Model for Technical-Economic Analysis of ENTSO-E and IPS/UPS Power System Optimal Interconnection Concepts

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***Abstract* – This paper considers the analysis of large-scale power system optimal interconnection concept as well as description of the model for evaluation of its costs and benefits. Paper contains the method for technical-economic analysis of different scenarios of interconnection of two world largest power systems - ENTSO-E and IPS/UPS. The research has shown that developed model is capable to make deep analysis and is ready for calculation of interconnection links optimal locations, transmission capacities and interconnection type.**

***Keywords* – ENTSO-E, IPS/UPS, large power systems (LPS), interconnections.**

I. Introduction

The interstate integration of power grids provides multiple advantages and due to this fact UCTE power system expands continually since its establishment. Currently, consideration is given to different scenarios of joint operation of UCTE and NORDEL with power grids on the territory of the former USSR. Due to the fact that such an interconnection is second to none in the World in terms of the scale and distance of the interconnection and number of countries involved, strong R&D and innovations are urgently required along with the recent development of technologies. The benefits from power system interconnection are (they are generally valid and do not depend on the kind of the interconnection):

- Optimization of the use of installed capacities
- Reliability improvements reducing the economic cost of power outages
- Improved control of system frequency to minimize major disturbances
- Sharing reserve capacities and reducing the level of reserves required
- Providing mutual support for the interconnected systems in case of emergency
- Improved energy market conditions in better integrated large scale systems
- Facilitating large scale integration of renewable energies due to higher flexibility of the interstate network operations

II. Possible Scenarios of Interconnection of Large Power Systems

When the interconnections are heavily loaded due to an increasing power exchange, the reliability and availability of the transmission will be reduced. The main question here is finding reliable and cheap way of connecting large power systems. Possible technical ways of interconnecting two large-scale power systems are shown in Fig. 1. They are: a) AC + AC, b) DC, c) AC + DC.

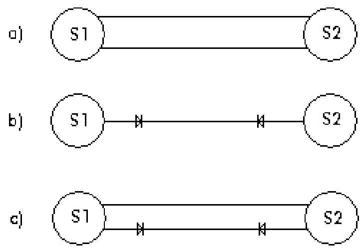

Fig. 1. Possible types of power system interconnection

Considering “AC + AC” interconnection type, only one line cannot keep necessary stability level, that’s why for large-scale power systems it is assumed that more than one AC link between systems is needed. AC link can be a cable or an overhead line.

DC link provides power flow from one power system to another without voltage frequency and level synchronization. DC links is divided into back-to-back and generation-to-load links. Also DC link can be a cable or an overhead line.

In case of hybrid interconnection “AC + DC”, direct current link makes synchronized system more stable and prevent from numerous types of accidents.

Generally, main advantage of HVDC system is higher possible transmission capacity. The disadvantages of HVDC are in conversion, switching, control, availability and equipment maintenance problems.

III. Methodology for ENTSO-E and IPS/UPS Power System Interconnection Cost Calculation

Since interconnection cost calculation is complicated task, we propose to utilize information technology LDM-TG’08 for this purpose.

A. Description of the LDM-TG’08 information technology

LDM-TG’08 software was developed in 2008 in Laboratory of Power System Mathematical Modeling for calculation of optimal sustainable development of power systems. The possibilities of the software include:

- Annual technical-economical criteria calculation;
- Total technical-economical criteria calculation;
- Development plan sensitivity analysis;
- Risk analysis of forecasts;
- Power flows in model;
- Voltages, voltage loses and balance in nodes;
- Network reliability;
- Switchgear reliability;
- Annual energy balance.

B. ENTSO-E and IPS/UPS model forming

Fig. 2 shows the structure of ENTSO-E and IPS/UPS power system network in LDM-TG'08 software environment.

