RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Power Engineering

Anna MUTULE

Electrical Engineering Doctoral Programme
(student card No. 951REB154)

THE DYNAMIC MODELING OF OPTIMIZATION OF LOW VOLTAGE NETWORK

Summary of Thesis of Scientific Degree of the Doctor Engineering Sciences (Dr.Sc.Ing.)

Scientific supervisor
Dr.Sc.Ing., Prof.
Zigurds Krišāns

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EXECUTIVE SUMMARY

Actuality of the problem

Today any project development is essentially depends on its rentability and economic viability based upon qualified motivated and technical & economic evaluation or calculation. Besides, the more substantial financial investments share is envisaged, the more significant is dear-cut technical and economic analysis. In order to ensure the efficient and operative performance of technical &economic analysis and calculation in power energy industry the optimisation method software in computers is to be used.

The dissertation promotion work has been elaborated in Power systems mathematical modelling laboratory (EMML) of Latvian Academy of Science Physical Energy Institute where since the year 2001 I have been working combining work and study. In the promotion work the solutions are suggested on low voltage network optimisation problems.

The power system mathematical modelling laboratory (EMML) already since 1969 has been dealing with electric power systems development optimisation dynamic models using big electronic computing machines, in this area it has a leading position in Academies of Science of former USSR and a sole laboratory which created models still operable and that are used for specific development projects options analysis. In 1992/1993 in EMML serious investigations were started on dynamic optimisation model elaboration with personal computers and in 1993 when demand for specific calculations and analysis was forwarded by Latvenergo Development Department the specialists of Laboratory were ready to perform these calculations and simultaneously introduce the research into practice. In 1994 the system was worked out on medium voltage economic analysis LDM-VS Latvenergo distribution networks. In 1994 the created system was applied for the fulfilment of Latvenergo assignment as motivation and background of Liepajas network reconstruction. Summarising the obtained experience in 1995 new medium voltage technical and economic analysis system version LDM-V5-95 was created, which comparing to LDM-V5 Latvenergo has wider application sphere and higher utilisation efficiency. In 1995/96 the medium and higher voltage (6-110kV) network technical and economic analysis system was improved and altered according users equirements and ensured other author's modules of LDM-VS in SJSC Latvenergo subsidiaries and head quarters.

In 1995 the programme system LDM-VZS was created on low voltage and medium voltage 20 (6-10) kV network development and operation technical and economic analysis. That was the first low voltage analysis programme, which was created by specialists of EMML.

Within the period of 1993 till 1999 the elaborated software systems which were handed over to Latvenergo for application in the company, its subsidiaries and structural units have been adopted to Latvenergo needs and specific requirements of Eastern European countries, that consequently hampered the use by Western developed countries for software projects optimisation and analysis. But still it was not Window programme and therefore it was not sufficiently friendly to users.

In 2001 EMML created new technical and economic analysis and optimisation programme LDM-VZ'01. The programme was created in Delphi language, using all operative system Windows advantages. The software LDM-VZ'01 is capable to perform analysis on reconstructed and newly built low voltage network objects as well as on transformer substations (20/0,4 or 10/0,4 kV), new objects and reconstruction investments effectiveness analysis under conditions of ambiguous perspective information, using Net Present Value (NPV) criterion and network dynamic optimisation. LDM-VZ'01 is tailored for application in distribution network enterprises. Since 2001I have been working with this programme on its testing and implementation stages.

The objective of the work

The targets of the promotion work:

1. to select low voltage network development optimisation process method scientifically based on comprehensive research solutions of real low voltage network development assignments(tasks)
2. To work out construction principles of users friendly low voltage development optimisation programme.

Research methods

The system research methods are firstly analysis and synthesis. The system access principles are used in the work as tasks (assignments), targets and criteria cohesion, the definition of system essential features and mathematical modelling methods. Besides, mathematical statistical methods are applied.

The results of the work

1. The requirements are worked out on low voltage development optimisation methods for the Latvian conditions;
2. Optimisation method on low voltage development is selected and approbated.
3. The constructional principles on users friendly optimisation programme of low voltage network development are elaborated;
4. The programme Darja on low voltage network optimisation process research is created;
5. Optimisation criteria have been researched and recommended that ensure electric energy quality in sites that economically are not feasible.

The practical significance of the work

In the result of the work the model LDM-VZ is shaped that is envisaged for low voltage network dynamic and investments effectiveness analysis.

