Models for Cross Border Trade Simulation

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***Abstract**: The national power systems was planned for the supply of the European countries. These systems were interconnected for the mutual help in case of emergency. Nowadays a new trend uses the bottle-neck interconnections: the long distance international bulk trade. The simulation of the trade is crucial for planning the network development and planning the daily schedule too. The proposed model based on optimization of the trader's energy purchase, the trade path, the border crossing prices – minimization of the traders' costs. In this paper we introduce considerations how to model the flows, how to predefine the circumstancies of the trade: generation prices, border crossing prices, etc.*

***Keywords**:* Terms-- *Border crossing costs, Power trade simulation, Power demand and flow forecast, Price forecast*

1 Introduction

The aim of the simulation is on one hand a better understanding and modeling of the causes of the present energy trade, on the other hand the forecast of medium term trading directions and amounts (see Fig. 1).

The relevant data are forecasted for Each Central European countries. We investigate the compensation energy flow (totality of the transactions) in the connected control areas driven by the price difference. The control areas are roughly identical with the national grids.

The simplified data refers to the

- present power and power plant mix
- development plans
- renewable developments
- present and planned network (mainly the international connections)
- forecasted power consumptions
- development of the local power market
- energy, CO_2 , transmission and border crossing prices

- price sensibility
- method of border crossing capacity allocation
- ratio of the long term-, bilateral and spot turnover

In this simulation test bed different scenarios will be investigated:

- stagnant, low and dynamic economy increase
- different countries – different development trajectories
- sensibility analysis for power plant capacity and cross border capacity development
- provisional surplus or lack in the weather dependent production
- single trader-transaction

The model is capable of the simulation of

- demand – offer balance
- price compensation mechanism
- cross border capacity allocation
- individual transactions

2 Considerations

2.1 Energy Balance

Due to the fact that electrical energy can't be stored economically in electrical form, the produced and the consumed energy are in balance during the investigated period. We handle the large scale energy storage e.g. pumped stored plants.

Short term energy balance for a country or for a set of countries:

production + consumption + exported + stored energy = 0

$$E_p + E_c + E_e + E_s = 0$$

where

E_p - produced energy

E_c - consumed energy

E_e - exported/imported energy (balance)

E_s - stored energy

Long term energy balance for a country (the average of the storage is zero):

production + consumption + exported = 0

$$E_p + E_c + E_e = 0$$

Short term energy balance for the whole system, if there is no external connection (no export/import):

$$E_p + E_c + E_s = 0$$

Long term energy balance for the whole system, if there is no external connection (no export/import, no storage):

$$E_p + E_c = 0$$

The national regulations, subventions are mapped in the local average energy prices and into the border crossing access. We focus on the quantity of traded energy.

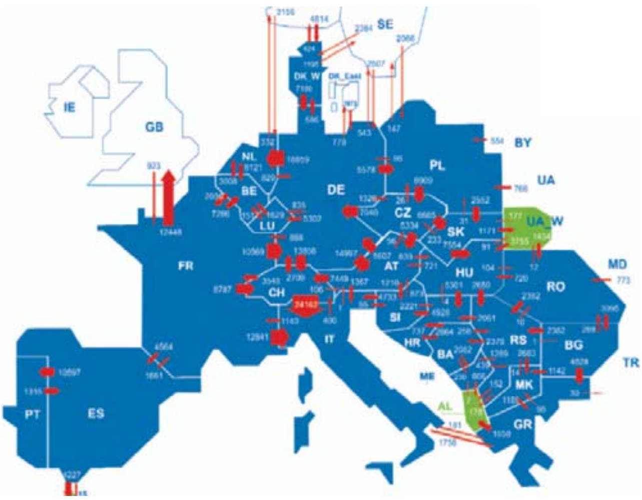

Figure 1

Energy trade/change in the UCTE system in 2008 (source: www.ucte.org)

2.2 Prices

- The local end-user transmission prices (medium and low voltage network usage costs) do not affect the international energy trade, only the end-user price. (It is the first approximation.)
- In the UCTE system the transit costs are covered by the Cross Border Tarification (CBT) system. [1]As a first step we model it, as the sender

[1] The traditional CBT mechanism was changed by the Commission Regulation (EU) No 838/2010 of 23 September 2010 on laying down guidelines relating to the inter-

(exporter) and the receiver (importer) country pays a post stamp tariff (cca. 0,5 €/MWh).

