Application of Optimization Techniques in the Power System Control

Péter Kádár

Power System Department Faculty of Electrical Engineering, Óbuda University, Bécsi út 96/b, H-1034 Budapest, Hungary
e-mail: kadar.peter@kvk.uni-obuda.hu

Abstract: In this paper we introduce some of the power systems' control and operation problems. The management of the modern power system faces mainly optimization tasks. We show some single and multi objective optimization solutions, these are: Decision making; Optimization of the schedule of renewable sources; Energy storage problems; Optimization of the network structure; Definition of the right power mix in single and also multiobjective case, Regional energy trade. A large variety of applied technologies is described. In the industry the fast and robust methods are favored.

Keywords: power system; optimization problems; single and multi objective optimization

1 Introduction

The electric (and heat) power generation are more than a century old technology but each element of the system contains high-tech solutions (power plant technology, generators, transformers, power lines, power electronic devices, Supervisory Control And Data Acquisition, etc.) The controlled elements are several millions so the system operation, stability, control, balance, optimization, settling is a really complex and distributed task.

1.1 Challenges

In spite of the clear technical knowledge and the capability of the full control of the system elements a lot of new and vague non technical questions emerged. In the following section some current topics are mentioned:

Monopoly and Deregulation

> Most of the power systems start off as monopoly. The monopoly provided the secure and relative cheap energy – and an uncontrollable bureaucratic organization. The deregulation philosophy broke the monolithic power

sector into distinct parts, as generators, transmission, distribution, trader, etc. After the liberalization problems emerged in the supply, investment and price side. The state stepped back to control the uncontrolled free market

Profitability

In the monopolistic case the organization prospers, the energy is supplied. If the company makes a loss, it will be covered by the state/owner. Normally the prices contain the reserves for long-term investment, some profit and the cost of the huge organization. In the deregulated environment the profit is the only driver. There is no investment without the hope of return and there is no energy supply if it is not profitable.

Investment and Development

In the present deregulated market operation there is a lack of long term investments. The profitable developments are made by private companies, the low ROI[1] high costs constructions (e.g. nuclear power plant) stay public.

Fossil, Nuclear or Renewable Sources

A really hot topic is the modification of the actual power mix, the search for the appropriate energy resource. The main decision maker in this question is the government but the lobbies, the greens have their votes, too. The environmental consequences are clear but the long term interests often go by the board of the daily politics.

Distributed and Centralized Generation

The "traditional" centralized energy generation methods are replaced or completed by distributed generation as the gas engines, PVs [2] or small hydros, etc. It poses several issues as the controllability of the net, the standardized design and operation, scale of economics, etc.

Who Rules the System?

The right operation of the power system must incorporate the triumvirate of legal regulation, the technical and trading approaches. The parties concerned work on different time scales (from the long term planning to the intraday market operations).

[1] Return On Investment
[2] PhotoVoltaics

Demand Growth and/or Efficiency

By the traditional paradigm all the energy demands are fulfilled by the producers. The customer has no interest to decrease its consumption. The present trend is the introduction of low-energy-need technologies and the better efficiency of the usage.

Smartening the System

Because of the drastic fall of the reliability of the old networks a new trend emerged that contains a lot of switches and meters outside the substations, open for the small scale bidirectional energy trade, ready for the Demand Side Management. The traditional heavy current power system is completed by Information and Communication Technologies.

Out of Control? Overcontrolled System?

The traditional, centralized power system control philosophy and the market philosophy don't match. The emerging complexity of the (intercontinental) networks and the subtle control system augurs large black-outs (greater area/cost/volume). The reliability and network security can be kept only by huge investments. The life cycle of the early devices in the system was over 50 years (e.g. electromechanical protections) but today the over computerized systems can't work over 10 years. The huge amount of the acquired on-line data overloads the dispatchers. It can be alleviated by some AI applications.