The approbation of the work

The results have been available to public audiences and these have been under discussion: During the Conferences:

1. RTU 43 -d Students scientific and technical Conference
2. RTU the 43d International Scientific Conference
3. The 2nd International Scientific Symposium "Elektroenerģetika" Stara Lesna, Slovak Republic;
4. Scientific Seminar of Russian Academy of Science Ural Department "Power system operative management - new technologies ", Siktivkara, Russia.
5. 11th International Power Electronics and Motion Control Conference, Riga Latvia.
6. International Scientific Conference: Power system: control, quality and competitiveness " Russia Ekaterinburga;
7. The XIIth International Conference on Present Day Problems of Power Engineering" (APE 05) Jurta, Poland;
8. International Scientific Conference 2005 IEEE St-Petersburg, PowerTech, St Petersburg, Russia;

and others.

Seminars (training courses) for SJSC Latvenergo subsidiaries employees (REN, CEN, EEN, NEEN, NEN) on losses -WGD and LDM -VZ (in 2004) 30 persons participated.

Publications:

In journals:

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14. Z. Krishans, A. Mutule, A. Kutjuns, Integration of distributed generation in the networks of Latvian power system. 2005 IEEE St. Petersburg Power Tech, St. Petersburg, Russia, June 27-30,2005

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The structure of the work

The promotion work includes introduction, 5 parts, conclusions and annexes.

1. THE ASSIGNMENTS ON LATVIAN LOW VOLTAGE NETWORK DEVELOPMENT OPTIMISATION

In the First part the Latvian low voltage network structure and loads dynamic analysis is performed which has been as the basis for optimisation area and variable characteristics determination.

The distribution network cannot be characterised in a distinct way. The created scheme is correct in principle but it is not rational in all sites. There are two reasons for that- due to industrial and agricultural large producers decay after 1999 the electric power loads centres have been changed and historically the situation is being created that distribution network transformers users transfer electric energy using two times longer low voltage network comparing with medium voltage line using for transformer supply.

The major task of distribution network is to improve the electric power supply reliability and electric energy quality. Therefore it is required in the perspective to keep the existing medium voltage main network curve scheme, e.g. double-edged supply lines from two substations or one substation varied bus bar sections. The lines are operable in radial regime with division link in power flow point; maximally exposing 20/0,4 kV transformer nodes to load centres. In the renovated and reconstructed distribution network districts to prolong 10 and 20 kV lines length in regard to 0,4 kV network from 1/2 up to 1/1,2; more widely introducing medium voltage and low voltage lines total suspended cables. This makes lines more economic; fewer problems will be for landowners; to use more buried cables lines in rural areas; in the nearest future gradually reduce specific weight of bare wires lines during regular renovation and reconstruction works, replacement of bare wire lines with cables and lines with suspended cables,

Low voltage lines statistical indicators within the period of 1998 up to 2004 are given in the table 1.1. (Measurement unit - km)

Table 1.1

Statistical indicators

Name	1998	1999	2000	2001	2002	2003	2004
0,4 kV lines	64720	64577	65546	65687	65796	66 320	66 876
0,4 kV overhead lines, incl. :	58426	58134	58585	58027	57362	57 131	56 896
0,4 kV suspended cable (AMKA)	186	628	1461	2059	2665	3 467	4 087
0,4 kV cable	6293	6442	6960	7660	8434	9 189	9 979

The total length of low voltage lines is twice as long as medium voltage (6-10-20kV) networks length and 13 times longer than transmission (110-330 kV) network total length. This reflects the significance of low voltage network. The total length in this period (1997-2004) is increased by 2156 km. The network structure has been altered replacing overhead lines by new lines types with suspended AMKA cables that increase electric power supply reliability to low voltage network customers.

The number of 20/0,4 kV substations since 1998 till 2003 has been increased by 1675 (10.3%). The total installed capacity up to the year 2000 is being uninterruptedly increased but within the period of 2001 up to 2003 is being systematically reduced. In 2003 the summary capacity is by 19 MVA (0.7%) higher than in 1998. The number of 10-6/0,4 kV substations since 1998 up to 2003 is increased by 276 (10,7%), but the smallest number of substations was in 2000. The summary installed capacity is increased by 238 MVA (20%).

The decreasing of summary capacity justifies about the reconstruction taken place in low voltage substations - with the target to reduce losses, the old unloaded transformers were replaced by new ones with lower capacity and less idle losses.