- The border-crossing has a cost
- The financial balance is always achieved. (The demand and offer curves meet in a point at an appropriate price.) A power balance means the financial balances of the selling and buying side.

The local price of the energy in a country is:

quantity * (production price + CBT of exporter + border crossing fees + CBT of importer)

One must mention that the energy prices and the production cost have a loose correlation.

$$P_e = Q_e * \left(P_p + P_{CBTe} + \sum_{i=1}^{n} P_{bc\,i} + P_{CBT\,i} \right)$$

where

P_e - local energy price

Q_e - quantity of the energy origin from a distinct location

P_p - production price

$P_{CBT\,e}$ - CBT fee of the exporter

$P_{bc\,i}$ - border cross fee on the i th border

$P_{CBT\,i}$ - CBT fee of the importer

2.3 Optimization

The main idea of the simulation is that we are looking for the optimal – that is the minimal price. All the countries are looking for the appropriate amount of energy for the cheapest price. But to which country should we optimize? It would be a Multi Objective Minimization. In the first step we minimize the total market costs (the sum of all national energy costs).

$$C_t = \sum_{i=1}^{n} C_{nat\,i}$$

where

C_t - Total energy costs

$C_{nat\,i}$ - energy cost in the i th country.

transmission system operator compensation mechanism and a common regulatory approach to transmission charging. In our model the cross border related costs we call CBT costs.

In the next round this global and ideal solution is modified by the local business interest.

The simulation = optimization + second round iteration

2.4 Constraints

The ideal solutions are influenced by

- limited production capacities (the total generation capacities are sufficient but the cheap sources are run out).
- network capacity – in the countries there are no bottlenecks but the border crossing is limited.

3 The Input Data of the Simulator

The balance model works with the power values and this is the base of the energy calculation. The relevant data are forecasted for Each Central European countries. The following data are collected and estimated for each country. The local generation capacity data are taken from public data sources (see Fig. 2).

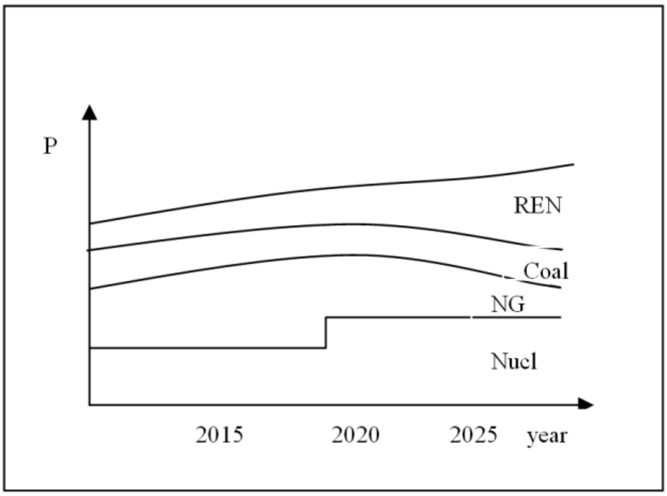

Figure 2

Local generation capacities

The time series of the different forecasted values are represented in functions of time stored in line matrices (see Fig. 3).

$$[Nucl \quad NatGas \quad Coal \quad Wind \quad Hydro \quad Biomass]$$

$$\begin{bmatrix} H \\ SK \\ CZ \end{bmatrix} \begin{bmatrix} [7 \quad 7 \quad 7] & [x^2/5 + 2x + 6] & [\ldots] & [\ldots] & [\ldots] & [\ldots] \\ [\ldots] & [\ldots] & [\ldots] & [\ldots] & [\ldots] & [\ldots] \\ [\ldots] & [\ldots] & [\ldots] & [\ldots] & [\ldots] & [\ldots] \end{bmatrix}$$

Figure 3
Local generation function representation

The local generation prices are forecasted beginning from the present price situation (see Fig. 4).

