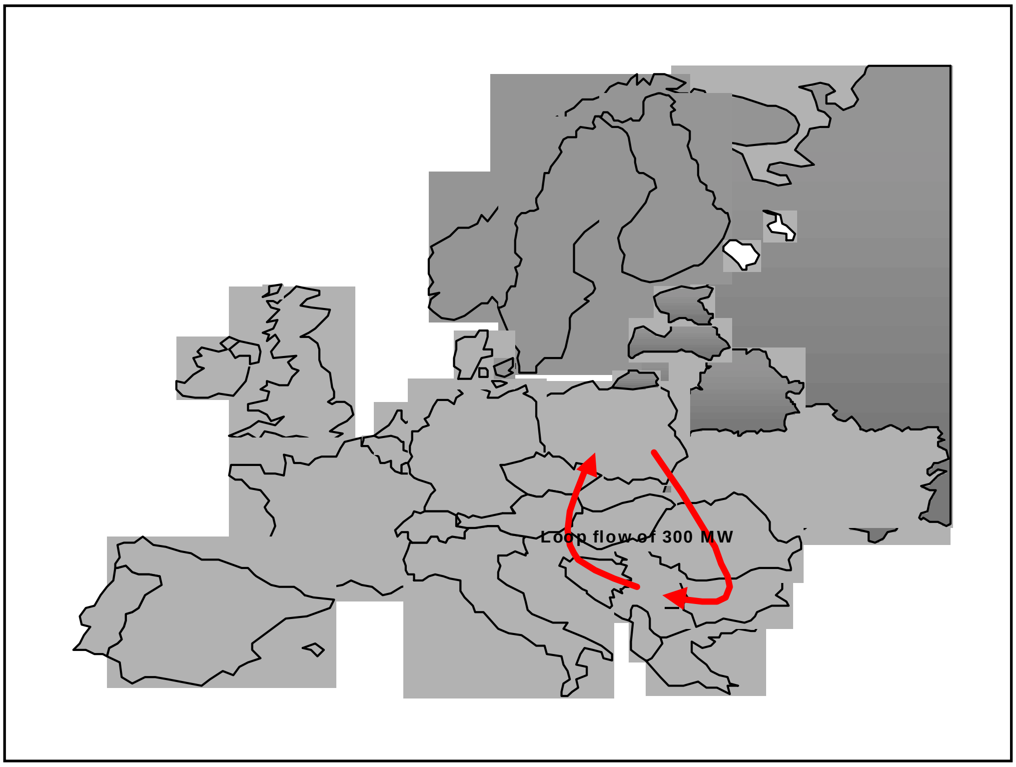

Figure 4: Loop flow in the base case caused by interconnection with IPS/UPS

This means that the interconnection of the 380 kV grid with the rather powerful 750 kV lines of IPS/UPS, in a partly meshed way, results in significant effects on the UCTE side. This may vary in a relatively large range depending on the operational network condition on the IPS/UPS side. The regional interactions between the networks have to be studied in greater detail and in co-operation with IPS/UPS.

The detailed values for the base case with and without interconnection of IPS/UPS are attached in Annexes 1a and 1b.

3.2 Imports from IPS/UPS to UCTE

The East-West transfer is strongly limited by the congestions existing within UCTE; especially in the case of exports from IPS/UPS into UCTE areas, which currently are already importing areas (case A.2) and no significant amount of energy exchange can be realized. Existing bottlenecks are more heavily loaded mainly in Austria, Czech Republic, Germany, Italy and Serbia.

Even in the most favourable case regarding optimal usage of transmission capacities where the new import from UPS/IPS would replace generation located in the present exporting areas (case A.1, A.3) the amount of exports from IPS/UPS to UCTE would be limited below 1,000 MW. The detailed results for these cases are shown in Annexes 2c2, 2c3 and 2c4.

3.3 Exports from UCTE to IPS/UPS

In case of West-East transfer to IPS/UPS, bottlenecks were identified in the networks of Italy and Slovakia mainly, which result in export limitations in order to of some hundreds of MW. However, it must be pointed out that another generation scenario could improve the situation. Due to the strong time-pressure for the study, this aspect was not investigated in more detail. The detailed results for these cases are shown in annex 2c5 and 2c6.