1.2 Tasks and Techniques

The numerous activities related to the operation of multilevel continent wide power system(s) require some optimum searching techniques [1] [2]:

Preparation and planning

- Prioritizing investments in distribution network
- Optimal protection and switching device placement
- Generation scheduling
- Maintenance scheduling
- Power mix planning

Operative control

- Constrained load flow
- Power plant operation optimizer
- Unit commitment – economic dispatch

- Optimal power flow
- FACTS (Flexible AC Transmission System) control
- Voltage/VAr and loss reduction
- Dynamic load modeling
- Short-Term load forecast
- Network reconfiguration and load reduction
- Market operations, etc.

The area of the optimizing methods is one of the most diversified areas of applied mathematics.

"Traditional" techniques

- Weighting Objectives
- Goal programming
- Constraint programming
- Stochastic
- Linear Programming
- Gradient Based/Hill Climbing
- Sequential Optimization, etc.

AI solutions

- Evolutionary Computation
- Genetic algorithms
- Particle swarm optimization
- Fuzzy Set Theory
- Ant colony search algorithm
- Simulated Annealing
- Pareto multi objective Optimization

Solving the problem by different techniques we should arrive at the same conclusion. The difference of the approaches can be characterized by the time spent for the prototyping, the robustness in industrial environment.

1.3 The Optimization Problem

In case of optimization some parameters are set between predefined limits. Typically we look for the minimum or the maximum of the objective (or cost) function. In a simple case we have only one cost function, we call it Single Objective Optimization – SOO, in other cases we look for the optimum of more values. This is the Multi Objective Optimization – MOO. In the complicated energy sector we face mainly the MOO, e.g. the energy strategy.

Nowadays dozens of tools stay at disposal to solve the large optimization tasks by computer. In our case we concentrate on the problem definition and problem mapping.

In the Single Objective Optimization (SOO) we look for min or max of a cost function (1) taking into account constraints:

$$Min/Max\ F(X) \tag{1}$$

where F(X) is the cost or objective function.

In MOO case the general formalization is [3]:

$$Minimize\ F(x) = [F_1(x), F_2(x), F_3(x), \dots, F_k(x)]^T \tag{2}$$

2 Optimization Solutions in the Power System Area

The development and operation problems of the power systems are mostly optimization tasks.

2.1 Decision Making

The power generation, transmission and service projects beyond the technical aspects are influenced by social-economy view points. A typical question to decide is: “To build or not to build a large hydro dam?” “construct or not a fossil or nuclear plant?” There is no good or bad choice but all the choices have effects on dozens of different aspects. We developed a weighting methodology that measures if we are getting closer or not to the optimal market conditions. The market is measured by heuristic Key Performance Indicators based on qualitative functions.

This method [4] is a possible solution if we have a complex incomprehensible problem space that cannot be handled analytically, where we must take into account e.g. the STEPLE framework (Social – Technological – Economic – Political – Legislation – Environmental aspects).

$$\text{Outcome} = w_1{*}f_A(x_1) + w_2{*}f_B(x_1) + \dots + w_{i-1}{*}f_P(x_n) + w_i{*}f_Q(x_n) \tag{3}$$

