# Dynamic Simulation Method for Transmission and Distribution Planning

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**Abstract:** - Under the conditions of liberalised market development optimisation role is not to be decreasing but even increasing. Basic definitions and model structure of optimisation system under market conditions is discussed in a paper, as well the experience of LEPSS is given.

**Keywords:** Power System Planning, Power Transmission, Power Generation, Power System Simulation, Development Optimisation, Liberalised Electricity Market, Uncertainty, Risk Analysis

## 1 Introduction

The main research area of Laboratory of Electric Power System Simulation (LEPSS) is show in figure 1.

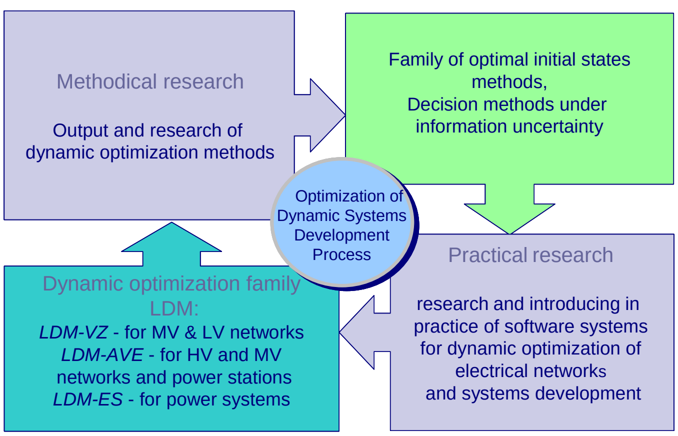


*Fig. 1.* Research area of LEPSS

LEPSS worked out these studies taking into account power system present conditions.

Liberalised electricity market considerably effects the power system development and it's planning. It is determined by the condition that electricity generators are independent from transmission and distribution operators and therefore their interests differ. This fact creates higher uncertainty conditions for the perspective forecasts than before. Therefore the power system development planning and optimisation is hampered. The question could arise whether optimisation under such conditions could be probable or even required. But still if the compromise has not been reached matching interests between generator and supplier, customers will be jeopardised - electricity quality and power supply reliability will be impaired. This could lead even to the decay of power system or disintegration of liberalised market. Therefore under the conditions of liberalised market development optimisation role is not to be decreasing but even increasing. Only the existing criteria and methods for power system development planning are not valid any more because optimisation costs became more complicated. Therefore it is very urgent to elaborate new criteria and methods introducing new IT technologies. The major optimisation method under the liberalised market conditions is risk analysis and risk assessment as the significance of technical criteria of electricity quality and power supply reliability criteria are growing evidently. Besides, at present conditions and even more in future ecological criteria are not to be ignored too [1].

Optimisation model systems structure to our mind shall be as follows. Transmission network and generation system shall be assessed in one model and distribution networks with local PP shall be assessed in other model.

## 2 Decision Making Principles

Economic analyses determine objects economic life cycle, in networks - 20-25 years. Efficiency function calculates to all estimation periods T. Under the information, uncertainty conditions on making decision only in the nearest future (approx. 5 years forward). These time intervals call as decision-making period $t_d$<T (see Fig. 2.)

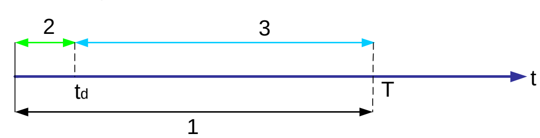


*Fig. 2. Development process. 1 - estimation period; 2 - decision-making (planning) period; 3 – adaptation period.*

Information about development period is uncertainty, therefore for decision-making is necessary the regular decision adaptation.

The planning process of development occur step by step [3]:

1) To keep up external information adaptation.
2) To use decision-making for advance stage (horizontal information flow).
3) To use adapting information about advance development of the system (vertical information flow).

Reviewing dynamic planning process, life cycle cost is taken as 20 years, which is determined by divided in four 5 years stages (see Fig. 3.). Moreover, in stage "0" analysis, decision-making and designing occur only for I stages. For technical and economic analysis in first approximate option there are new objects for stages II, III and IV.