3.4 Imports from IPS/UPS to the present 2nd synchronous zone

The load-flows in the previous cases can be classified as long distance transfers between UCTE and IPS/UPS. An additional Balkan case was investigated with relative short-distance load-flows from IPS/UPS.

For this "short-distance transfer" from IPS/UPS to the Balkan area, higher transfers can be realised. The load-flows are limited by around 1,600 MW in both cases through congestions in the networks of Austria, the Czech Republic and Poland. The detailed results for these cases are shown in Annexes 2c7 and 2c8.

3.5 Transfer Corridors

On the basis of the load-flow results, "distribution factors" detailing the percentage usage of transmission lines in different transfer scenarios were evaluated. Table 1 presents the "high loaded" profiles (additional power flow ≥8 % caused by the load-flows). The complete list is given in Annex 3.

This selection shows that there exist characteristic power flow "highways", which are relatively independent of load-flow cases, i. e. of transfer directions. Therefore, it is possible to identify typical "*Transfer Corridors*" based on the main transfer scenarios investigated. Figure 5 shows the major transfer corridors. The maximum share of the East-West transfer load-flow through the most important (from the point of this study) existing bottlenecks is given for each transfer corridor.

It can be seen that many bottlenecks in central Europe are highly affected by the East-West (and West-East) transmissions; therefore these transmissions will have a great influence on several congestions within the UCTE power system.

	case 2	case 3	case 4	case 5	case 6
BG-RO	-13%	-14%	-13%	13%	13%
B-NL	-10%	-13%	-9%	10%	9%
CR-BIH	-8%	-9%	-9%	8%	9%
CR-SL	21%	25%	22%	-21%	-22%
CZ-D	27%	29%	28%	-27%	-28%
CZ-SK	-28%	-26%	-30%	28%	30%
D-A	-12%	-10%	-15%	12%	15%
D-NL	13%	26%	9%	-13%	-9%
F-B	-7%	-4%	-9%	7%	9%
F-CH	-11%	-10%	-11%	11%	11%
F-D	-14%	-15%	-13%	14%	13%
F-I	-9%	-3%	-12%	9%	12%
H-A	13%	12%	14%	-13%	-14%
H-CR	10%	12%	8%	-10%	-8%
H-SK	14%	12%	17%	-14%	-17%
IPS-"BI"-H	30%	31%	30%	-30%	-30%
IPS-PL	32%	31%	33%	-32%	-33%
IPS-RO	24%	24%	22%	-24%	-22%
PL-D	18%	19%	19%	-18%	-19%
SK-"BI"	-9%	-8%	-10%	9%	10%
SL-I	18%	23%	17%	-18%	-17%
YU-MKD	9%	9%	9%	-9%	-9%