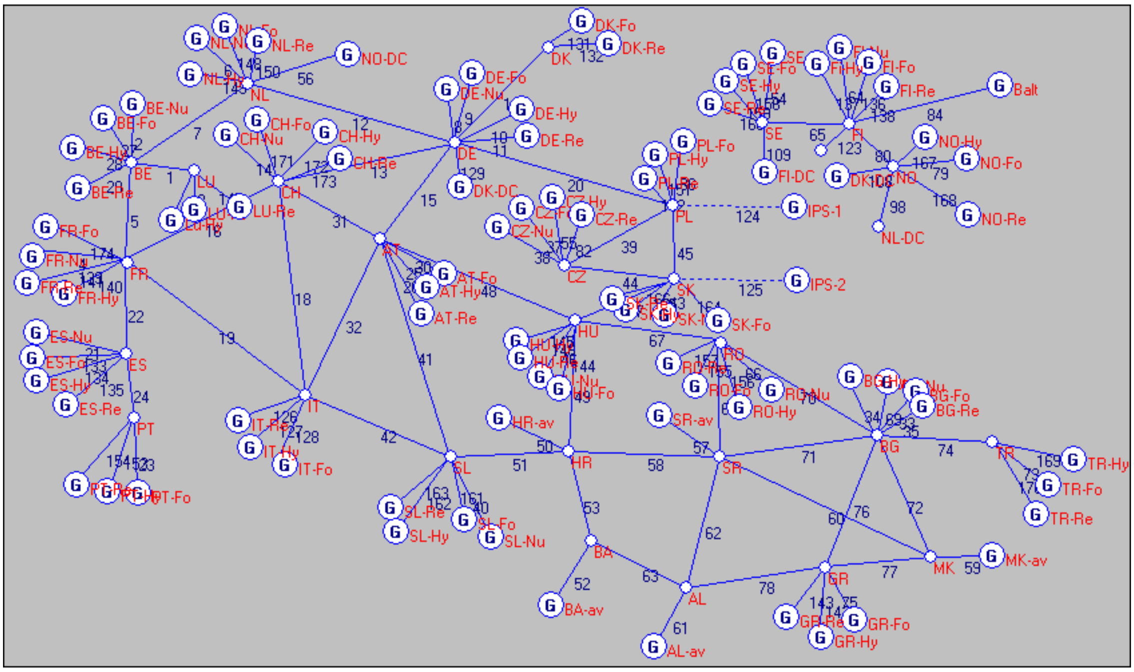

Fig. 2. Structure of the power system model

ENTSO-E power system is modeled with set of countries-members with nominal voltage of 400 kV. IPS/UPS power system is modeled with set generators connected to ENTSO-E network. Place of connection of IPS/UPS system (generator) as well as their power depends on interconnection scenario considered. In example shown in Fig. 2 IPS/UPS generators are connected to Poland and Slovakia.

Each country or subsystem is modeled with a load node and several generator nodes (equivalent power plants). Each equivalent power plant corresponds to different power plant type. Number of equivalent power plants depends on types of energy sources that are used in the country. Maximum number of equivalent power plants is four: nuclear, fossil-fired, hydro and renewable. For some countries it can be three or two, for example Italy do not have nuclear power plants at all.

Network member annual generated energy of 2010 was input data of the model [3]. Since parameter "Relative maximal load in operational state" is set to 1 (power plant non-stop works at set load), power of each equivalent power plant is:

$$P_i = \frac{(\text{annual generated energy})_i}{8760} \quad (1)$$

Average load of nodes in the model are calculated the same way:

$$L_i = \frac{(\text{annual consumed energy})_i}{8760} \quad (2)$$

Generated energy, consumed energy and peak demand are given values in this case.

Prices of electrical energy in equivalent power plants of each country were set according to study of International Energy Agency [4]. For countries that didn't provide information about electricity prices from their power plants, average prices from all other countries are assumed. According to our study, average price of electricity production at ENTSO-E power plants is 0,087 EUR per kWh and average price of electricity production at IPS/UPS power plants is 0,058 EUR per kWh. In the model prices of electricity from different energy sources are calculated separately. Relation of electricity prices from different power plants of different countries gives possibility to build the ranking of equivalent power plants in the model (to let the plant with cheapest energy work first).

Links between the countries (nodes) are modeled with overhead lines and cables. It is assumed that mark of these links is the same for each interval of 400 kV ENTSO-E network - 3xAS-400/51 overhead line. Maximal transmission capacity between countries (nodes) is calculated as:

$$P_{MAX} = P_{MAX.SINGLE} \cdot n \quad (3)$$

where P_{MAX} - maximal transmission capacity between countries (nodes);

$P_{MAX.SINGLE}$ - maximal transmission capacity of single line; n - parallel line number on given interval.

LDM-TG'08 software has special block for power system development plan forming and its comparison. Development plan forming starts with development action setting. Development action setting window is shown in Fig. 4.