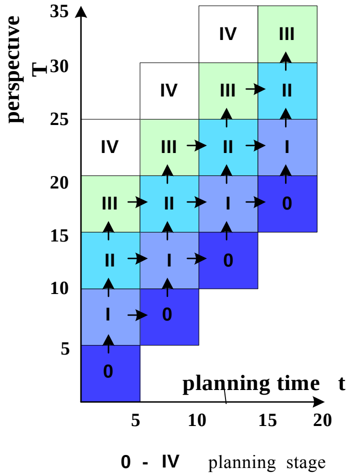


*Fig. 3. Dynamic process*

Final decisions about these objects are made in next design stages (after 5,10 and 15 years).

## 3 Principles of Methods of Generation System Simulation

For power system planning under liberalized market conditions model of power states is necessary to consider like an integrated approach - transmission system and generation system together. Generation system is necessary to simulate with specific methods.

In mathematical models reciprocal interrelations among multiple energy objects shall be taken into consideration, including operation conditions of the enterprises, structural changes of economic situation of the certain cycle period, great number of different limitations, as well as many criteria, out of that the compromise shall be achieved. During the latest ten years the effective method has been created "energy source-customer" for technical economic optimisation. This is successfully applied by the enterprises. Technical economic optimisation of network is not yet so developed because the existing methods do not provide the opportunity to perform sufficient adequate analysis of the energy supply enterprise as well as optimal plan synthesis. The consolidated technical economic models of "energy sources-network" are in the stage of "idea, although only reviewing as one unit the whole chain "fuel-electric power plant-network-customers" is possible to obtain the most feasible solution observing the requirements on environment protection, rational use of energy resources and other essential factors.

LEPSS worked out the scientific project Dynamic *optimisation methods of electric power supply systems (fuel-electric power plants-network-customers) and its realisation technology, observing technical economic and ecology factors*. The target of the study is to create theoretical basis for elaboration of automated optimisation system on personal computer basis. Optimisation assignment is to reach a compromise among technical, economic and ecology factors. The new methods shall provide the opportunity of reaching a compromise between the computer capabilities and optimisation accuracy under conditions of information uncertainties.

The model structure. In order to simulate energy source new generator unit is added to the system model (see Fig. 4). The generator node and network node, to which the energy source has been connected, is connecting with generator's element.

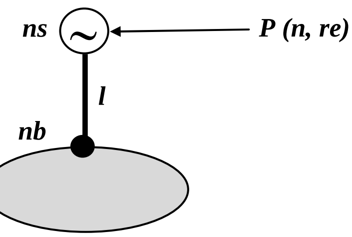


*Fig. 4. Energy source model*

By means of generator element energy saving technologies and electricity import in the neighbouring power systems can be also modelled. Solving the assignments on energy source and network development simultaneously, annual loads and generation curves are modelled with several "modes", for instance winter peak (maximum) load, winter night minimum, end-user mode in power systems with HPP, when HPP has interrupted operation and others.

The energy sources number and structure is changing in the simultaneous optimisation process of energy source and network depending on the development plan (option) and step. In order to compare several options objectively these shall be reviewed at the respective optimal load dispersing among energy sources. Optimisation model system performs such optimisation calculation for all options, for all steps and all modes (see Fig. 5). The optimal output $Pl(l,re)$ on generator elements is determined, to ensure summary costs on fuel in all modes be minimal.

$$Cfl(t) = \sum_{re=1}^{rem(t)} \sum_{l \in MG} Czfl(re,l) \rightarrow \min, \tag{1}$$

where $Czfl(re,l)$ - fuel costs in $l$ mode $re$:

$$Czfl(re,l) = \\ = Pl(l,re) \cdot Tr(re) \cdot b(l) \cdot transp(l) \cdot Cf(l,t)' \tag{2}$$

where $b(l)$ - Specific fuel consumption for electricity generation, kWh (t)/kWh (e),

$transp(l)$ - Relative fuel transporting costs, relative units,

$Cf(l,t)$ - Fuel costs, Ls/kWh (t).

Optimisation observes limitations:

1) $Pl(l) \le P(n,re) \cdot sk(l) \quad l \in MG$,

2) $\sum Pl(l) = Psd(re)$,

where $Psd(re)$ - the total demand (load) of power system in mode $re$.