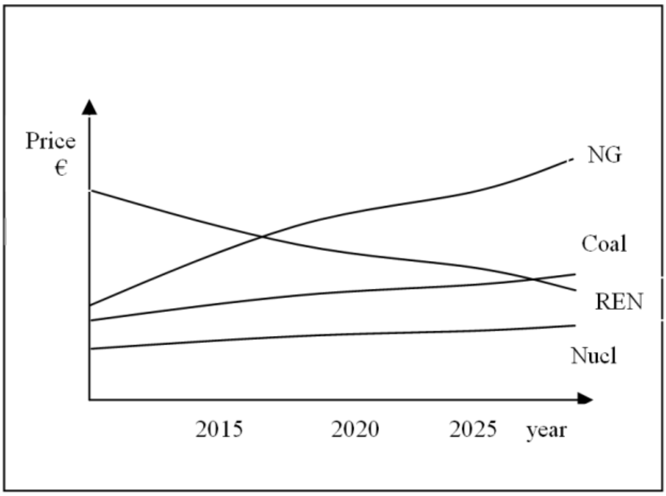

Figure 4
Local generation prices

The generation prices (and also the consumer prices) in an appropriate moment can have different characteristics (see Fig. 5). There is fixed (flat) price mainly from the bulk producers. The normal producer has amount-sensitive characteristics, and some other producers' prices can be built from well defined segments.

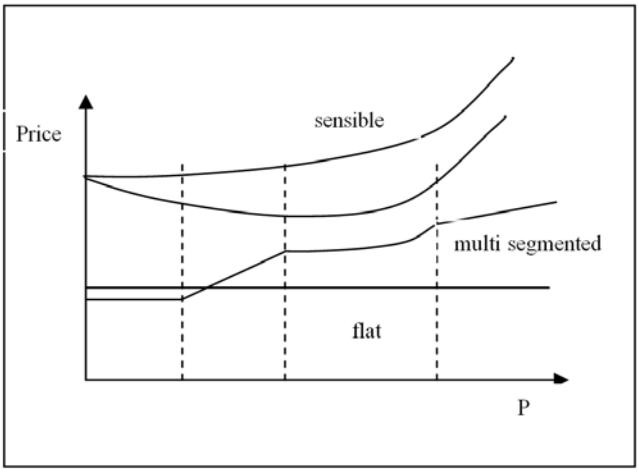

Figure 5
Price characteristics

The country load is forecasted by different economy development scenarios with different energy consumption growth rate (see Fig. 6).

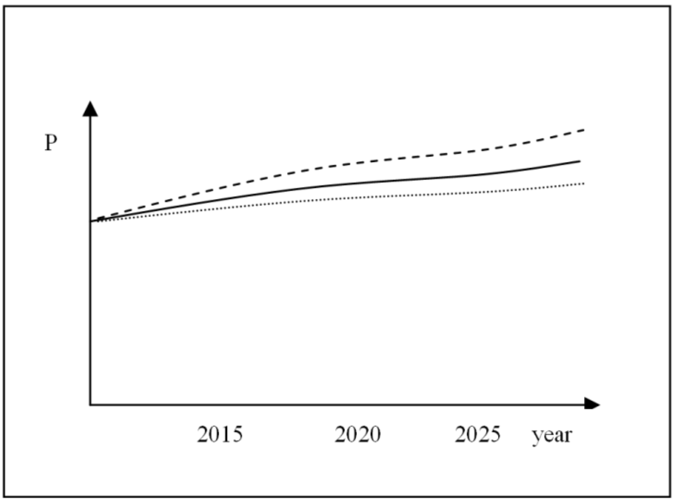

Figure 6
Local consumption forecast scenarios

In a country the price sensitivity differs for energy products. The public supply is not really sensitive, this price is relative low. The spot market does not affect such a large amount of energy, but the market is really susceptible to the peak energy price (see Fig. 7).