where

f_{A-Q} = qualitative functions

$x_{1...n}$ = influence variables

$w_{1...i}$ = weight factors

A decision at a place/date and time is better

IF

$$\text{Outcome}(\text{Option}_A) > \text{Outcome}(\text{Option}_B) \quad (4)$$

THEN

Option A is recommended

KPI function matrix	*← Independent variables*	**Social**	Employment	Right to the energy	Value of human positions	Social mission	**Technology**	Energy security	Quality	Efficiency	Standardisation	Integrity	**Economy**	Costs	Price of the energy	Growth rate	Profitability, ROI	Investment/development	Life time of the assets	**Political**	State decision
weight factors →		**W_s**	w_1	w_2	w_3	w_4	**…**														
Monopolistic or deregulated structures (level of unbundling)	x_1		**B**	**B**	**C**	**C**		**B**	**A**	**G**	**B**	**B**		**B**	**B**	-	**A**	**C**	**B**		**C**
From fossil toward the nuclear plants	x_2		**C**	**E**	**B**	-		**G**	**E**	**E**	**G**	**G**		**B**	**B**	**E**	**D**	**E**	**D**		**E**
Level of network development	x_3		**E**	**E**	**E**	-		**E**	**H**	**E**	**E**	**E**		**E**	**E**	-	**C**	**E**	**E**		-
Level of maintenance	x_4		**E**	**E**	**E**	-		**G**	**G**	**G**	**G**	**G**		**G**	**G**	-	**H**	**G**	**G**		-
From traditional towards the distributed gener.	x_5		**G**	**G**	**G**	**G**		**G**	**G**	**H**	**G**	**G**		**G**	**G**	**G**	**H**	**G**	**H**		-
From traditional to renewable sources	x_6		**G**	**G**	**G**	**G**		**H**	**H**	**G**	**G**	**G**		**G**	**G**	**G**	**H**	**G**	-		**G**
OPP price	x_7		**H**	**H**	-	**G**		-	-	-	-	-		-	**G**	**H**	**G**	**G**	-		**G**
Tariffs (net/ISO/PX)	x_8		**G**	**H**	**G**	**G**		**G**	**G**	-	**G**	**G**		**G**	**G**	-	**G**	**G**	**G**		-
Level of the general investment	x_9		**G**	**G**	**G**	**G**		**G**	**G**	**G**	**G**	**G**		**G**	**H**	**G**	**G**	**G**	**G**		**G**
Level of the import	x_{10}		**H**	**G**	**H**	**H**		-	**G**	-	-	-		**H**	**H**	**G**	**H**	**H**	**H**		**G**
Level of the control (raising)	x_{11}		**G**	**G**	**G**	**G**		**G**	**G**	**G**	**G**	**G**		**G**	**G**	-	**H**	**G**	**G**		-

Figure 1
Part of the qualitative weight table

2.2 Optimization of the Schedule of Renewable Sources

In vehicles, spaceships but also in island mode power systems the load maximum, minimum, battery capacity and also some production forecast are known (e.g. wind and PV, fuel-cell, battery status). [5] [9] [10]

The objective function is the continuous power supply by minimal costs. The sources have different costs, as the "cheap" wind and PV but the fuel cell operation should be minimized.

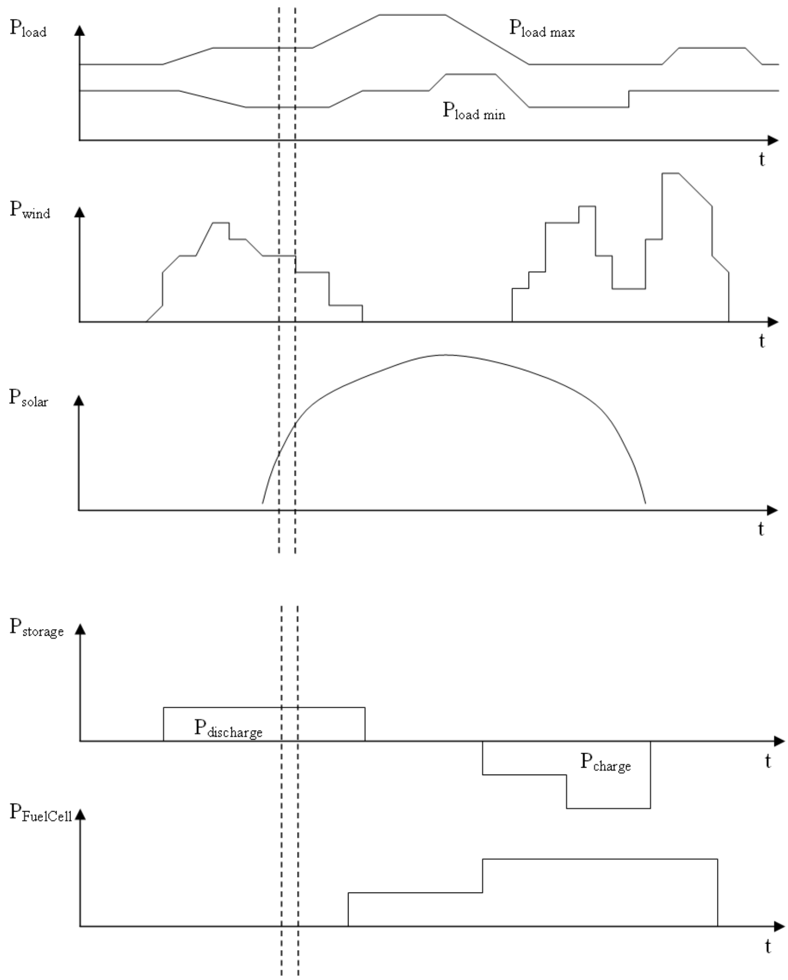

Figure 2

The load limits and the different generation curves

The constraints of the problem are the load limits, the actual generation capabilities, the status of the battery, the forecasted production schedule.