At present low voltage networks are characterised by substantial voltage losses. Low voltage network admissible voltage losses are 5%, in the reviewed selection part of the network the maximal voltage losses contain 11,84%, 50% from the selected network voltage losses exceed the admissible level. It means that the significant criterion for low voltage optimisation method is voltage losses; in the result of optimisation the technically acceptable option shall be obtained where no non-admissible voltage losses be in any nodes.

The dynamic of electric energy consumption within the period since 1990 up to 2003 for different customers groups is represented in Figure 1.1.

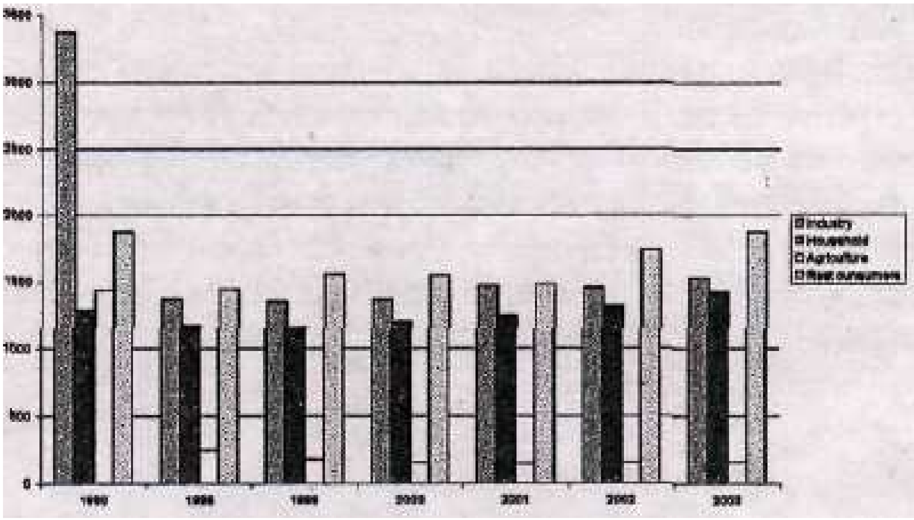


Fig.1.1. Electric energy consumption within the period 1990 up to 2003.

Usually low voltage network provide the power supply to such consumers groups as: household, agriculture, other consumers (shops, hospitals, schools, offices etc.). The household demand in 1995, 1999, 200 and 2001 was slightly less than in 1990 (the maximal reduction in 1999 -10.8%). In 2002 demand is already by 2,4 % more that in 1990, but in 2003 - by 9,5%. The demand elevation in household in 2003 comparing with 2002 increased by 7.3 %. The dynamics of demand of the rest consumers is analogous to household demand dynamics. The demand elevation for the rest consumers group in 2003 comparing with 2002 is increased by 7.3%. The demand dynamics of agricultural users group is similar to industrial demand dynamics. The loads are decreased by 9,6 times. But still during the latest years there is a substantial growth. Load elevation in agricultural group in 2003 comparing with 2002 has increased by 4.3 %.

The analysis has shown that in the foreseeable perspective the load in low voltage network can be increased. Therefore for optimisation programme of low voltage network the dynamic optimisation is to be done observing the load elevation and demand elevation probable structure.

The loads have been changed not only in quantity but also in quality. Due to the introduction of modern electric appliances and new technological equipment the loads curves are changed principally. These become denser.

The technical economic network analysis and optimisation shall be done in operative and regular way, The changing situation and previously taken decisions shall be corrected - to gain economic effect. Judging by the developed countries experience the initial economic analysis is very significant stage for rational decision taking - decisions which are taken in the stage of analysis and planning of the respective measures or activities already by 85% determine the total cost value in entire economic life cycle, but project, construction and maintenance total costs could be influenced only by 15%.

The most urgent requirement to solve reconstruction and modernisation issues is for low voltage network. At present loads deviations are very irregular; in some regions the loads are decreasing but In other areas increasing rapidly. In low voltage network the load probable characteristic curves shall be assessed.

The tasks of technical economic analysis of low voltage networks are;

- Regular analysis of the current conditions - in order to identify bottle-neck places and major problems;
- New users optimal connection;
- Optimal network reconstruction - wires replacement, new lines and substation construction;
- Modernisation - wider use of suspended cables AMKA, replacement of transformers.