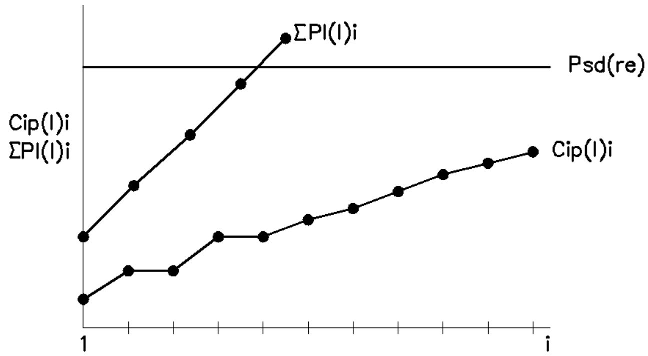


*Fig. 5. Optimisation scheme of sources operation mode:*

## 4 Model Structure of Optimization System

The structure of major models is represented in Fig. 6.

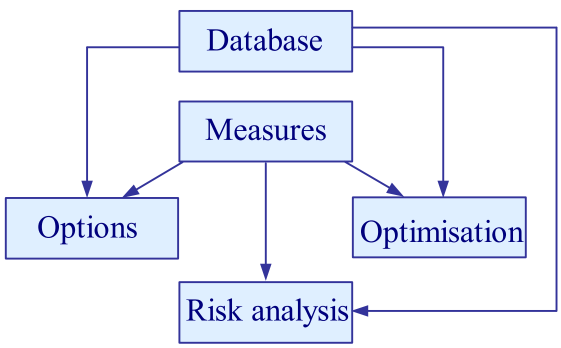


*Fig.6. Scheme of major models (LDM software's)*

Let's review the major models in a more detailed way.

## 5 Model Measures

***Measures*** - forming model of development events. The modelled events are used searching for the optimal option with simulation method (*Options*), as well utilising optimal output state method (OISm) [4,5,6].

The significant definition applying the complex of network economic analyses are probable (alternative), measures - electric power plant, lines or substations construction, reconstruction or demolition. The measure is assigned with capital allocations and network appropriate elements, which in the result of the event are included or are excluded from the calculation scheme. The measures are assigned by the user (users' group) motivated by the specific assignment, experience etc. The user's assigned measures development optimisation model utilises as "bricks" for development options formation and optimal options synthesis. The measures are variables of electric system development dynamic optimisation assignment selection. All probable measures in common form this assignment optimisation range. "The measures" can be interpreted as "purchases". The measures are always related to certain activities. Such variables differ from traditional approach in many other optimisation models, where parameters elements are modelled. We are searching for "what to do" and "when to do"; parameters elements appear in the result of researching work. The measures are subdivided: 1) simple, 2) compound.

The compounds are created from more simplified events, applying logical preconditions: "one of " and "after".

The power system state structure is shown in Fig. 7.

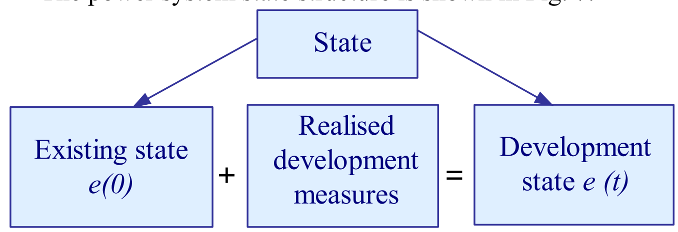


*Fig. 7. Structure of power system state*

The definition of the ***realised measures*** is motivated by the respective object construction, reconstruction or liquidation completion (closing), but not the time of construction, reconstruction or liquidation. The model assumes that the event is realised at the beginning of the first year of the development step. The time of construction, reconstruction or demolition expires with this year. The duration of this time interval is observed according to the costs (capital investments) calculation of respective measures. During the measures realisation the calculation scheme is being changed.

***Probable realisation period.*** This period commencement usually is determined by time duration of construction, reconstruction or liquidation. Usually it's expiry term coincides with the assessment period expiry term but under specific conditions the realisation period could be finished earlier. For instance, if on the site, on which a new power substation has planned to be built, before the calculation period completion, other civil construction works could begin.

## 6 Model OPTIONS

By this model applying development measures, the user forms development options and performs its technical economic analysis. In Fig. 8 the model structure is presented. The model *Options* can be used for simple optimisation assignment direct solution or for complex assignment on optimisation range reduction.