We assigned production costs to each type of generators, also to the battery. The time line is split into short periods. The objective function is:

$$C_p = \sum_{i=1}^{n} C_{source} \tag{5}$$

where

C_p - energy costs during the period

C_{source} - generation cost of the i th device

The objective function of the linear program is to find the least cost.

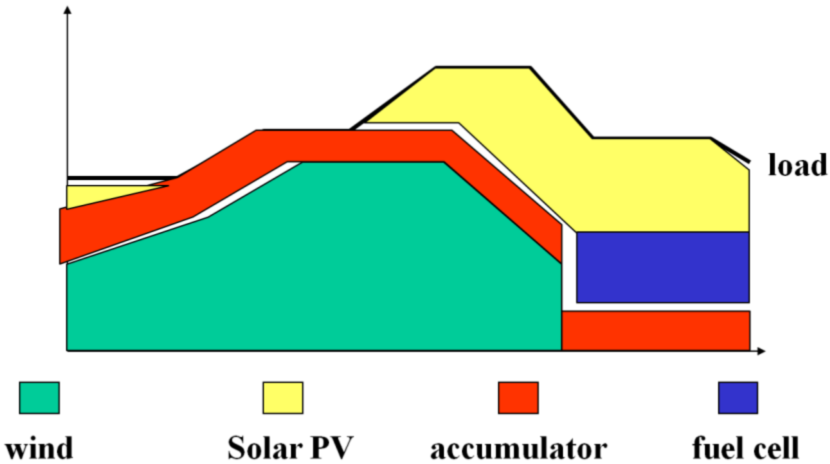

Figure 3
The Tetris[3] problem

2.3 Energy Storage Problems

In the energy market the players are the generation, consumer and trader entities. [7] The deal is the profit maximization. If a generation company has renewable generation capability and also storage possibility it is hard to say, when to store the energy and when to sell directly to the market.

A rule based system was developed to make decisions when to sell/buy/store in function of renewable production possibility and market price.

An example from the rules:

Generate AND store IF (6)

There is renewable potential

AND there is storage capacity

AND Prod. Cost + Cost of Storage is remarkable lower than the Selling $\text{Price}_{\text{average}}$

[3] Tetris (trademark of The Tetris Company)