All these issues are to be solved on the levels of maintenance and operation, planning and project elaboration. The optimisation occurs both in time and in premises, where the optimised network model is placed (calculated scheme that described in graph way). Time axis is divided into steps that cover life-cycle operation period (25 years). Steps number - up to 15. Optimisation premises side can be characterised by number of nodes,

The calculated model value is dependable on solved optimisation task:

1. Wires replacement, wider use of suspended cables AMKA and new lines constructions - calculated model corresponds to low voltage object model - 50 nodes.
2. Construction of new power supply substations in the existing network - in the calculated model four objects models are to analysed and reviewed in total - 200 nodes.

Optimisation variables are:

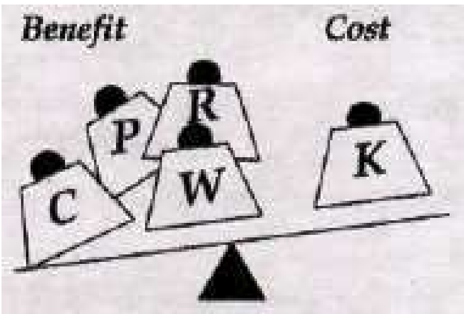
1. sampled network elements groups;
2. binary (are or not) variables with logical restrictions.

2. OPTIMISATION CRITERIA OF ELECTRICAL NETWORK DEVELOPMENT

In the second part optimisation criteria are reviewed and selected from the point of view of electrical network expansion reconstruction and modernisation activities optimisation principles and problems solution. The determined and diversified criteria are selected which are to be applied in the dynamic model of low voltage network optimisation.

The target of electrical network optimisation is to ensure opportunity for different level managers to take a decision, which is based on objective factors but not only on expert judgements and assumptions.

From the mathematical point of view optimisation means methods and algorithms with the help of which is calculated minimum or maximum of target function F, usually with many variables, observing additional requirements, expressed by equations or no equations way. In the assignments of electric network the variables are development activities (or measures), but restraints- technical criteria - voltage losses, lines and transformers admissible loading etc. For the assignments of electric network development optimisation usually are many criteria.



2.1. *Development activities assessment*

One side of the weight scale are capital resources contributions (finance), that is required for the activities realisation, the second - acquired advantages or benefits that are created due to realised activities:

1) operation and maintenance costs (including energy losses costs reduction, C);
2) voltage losses reduction (P);
3) new users load connection (W);
4) energy supply reliability improvement (R) and others.

For one side of these acquired benefits are just monetary value, but in other there such acquisitions that it is difficult to evaluate by monetary value. But still for optimisation performance that is necessary.

The measures or activities are to be evaluated, applying the method, which is called as energy object life-cycle concept. The effectiveness of capital investments is to be evaluated observing maintenance and service costs, fault maintenance costs and other costs. On the stage of project elaboration of construction object it is not sufficient with cost analysis for one year. All these assignments are to be reviewed for the entire period of the object equipment life cycle.

The major economic effectiveness ratio are net present value (NPV), IRR Internal Rate of Return and pay-off period. An Indicator of net present value observes discounting or money value during discount period (according to discount rate). NPV is expressed by monetary units. If NPV>0, the project is economically effective and the more NPV, the project is more effective, but, if NPV<0, the project is not effective, it is not paid-off and cause losses. If NPV-0, the project is paid-off but it will not profitable.

$$NPV = \sum_{t=0}^{T} C_t \cdot \frac{1}{(1+i)^t} = \sum_{t=0}^{T} C_t \cdot d_t \quad , \qquad (2.1)$$

where i - income rate;
$C(t, e)$ - annual cost in step t;
d_t - discount coefficient in step t .

The technical criteria depend on network nominal voltage. In dynamic development optimisation models technical parameters restrictions, for instance, power flow permissible values etc. observe not with rigid margin values but with so-called fluctuating margins.

Using rigid margins network condition is inapplicable (not considered further on), is any element margin is exceeded by some percents and this hampers development process analysis and optimisation. First of all margins data are approximate. Secondly, in real new assignments there is high probability not to obtain not only optimisation results but also information for further activities. Using fluctuating margins for the target function shall be added additional criterion (penalty functions).

In dynamic models the comparison (bench-marking) options are obtained optimising reviewed energy objects at the level of average data (base forecast). In the result of optimisation up to ten highly competitive options are obtained. Further on "researcher", utilising his own experience could decrease or supplement this data amount. For the optimal option selection costs matrices are used. The matrices rows (in dynamic models) correspond to forecast but columns - to options. In the matrix the respective target functions are recorded- The economic analysis in compliance with the method shall be performed in regard to object economic life - cycle (in electric network - 20-25 years).