Table 1: Distribution factors for East-West transfers

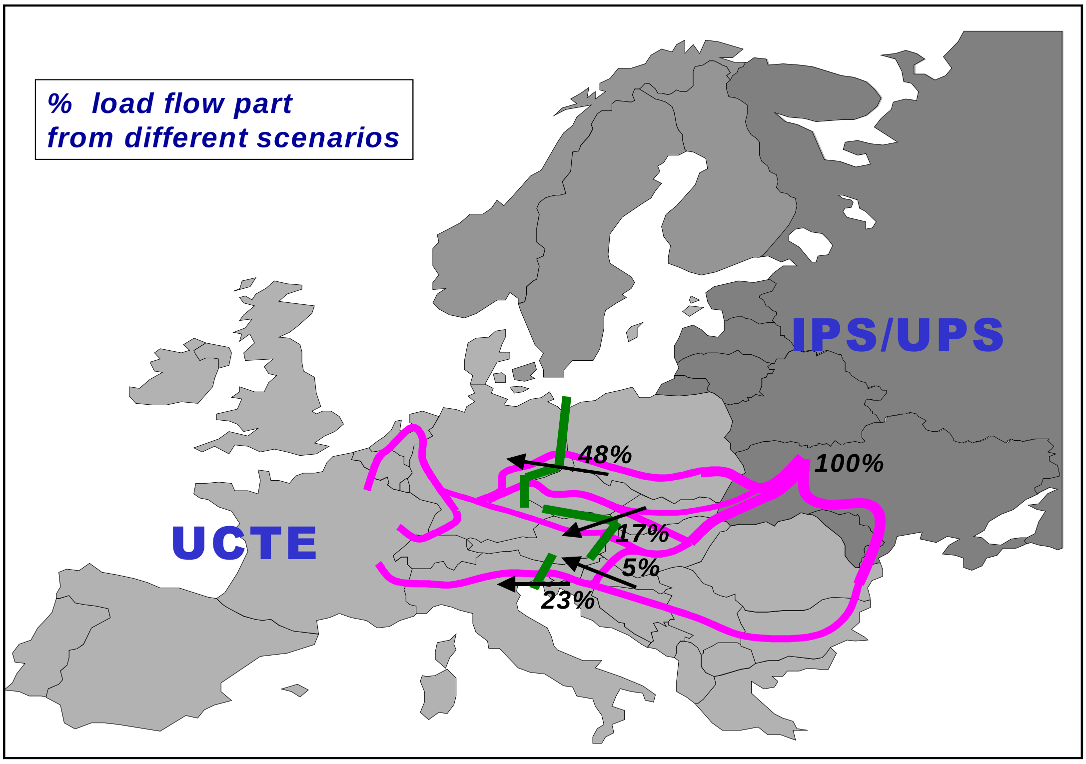

Figure 5: Main transfer corridors for the East-West flows versus the most important bottlenecks

3.6 Assessment of the Transfer Scenarios

The transfer corridors overlap with the typical North-South bottlenecks (profile between the Baltic Sea and the Adriatic Sea), as shown in Figure 5. Especially East-West load-flows will have a significant influence on that "congestion line" and therefore affect the system security *negatively*.

By means of a specific generation pattern, the situation might be improved. Nevertheless, it can be summarised that beyond a certain amount of power exchanges, a secure operation of the power system reduces the flexibility of the unit commitment and thus impairs the function of the market.

Without crossing the "North-South bottlenecks profile", it seems that "short distance transfer" into the Balkan and CENTREL countries could be possible.

4 Evaluation of Primary Control

4.1 General Aspects

According to UCTE rules, the generation outage of 3,000 MW must be managed in a secure manner and the overall system must remain in a secure condition. That means that

- the outage must be managed even under a low-load condition.
- the frequency must be set back to the normal operating range (+/-200mHz) within less than 1 minute
- the resulting load-flow must be managed taking account of the (n-1) security.

The following analysis was carried out <u>only for the base case</u> with a generation outage of 3 GW.

4.2 Modelling of Primary Control

The network model for 2005 was extended to the primary control contribution given by the network characteristic numbers:

λ_{UCTE} = 19,000 MW/Hz
and λ_{UPS} = 7,000 MW/Hz (obtained from the TACIS-Study 9601)

In the UCTE model, the primary control activation was spread among more than 400 generation units. The participation of each control zone within UCTE corresponds to their individual network characteristic numbers λ_i (Annex 4), in which $\lambda_{UCTE} = \Sigma \lambda_i$; so the effect on the global load-flow by primary control action can be calculated in a realistic manner. The geographical distribution of the primary control power is shown in Annex 5.

4.3 Generation Outage of 3,000 MW in UCTE

The generation outage of 3,000 MW in Italy (Montalto) and France (Tabarderie) is considered as an example of a generation loss in UCTE, which has to be managed in a safe manner according to UCTE rules (detailed physical power exchanges are given in Annexes 6a, b and c for Montalto and Annexes 7a, b for Tabarderie). In case of synchronous interconnection with IPS/UPS, additional primary control power will be activated by IPS/UPS, which causes corresponding power flows to UCTE. In Table 2, the power flows with/without IPS/UPS are presented and the differences for selected profile are given. Furthermore, in Figures 6a, the differences in power flows caused by primary control action of IPS/UPS after generation outage in France are shown geographically.