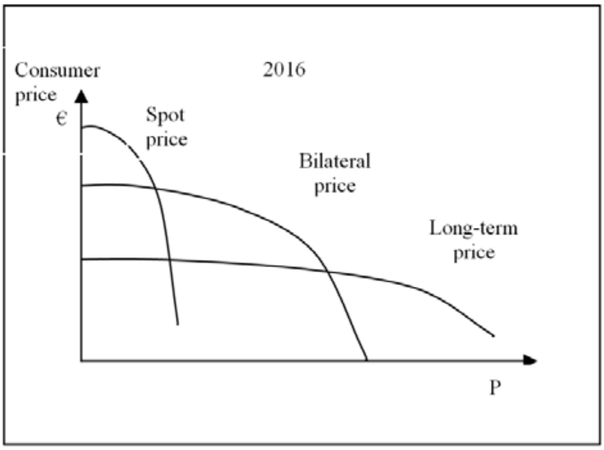

Figure 7
Local consumption price sensibility forecast– in a specific year

The border crossing capacities are (Available Transfer Capacity – ATC) published monthly (or daily) for the auction. We forecast the Natural Transfer Capacity (NTC) and the probable usage ratio of the future long term, bilateral and spot trade deals (see Fig. 8).

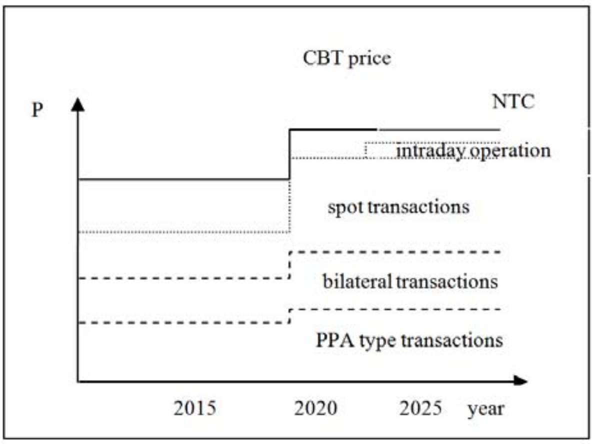

Figure 8
Border crossing capacities

The long term forecast of the border crossing prices is not easy (see Fig. 9). The practically used total capacity does not really depend on the allocation method (priority list; pro rata; auction). These prices influence the average end-user prices moderately. The market coupling and splitting method has more correlation with the neighboring countries prices. This is modeled in the second, iteration phase.

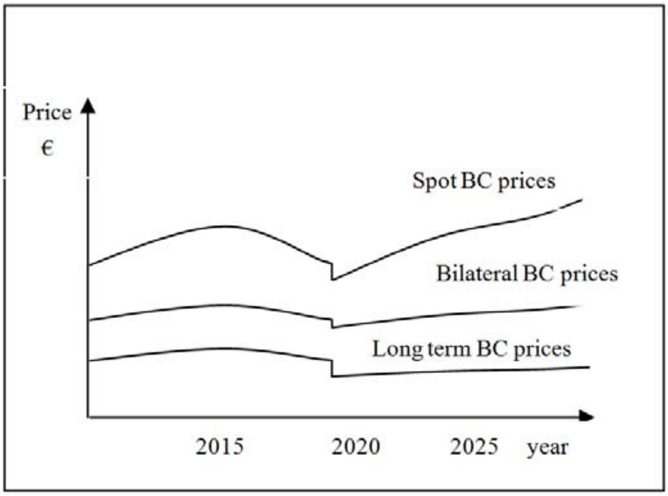

Figure 9
Border crossing price forecast

4 The Operation of the Simulator

4.1 Timescale

The typical timescale of the simulation is an individual "moment" in the future (5-10-15 years ahead). A found equilibrium with the future average prices, loads and energy flows is extended for a month or a year as the "yearly" energy trade.

In another operation mode the daily trading schedule can be simulated by the sequence of 24 hourly matching. In this simulation the different energy products simulated independently.

The rough test can be done by the data of the last years' prices and energy data.