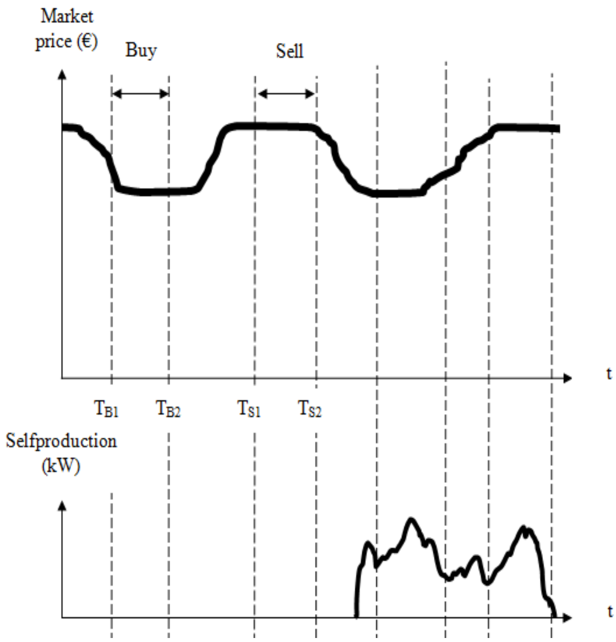

Figure 4a

A possible dynamic operation schedule

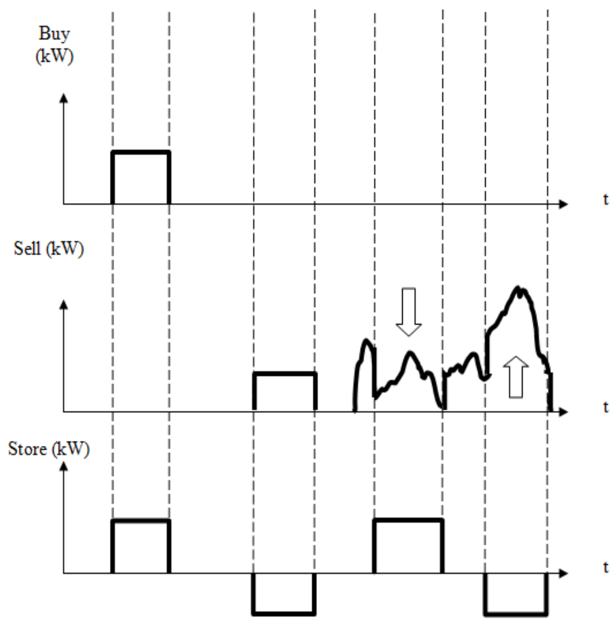

Figure 4b

A possible dynamic operation schedule

2.4 Optimization of the Network Structure

The „Smart" network means that there are renewable sources, adaptive protections, on-the-line switches, intelligent meters, on-the-line metering devices, etc. But how many smart devices should be built in the network? [6]

The reliability raise of the network means the reduction of the amount of the non-delivered energy.

Reliability can be increased by building in primary and secondary gauges, remotely controlled line breakers, redundant network parts or reconstructing parts of the old network. These measures have different costs and results.

The objective is the not-lost-energy maximization.

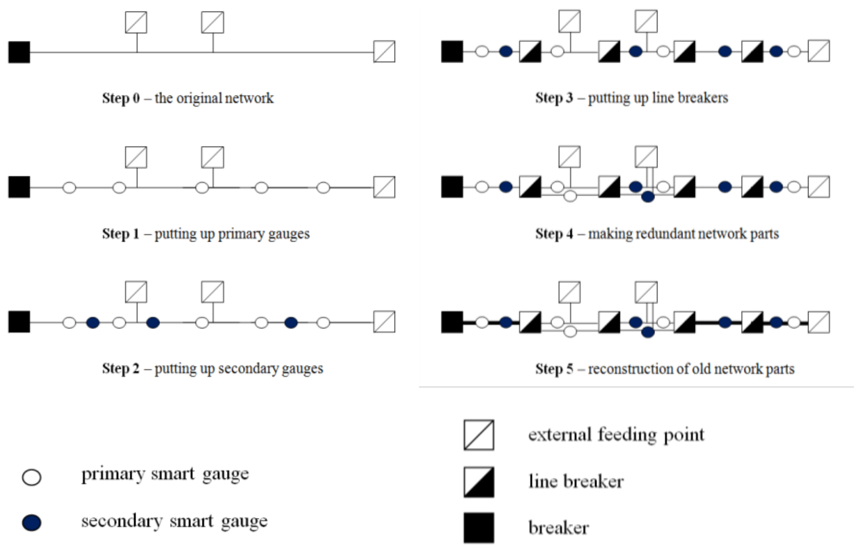

Figure 5

Options to improve the network's reliability

2.5 Definition of the Right Power Mix

The problem is to define the relatively cheap, low CO_2 emission, secure and sustainable power plant portfolio for a country or for continental communities (EU/Russia/USA, etc.). We investigated only the electricity generation, but for the CO_2 emission it can be stretched to the heat generation, traffic and the transportation. [11] [12] [14]

The options are to construct or replace fossil (oil, coal, gas), nuclear, renewable (wind, hydro, PV, geothermal) sources.