The main parts of model are:

**Options** - options formation model; ***v* m** - number of formatted options

**External cycle** - that is, by options $v = 1,2,\ldots v\,\mathrm{m}$;

**Internal cycle** - that is, by development steps $t = 1,2,\ldots t\,\mathrm{m}$;

**State** - forms calculation scheme, loads and generation for power system state $e(t)$; reviews all the load states; calculates power flows, energy losses; determines whether the state is technically adequate; calculates power supply reliability and ecological criteria;

The output of model options - range the options according to the integral criteria and discharge calculated technical economic criteria.

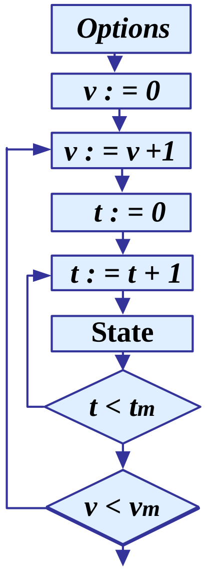


*Fig. 8. Structure of model Options*

# 7 Optimal initial state model

OPTIMAL INITIAL STATE *(OIS) model* - dynamic optimisation model, utilising optimal output state method [4,5]. Optimisation range is formed by formed measures (see Fig. 6), OIS model structure is presented in Fig. 9.

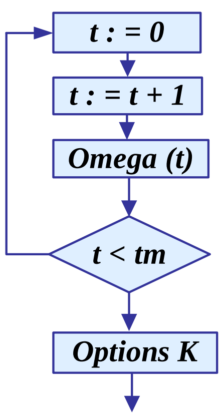


*Fig. 9. Structure of model OIS*

The main parts of model *OIS* are:

**t: =** - direct cycle according to development steps;

**Omega (*t*)** - optimal output state at the collection step $t$ model; total omega $(t)$ is input information set omega $(t+1)$ searching;

**Options K** - more optimal development options formation, applying *OIS*; in total omega $(t)$, $t = t\mathrm{m}, (t\mathrm{m}-1)\ldots 1$;

The output of model *OIS* is the same as in model *Options*.

***Optimization*** selects the competitive options group (up to 10 options). ***Optimization consists*** of two sub-blocks: 1) set up of alternative actions and 2) dynamic optimization. Optimization takes place under the determined information - average forecast.

In order to observe uncertainty after Optimization - ***Risk analysis shall be applied.*** Optimization is performed by the optimal initial state method (OIS).

*Optimal Initial States methods.*

The methods based on dynamic programming (*DP)* seem to be very attractive since they really allow representing the dynamic nature of the development process. Another advantage of the method is that there is no need for linearization of the objective function used in the optimization process.

This also means that the objective function can contain present values of costs, which reduce influence of investments allocated for the future.

Thus, the decisions made for the nearest future will be correct, but the decisions for the distant future can be corrected if more accurate forecasts are available.

The only challenge that makes *DP* not applicable to the real-size network-planning problem is the so-called "curse of dimensionality"; the method demands very capacious computational efforts. On the other hand, when talking about network planning, in many cases it means reinforcement of existing network. These are the types of tasks where dynamic programming could be applied efficiently.

The idea behind *DP* is that the decision at the $t^{th}$ stage is obtained from the decision made at stage $(t-1)$ minimising the transfer cost of moving from the starting point to this stage, which mathematically can be expressed as follows:

$$F(t,e) = \min_{\{G(t,e)\}} \left[ g(0,e(0)) + g(1,e(1)) + \ldots + g(t,e(t)) \right] \quad (3)$$

where

$\{G(t,e)\}$ is the set of acceptable strategies during the time $t$ and until $e$ is reached,

$g(t,e(t))$ is the component of the objective function at $t^{th}$ stage for the state $e(t)$.

Furthermore, it can be shown, that Equation (3) can be reduced to the following recursive equation of *Dynamic Programming*:

$$F(t,e) = g(t,e) + \min_{\{e(t-1) \subseteq e\}} F(t-1, e(t-1)) \qquad (4)$$

where $\{e(t-1) \subseteq e\}$ stands for the set of states $e(t-1)$ from which the transition to state $e$ is feasible.

Then the optimization process can be accomplished by decision of some set of equations according to (4) minimising the objective function for the period from the initial to the final stage.