4.2 Operation

In the first simulation step the optimization runs on the base of the forecasted average generation and border crossing prices. It followed by a short iteration. The new prices are maps the correlation functions – mutual interaction influences of the neighboring prices (e.g. the great price differences are compensated).

4.3 Topology

The energy flows inside the Control Areas (CA) without obstacles but between the CA-s are bottle necks that cause trade congestions (see Fig.10.). The CA borders are roughly identical with the national borders. The energy transmission is possible on the existing grid. The possible trading path is mapped in the 2D topology. In the first version we use “allocated path” method that is the energy flows from the origin country to the target country through a definite direct path. In the next version the flow based model (meshed multi-path) can be used. Theoretically the supra country – over continental direct “supergrid line” is modellable in 3D too (e.g. an HVDC line between two distant country).

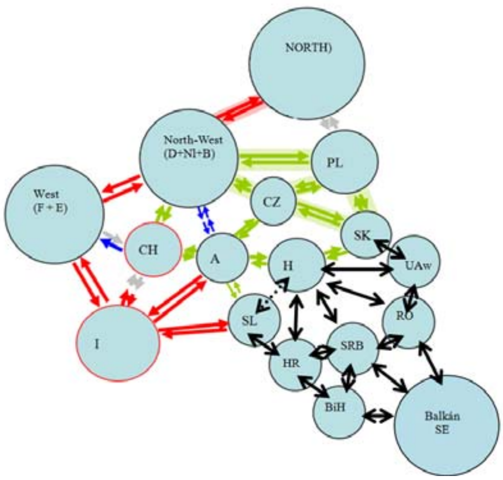

Figure 10

Bottlenecks between in the European control areas in the proposed Central European regional model

The topology of the Control Areas can be easily mapped into matrices (see Fig. 11).

	H	SK	CZ	PL	A	SL
H	1	1	0	0	1	0
SK	1	1	1	1	1	0
CZ	0	1	1	1	1	0
PL	0	1	1	1	0	0
A	1	1	1	0	1	1
SL	0	0	0	0	1	1

Figure 11

Topology matrix

Instead of connection Yes/No we can write in the appropriate NTC values.

4.4 Trading Layers

Analyzing the structure of the cross border transactions three layers can be identified. The actually traded volume as the actually consumed energy in a country consists of three types of trade deals(see Fig. 12). These levels, time ranges or deals are:

- long-term contracts (former Power Purchase Agreements – PPAs) with relative static prices that book a large part of the border-crossing capacities.
- medium-term bilateral contracts of that allocate border-crossing capacities more dynamically. Typical time range is one months. The long and medium term allocation makes the Already Allocated Capacities (AAC) of the Natural Transfer Capacity (NTC) in the border crossing capacity allocation (see Fig. 13).
- the rest is the Available Transfer Capacity (ATC) that is used to allocated partially or in whole for the international daily trade of Power eXchange (PX) sources.
- the fourth group would be the intraday contracts that could use the rest of the ATC. This is not typical yet in the EU for the hard control and congestion anticipating possibility

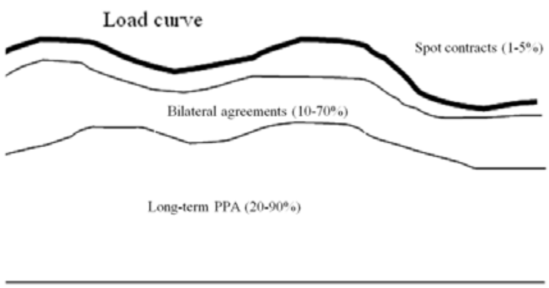

Figure 12

Typical supply sources of a daily demand curve

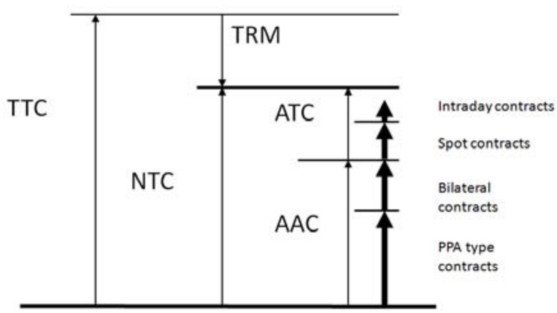

Figure 13

The use of the cross border capacities

In the model we estimate the allocation ratio for a cross border capacity in the future.