It is obvious that there is an additional usage of presently congested lines in UCTE by the primary control power transmitted from IPS/UPS; therefore, the free transmission capacity for dynamic effects of interconnection with UPS/IPS should be assessed on a case-by-case basis and eventually increased if those values exceed the present TRM. As a consequences of that the transmission capacity, which can be provided for the market, has to be reduced.

Furthermore, some cross border capacities within the CENTREL area are negatively affected, e.g. SK to CZ.

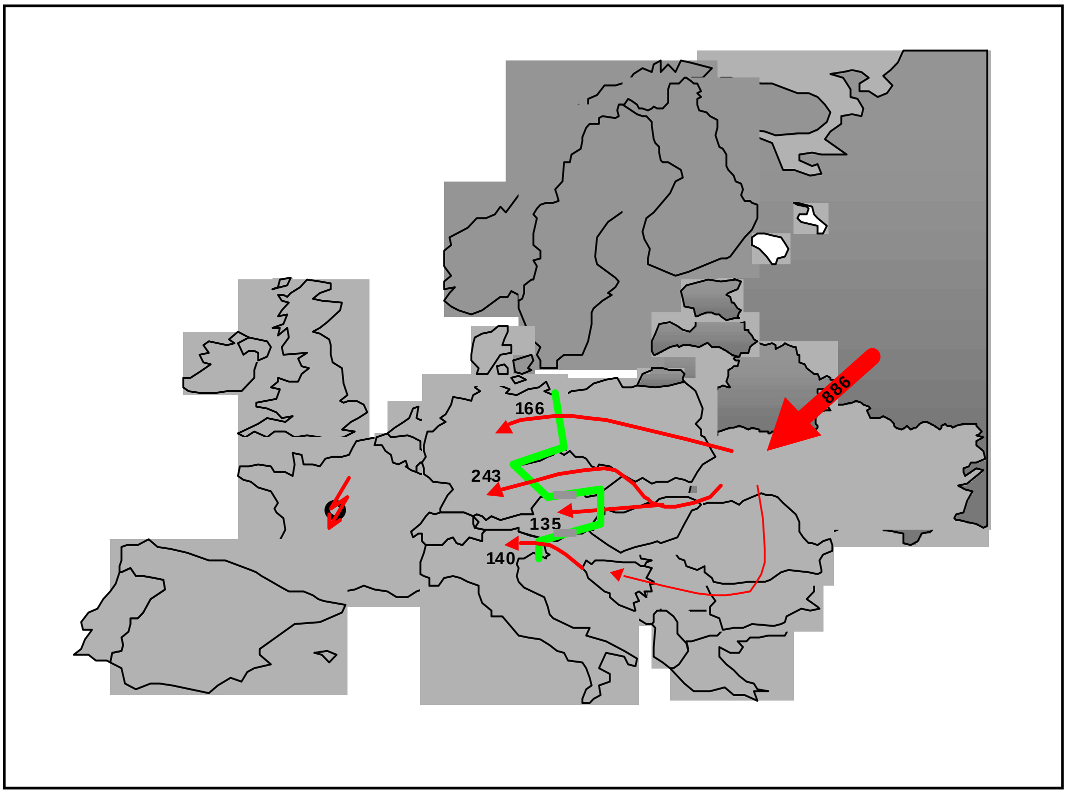

Figure 6: Primary control power flow from IPS/UPS after generation outage in Tabarderie (F), differences of primary control power flow [MW] with and without IPS/UPS

From	**To**	**Case a** Outage in Montalto (I)			**Case b** Outage in Tabardierie (F)			**Present NTC values** (ETSO)
		without	with UPS	difference	without	with UPS	difference	
IPS/UPS	UCTE	0	960	960	0	886	886	
A	D	-282	-132	150	100	200	100	1,500
CZ + HU	A	95	238	143	68	203	135	600
PL	SK	52	85	33	1	57	56	500
PL + CZ	D	27	508	481	369	778	409	2500
SK	CZ	-111	216	327	106	361	255	600
HU	SK	-138	34	172	46	162	116	600
SLO	I	671	750	79	100	240	140	380

Table 2: Power flows on the most important profiles caused by primary control [MW]

The activation of primary control reserve by IPS/UPS (stationary contribution including self regulating effect of the load) needs transmission capacity across the interface, which is relevant for East-West transfers and refer to the North South bottleneck profile:
CZ + HU to A, PL+CZ to D, SLO to I: 143 MW + 481 MW + 140 MW = 764 MW.