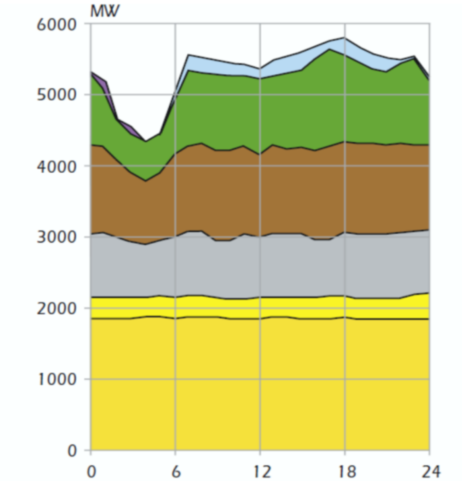

Figure 6
Daily generation portfolio[4]

The simplified SOO problems are solved by linear programming but the mathematically optimal solutions in the practice are often contradictory – as the cheapest OR lowest emission OR best fit to the social expectations.

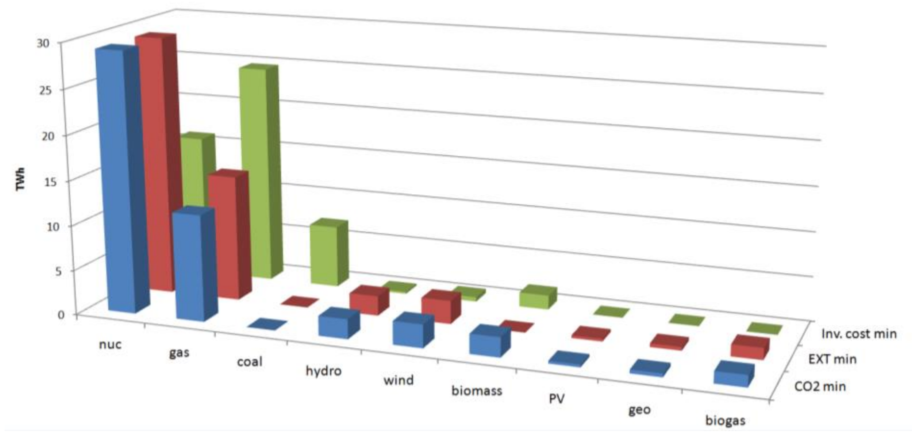

Figure 7
Visualization of generation ratios in different optimization alternatives

[4] source: MAVIR – Hungarian transmission operator

Facing the real MOO problem we developed the Reverse Weighted MOO [18]. In this method we applied the following steps:

1) defined independent SOO-s for each objectives for measuring the maximal "space"
2) identified the difference between the actual and optimal values of the objectives (actual – one-step-reachable SO Optimum)
3) by a priority list we define percentages for the different objectives as fixed constraint
4) we create a SOO for the last, non fixed objective beside fixed constraints

"Reverse" means that we apply the weights only after a series of SOO-s. The advantage of the method is the possibility to define the preferences (before the optimization). The different units (Mt, MEUR) are getting the same neutral percentage (%) dimension.

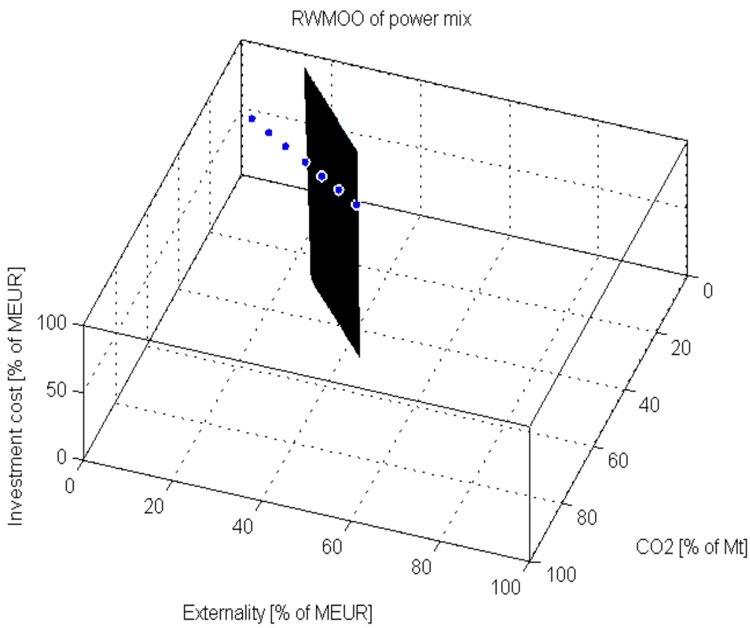

Figure 8

Optimal points by three variables as – CO_2 – Externality – Investment cost

2.6 Regional Energy Trade

The energy flows on the interconnected European network strongly depend on the traders' actions [16] [17]. The energy traders' tasks are to gain profit, to keep the margin high, to get cheaper energy. The local price consists of production price and transfer costs.