In order to overcome the difficulties related to high dimensions, there are attempts to reduce computational capacities needed for realisation of the dynamic programming method.

A number of researches have applied *DP* to the distribution network reinforcement problem, attracted by its advantageous features. Therefore, DP can not be applied for complicate (n>10) distribution network reinforcement problem solution.

Considerable limitation of the algorithm of the DP is that with the number of variables $n$ exponentially increases the number of states, which is $2^n$ ($n = 30$ milliard stages).

The method *OIS* considerably reduces the number of states for examination compared to pure *DP*. The idea behind this algorithm is that as the dynamic optimization proceeds at each stage only some states could lead to the optimal solution. These states called optimal initial states should be kept for further consideration. It gives great savings in computer time and memory.

Traditionally for *OIS* selected in real task we use character economics curves of network (see Fig. 10).

The *OIS* set is formed by gradient method.

$$grad\ f\left(t,e\left(t,m\right)\right) = \max_{e\left(t,m-1\right)\subset e\ \left(t,m\right)} \left[f\left(t,e\left(t,m\right)\right) - f\left(t,e\left(t,m-1\right)\right)\right] \quad (5)$$

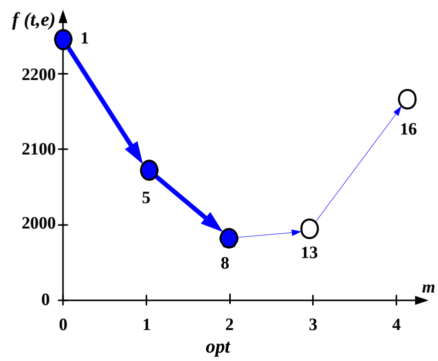


*Fig.10. Characteristics of economic curves of network (example)*

The value of the objective function to optimal number of measures opt $m$ is increase but, its go up then $m >$ opt $m$. If $m >$ opt $m$, then OIS search in this direction is stopped.

## 8 Model Risk

*Risk* - risk matrix formation model, applying *Options* or *OIS* options sets. The structure of model *Risk* is presented in Fig. 11.

The presented sets of development states can be selected before risk analysis, can be supplemented during risks analysis based on the obtained results. The optimal option is selected according to minmax R criterion.

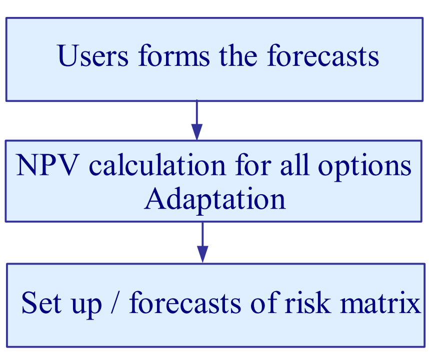


*Fig.11. Structure of model Risk:*

The forecast is characterised by:

- Forecast probability factor $q$,
- Load increase factor by steps,
- Losses cost elevation factor by steps,
- Interest percent rate,
- Inflation percent rate for investments and costs in network,
- Actions costs
- Capacity of new Power Plant.

Based on many researches having estimated options under uncertainty it is sufficient with relatively small scope of information groups, which represent information probability range. That is due to that: 1) the curve of target function in optimal area is very flat; 2) the system parameters are changed discreetly.

For the assignments of power supply utility development the most appropriate are the following criteria: target function mathematical expectancy minimal value and minimal maximal risks.

Minimal maximal risks

$$\min_{j\in v} R\left(j\right)_{\max} = \min_{j\in v} \max_{i\in\mu} \left(F\left(i\right) - F\left(j,i\right)\right)\cdot q \quad (6)$$

where $F\left(i\right)$ is maximal target function value in case of forecast $i$.

## 9 Conclusions

In LEPSS the researches of such information system take place for scientific background elaboration as well for practical studies. According to the assignment of Latvian power system transmission operator The Methods on assessment of transmission network and generation system capability for 5 and 10 years perspective in compliance with EU Directives on power supply reliability and investments for its provision is being elaborated [4]

In conclusions: 1) the study on elaboration of optimisation models system is at the initial stage; 2) although at present the simulation model software (*LDM-PG'05*) is already being applied, the work on optimisation models system elaboration shall be continued.

This work has been supported by the European Regional Developmental Fund project in Riga Technical University.

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