Due to the fact that the topology of the country-connection can be well represented by matrices the whole simulation is done in MATLAB environment with optimization toolbox.

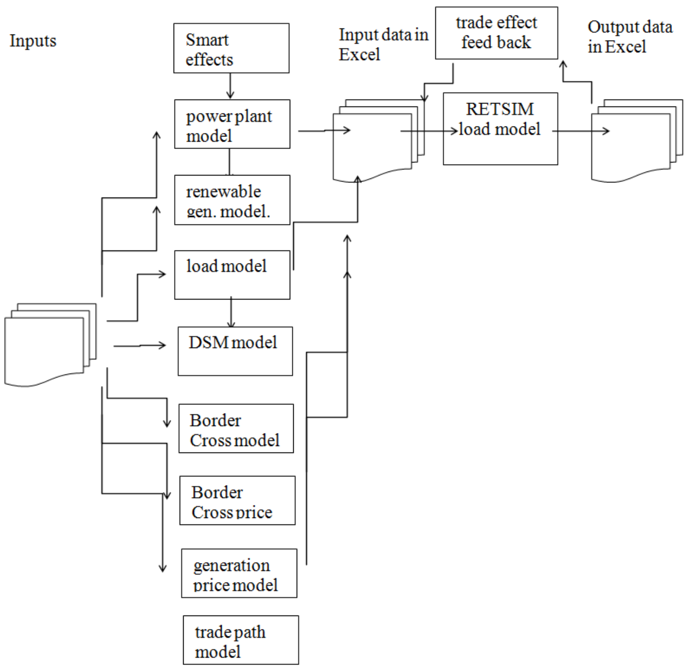

Figure 14
The partial data preparation models

5 Models

5.1 Power Mix Model

The role of the model: Definition of future portfolio

Input: ENTSO-E Market Modeling Database (08.02.2011)

Output: Available capacities in the future

Table 1
Power and price mix of Hungary

	price EUR/MWh	*participation in the local power mix - MW*
Lignite old	30[2]	860
Hard Coal old	40	240
Natural Gas conventional	70	1500
Natural Gas CCGT old	60	1000
Natural Gas CCGT new	55	400
Natural Gas OCGT old	65	1000
Nuclear	20	2000
Maximum hydro generating capacity average year	30	50
Onshore wind	60	200
Total		7250
Weighted average energy price	**47,02**	

5.2 Generation Price Model

The role of the model: Definition of future generation prices

Input: long term forecast

Output: spot prices, average prices

The long term average power generation cost is linked to the long term fuel price forecast and to the actual power mix.

5.3 Demand Curve Model

The role of the model: Definition of future demands, scenarios

Input: ENTSO-E Market Modeling Database: Demand

Output: Loads

Notes: No Power Exchange needs are modeled

[2] prices are expert estimations

All the market model used to have demand-offer curve matching. But where is this part in our simulator? Is the demand really sensitive to the price? The key is that which demand we talking about. The PX daily demand really depends on the offer price.

The enduser price do not changes during the run of the trader customer bilateral agreement. So having a fixed price contract, the demand will not be influenced by the actual spot prices.

By the way the enduser demand is not really flexible on the prices. A survey has been done how the demand changes by using different tariff stages. In case of ratio 35 of peak price/lowest price the peak was only with 12 % reduced, but the really energy demand didn't decreased.