4.4 Transmission Reliability Margin

The influence of primary control on the load-flow has to be taken into account by determination of cross border transmission capacities. According to ETSO rules (TTC = NTC + TRM , ***T****otal* ***T****ransfer* ***C****apacity*), the NTC values (***N****et* ***T****ransfer* ***C****apacity*) are calculated with a ***T****ransmission* ***R****eliability* ***M****argin* (TRM). The TRM is needed for unpredictable load-flow situations and dynamic effects. ETSO proposes to determine the necessary TRM for each border by:
TRM = $n^{½}$ x 100 MW - with n for number of interconnected lines between two countries.
It should be mentioned that this is a proposal for the present situation. Every TSO has to make his own rules, with the final decision depending on the concrete network situation.

For the most important profiles from the point of view of this study - the North-South profile – consisting of three single bottlenecks (CENTREL to D, CENTREL to A and SLO to I) the following unidirectional values result from the ETSO proposal:

Czech Rep. + Poland → Germany: TRM = 280 MW
Czech Rep. + Hungary → Austria: TRM = 240 MW
Slovenia → Italy: TRM = 170 MW.

It can be concluded that the present TRM-values have to be adapted to the additional load-flows caused by primary control of IPS/UPS (see Table 2). Therefore, the NTC values have to be decreased in case of a synchronous interconnection with IPS/UPS. Consequently, the synchronous interconnection of IPS/UPS will result in lower NTC-values for some existing bottlenecks. An additional transmission capacity for the control power flow coming from IPS/UPS (about 800 MW) has to be taken into account on the transfer corridor for the East - West transfers. Moreover, for the most influenced profiles , mainly in the central part of the UCTE power system, it will be an important item to take into consideration at the definition of TRM the possible high volume of power flows caused of the primary control contribution of IPS/UPS power system. In addition to this, one must notice that the evaluation of the needed TRM is strongly linked with the predictability of the flows, the more unpredictable the flows are, the larger the TRM will be.

5 Conclusions

The steady state load-flow analysis has shown that the present available transits capacities internal to the UCTE system are already fully used and that the synchronous way of connection between the two systems will naturally decrease these values:

- The first conclusion, already well known by the UCTE members, is that with the present pattern of exchanges between the countries, the UCTE grid is operated at the limits, all the transmission capacities on the borders between UCTE members being fully used.
- The simulations that have been performed with the different scenarios show that transit corridors which are more or less independent from the scenarios can be identified. The flows coming from the East along these transit corridors in the “UCTE importing” scenarios have to cross already congested borders, mainly between the CENTREL countries and Germany and Austria, and between Slovenia and Italy. The direct consequence is that in this context, the possible transits between the two systems are significantly lower than the physical capacities of the lines presently unused between East and West.
- The synchronous interconnection between the two systems lead to the participation of the two systems to the primary frequency control. That means that in case of an outage of production in one of the systems, the other system reacts to compensate the loss of generation. The direct consequence is that this reaction creates additional flows that have to be taken into account in the transmission capacities evaluation. In other words, the Transmission Reliability Margin will increase on the already congested borders, limiting more the available capacities for transits. It goes without saying that this effect does not exist in a DC type connection.

Proposal for some further profound investigations:

It is recommended to investigate several aspects in greater detail and in co-operation with the IPS/UPS experts. Therefore, the Terms of Reference should be worked out with the following main items:

- Detailed analysis of existing bottlenecks and weak network areas as well as constraints within IPS/UPS.
- Investigation of the special generation scenarios incl. wind power generation.
- Operational rules and compatibility of load-flow control methods on the interface between the two large power systems.
- Stability calculations including eigenvalue analysis and estimation of additional reliability margins from the dynamic point of view.
- Defence plan.