$$P_e = Q_e * \left(P_p + P_{CBTe} + \sum_{i=1}^{n} P_{bc\,i} + P_{CBT\,i} \right) \quad (7)$$

where

P_e - local energy price

Q_e - quantity of the energy originating from a distinct location

P_p - production price

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

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

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

The traders want to minimize it, so the paths from the cheap sources to the high priced regions are crowded.

The trade has a lot of physical constraints, such as the cross border capacities, the generation capacities, legal obstacles. The load of the border crossing network can be simulated by the profit maximization objectives of the traders.

We minimized the total market costs (the sum of all national energy costs).

$$C_t = \sum_{i=1}^{n} C_{nat\,i} \quad (8)$$

where

C_t - Total energy costs

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

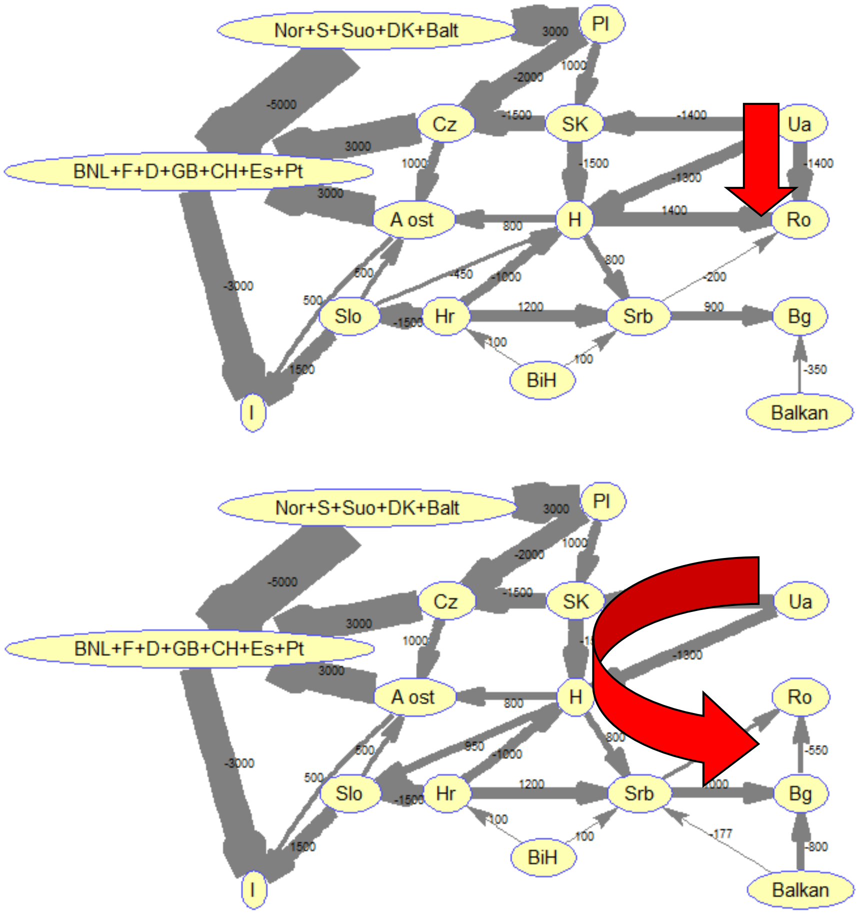

Figure 9
Shortest and cheapest path solutions

Conclusions

The examples have shown that in power systems there are a numerous complex tasks to be supported by computer control. Since the energy industry plays with large amounts of money, the optimization, moreover the profit optimization have high importance. A large variety of applied technologies have been described. In the industry the fast and robust methods are favored. At Óbuda University we developed several optimization solutions applying linear programming, constraint programming, weighting methods and rule based systems.

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