No.	Name	K (TEUR)	Km (TEUR)	Kc (TEUR)	p %	pu %	C (TEUR/y)	L.code	+/-	T(init.)	T(end)
1	IPS1 - PL	10000	10000	10000	1	1	1000	124	+	2015	2040
2	IPS2 - SK	10000	10000	10000	1	1	1000	125	+	2015	2040
3	New ENTSO-E PP	100000	10000	10000	1	1	10000	200	+	2015	2040

Fig. 4. Development actions of the test model

IV. POWER SYSTEM DEVELOPMENT PLANS AND ITS COMPARISON

This test case has two development actions concerning AC interconnections: IPS/UPS – Poland, IPS/UPS – Slovakia and one development action concerning new power plant building in ENTSO-E system (Italy). As it was already mentioned above, interconnections are modeled with alternative lines from generators, which model IPS/UPS system. In this case we can clearly set generation power and also we can assume that it this case it is transmission power from IPS/UPS to ENTSO-E system. Parameters of the development actions are approximate and considered for testing of the model. It was decided to compare different interconnection scenarios with scenarios of building new power plant in ENTSO-E system. New power plant building scenarios besides will take into account real capital investments for new modern power plant and oil price increment in region. Technical-economic calculation (that our model is ready to perform) results can clearly show benefits of interconnection scenarios.

After setting development actions, plan forming can be performed. Development plan formation window is show in Fig. 5.

In this test case we form three development plans. First development plan considers IPS/UPS – Poland connection in 2015, second - IPS/UPS – Slovakia connection in 2015 and the third – new power plant building in ENTSO-E system in 2015. Also model considers development plan with no actions.

Actions	Plans									
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
IPS1 - PL	2015	----	----	----	----	----	----	----	----	----
IPS2 - SK	----	2015	----	----	----	----	----	----	----	----
New ENTSO-E PP	----	----	2015	----	----	----	----	----	----	----

☑ Present plan

Fig. 5. Development plans of the test model

To perform sustainable development plan analysis, precise load increment forecast should be made. Our calculations showed that in period from 2010 – 2020 load increment in Europe will be from 0,5% to 10% and average 2,2% annually. In period from 2020 – 2030 it will be from 0,2% to 2,5% and average 1,5% annually. According to this study, average annual load increment value for period from 2010 – 2030 for whole ENTSO-E system is 1,9%.

After development actions and plan forming are done, we move on to power balance. Calculation results of power balance for 2010 performed by our model shows no misbalance. However, taking into account load increment that was shown previously, power balance of 2015 shows that ENTSO-E will need additional 27,88 GW of installed power by that time (Fig. 6). At the year of 2020 deficit is already 70 GW. Also, some overloaded lines in ENTSO-E system appear after 2010.

1.Plan(F) Year:2015 Op.state:1. January

Power balance (MW)

Country	$\sum P$	$\sum P_g$	$\sum P_g - \sum P$
ENTSO-E	421352,67	393471,00	-27881,67
IPS/UPS	800,00	0,00	-800,00

Overloaded lines

Country	400 kV	750 kV			
ENTSO-E	2	0			
IPS/UPS	0	0			

Fig. 6. Power balance in model for 2015

Obviously, to get maximal benefit in future, not only border connections or new power plants should be built, but also inter-system network has to be improved.

This paper provides only model testing. Further, it is possible to examine technically valid ENTSO-E and IPS/UPS interconnection scenarios to figure out interconnection links optimal locations, transmission capacities and interconnection type.

V. CONCLUSIONS

Since world's energy consumption and energy needs are constantly growing new generating capacities are essential, as well as, in order to optimally utilize resources, power systems development should include merging into bigger systems.

Developed model is capable and ready to make deep analysis and comparison of ENTSO-E system possible development plans, including different scenarios of new power plants building and interconnection with IPS/UPS system.

Test case calculation results show deficit in ENTSO-E system already in 2015, what proofs the necessity in the system's development. Also, since number of overloaded lines is growing with years, it can be concluded that in order to get maximal benefit from system's development, not only border connections or new power plants should be built, but also inter-system network has to be improved.

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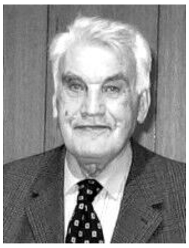

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