Table 2

Peak decrease effect of multi tariff systems[3]

Type	Name of study	Country	Details	p_{max}/p_{min}	Load reduction [%]
TOU	Saarland-zvlST	D	Households	2.18	6.50
TOU	Saarland-SESAM	D	Households[46]	2.18	8.70
TOU	BEWAG-T1	D	240 samples. Only households with more than 1,500kWh electricity consumption per year[47]	2.94	7.00
TOU	BEWAG-T2	D		3.82	9.00
TOU	Stw. München	D		1.88	1.20
TOU	ESW Wiebaden	D	1,300 households[48]	3.00	2.32
TOU	Imatra: w-sh HH-passive	FIN		9.26	10.00
TOU	NMPC	US		3.06	1.00
RTP	Paderborn	D	Industry	11.67	13.40
RTP	Eckernförde	D	1,000 households	6.00	11.54
RTP	NMPC	US	Industry	4.15	13.20
RTP	NMPC	US	Industry	2.78	3.90
RTP	SCE	US	Industry	2.89	2.00
RTP	PG&E: 1995	US	Industry	35.50	12.00

5.4 Trading Path Model

The role of the model: Not the physical but the traders path is defined

Input: Feed in and load points

Output: Used Border Cross capacities

Methodes: shortest, cheapest, predefined, predefined-branching

3 Michael Stadler: The relevance of demand-side-measures and elastic demand curves to increas market performance in liberalized electricity markets:the case of Austria, Priel, 2003 November

5.5 Border Crossing Capacities Model

The role of the model: Definition of future border crossing capacities

Input: ENTSO-E Market Modeling Database: Transfer Capacities

Output: CB capacity

5.6 CB Prices Model

The role of the model: Direction dependent CB prices

Input: Initial rough prices

Output: Modified prices (price increase/decrease scenarios

5.7 Weather Dependent Production Model

The role of the model: Extreme weather condition for PV, Wind, Hydro

Input: Base capacities – Base prices

Output: Modified prices, capacities

5.8 DSM Model

The role of the model: Simulation of the Demand Side management and the Demand Response

Input: Natural load, DMS methodologies (Peak-cut, Tariff control)

Output: Modificated prices

5.9 Flow Modeling

The role of the model: Calculation of the trade flows

Input: Production capacities, Loads, CB capacities, CB costs, Generation costs

Output: Flows, Costs

5.10 Trade Effect Feed Back Model

The role of the model: The real flows effects on the initial generation prices and CB prices

Input: Generation

Flows

Output: New generation costs, New CB costs

5.11 Smart Effects Model

The role of the model: Simulation of the smart gauges, as the Distributed Generation

Input: Generation capacities

Output: New generation capacities

5.12 Modeling the Daily Price Course

The energy demands of a country used to cover by the cheapest sources, this is the objective of the traders. The individual traders minimum costs are close to the global minimum cost of all the trading actions, so the Single Objective Optimization task is to minimize all sum of all the traders energy purchase costs.

The energy has daily spot price in the exchange, but the enduser prices is fixed for a year. The difference maximization is the profit interest of the trader. Of course, the PX trade is only some percent of the total energy consumption.

The model minimizes the total purchase costs.

The average energy price is the average of the changeable PX prices. We can estimate the long term average costs, but we can’t easily forecast the intraday price courses. It is simulated by the superposition of an average price and a daily PX price swing.

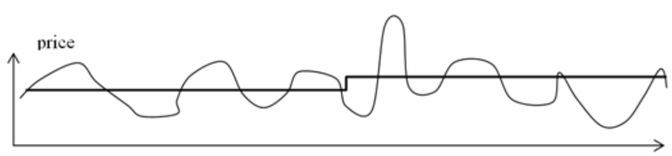

Figure 15

Forming the average price: Volatile spot price -> average price

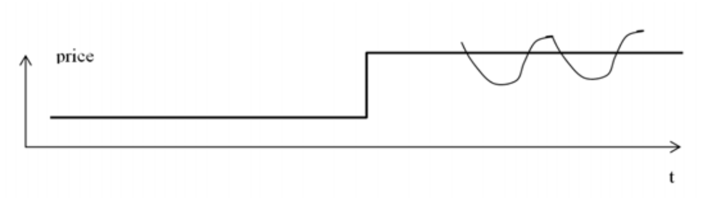

Figure 16
Forming the future spot price: Forecasted PX average price + spot wave superposition

Conclusions

The power trade has emerging role in the modern power systems. For the network planning is crucial the forecast of the trade flows. By this model we made a toll for estimation of the international trade. Of course the real flows can be calculated only by load-flow calculation.

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