In case of ambiguous information the analysis model shall be furnished with risk analysis. The risk analysis ensures the opportunity to select the optimal option under the ambiguity conditions. Selecting the options under the ambiguity conditions the sequence shall be the following:

- Select information the, that represents information credibility limit, further on i-data compilation set is named by forecast I;
- Select evaluation criteria option;
- Selection bench-marking (comparison) options;
- Select optimal option.

The most feasible and suitable criteria for the task solution of power supply utilities development are the following: target function mathematical anticipated minimal value and minimal maximal risk.

$$\min_{j\in v} R(j)_{\max} = \min_{j\in v} \max_{i\in \mu} \left(F(i) - F(j,i)\right), \qquad (2.2)$$

where $F\backslash i)$ - maximal target function value of the forecast in i - case.

The risk analysis ensures the opportunity to analyse parameters data - forecast influence on options reciprocal effectiveness and to select the best option by the minimal risk in case of ambiguous information, Options risk analysis is adopted. The forecast is characterised by - forecast weight (credibility), load increment by steps, losses prices elevation coefficient by steps, interest rate, inflation percent rate on investments and expenses in network, activities (measures) costs,

3. OPTIMISATION METHODS

The third part is focused on optimisation method selection. The principles for optimisation methods selections are worked out. The modern optimisation methods are analysed here. For the low voltage network development optimisation it is recommended to use optimal initial states s method.

For the selection method elaboration of electric network development optimisation a lot of research works have been done. On many classical methods concerned a rather significant assessment is elaborated, In promotion work new methods are analysed in a more detailed way.

In the first and second parts the requirements are formulated which are to meet the optimisation development models:

- Optimisation shall be with discrete variables;
- Optimisation shall be of many steps (time);
- In optimisation process load increment and economic ratio changes in time shall be observed;
- In optimisation process all depreciation period shall be reviewed (20-25 years);
- Technical restraints: voltage losses, unconnected load presence, lines and transformer loading;
- Selection criteria are summary discounted losses for calculation period;
- In the optimisation process many and different alternatives are to be reviewed: TP construction, replacement of transformers, wires replacement, use of other

type lines (suspended cables and cables) network configuration alteration, new loads connection;

- For all options electric calculations shall be done;
- In the result of optimisation more competitive technically adequate options are to be obtained;
- The optimal selection is to be performed taking into consideration perspective information ambiguous characteristics.

The adequacy to these requirements is optimisation method selection criterion, In the promotion work the following methods are compared:

- Artificial neurons network method;
- Evolution algorithm method;
- Monte - Carlo method;
- Optimal initial stares method.

Optimisation methods benchmarking

Criterion	Methods			
	Artificial neurons *network method*	Evolution algorithm	Monte-Carlo	OIS
Discrete variables	√	√	√	√
Multi-steps (time)	-	√	-	√
Observe load increment and economic ratio changes	-	√	-	√
Review all the depreciation period (20-25 years)	-	-	-	√
Technical restrictions (voltage losses, unconnected load presence, lines and transformers loading)	Only for one development step	√	Only for one development step	√
Review diversified alternatives (TP construction, transformers change, wires replacement, use of new type lines (suspended cables), alteration of network configuration, new loads connection)	Only for one development step	√	Only for one development step	√
For all options electric calculations are to be done	Only for one devel. step	√	Only for one devel. step	√
In the result of optimisation more competitive technical adequate options are to be obtained	-	√	-	√
The optimal selection is to be performed taking into consideration perspective information ambiguous /uncertain character	-	√	-	√

In order to achieve the best optimisation results I have selected OIS method based upon the following requirements:

1. It corresponds to the set needs;
2. There is substantial experience on network optimisation assignments solution;
3. There is opportunity to utilise existing LDM group software programmes.

4. THE ANALYSIS OF TECHNOLOGY CONSTRUCTIONAL PRINCIPLES OF THE DYNAMIC MODEL OF OPTIMISATION OF LOW VOLTAGE NETWORK

In the process of modern automated control system creation one of the major concerns is to work out special mathematical background (package of control software). Information processing and control algorithm and software design to great extent determine all control systems expenses (50-60%) and system creation time period; but the major - is efficiency of automated control system major target assignments fulfilment. In the technique development process the creation of sophisticated and complex systems and the control of these systems became one of the most significant modern scientific, technological and economic problems.

The practise of systems creation put forward new assignments that cannot be solved with traditional tools and methods. The automated control system designing problem can be split into more further particular problems: functional problems, construction problems and technological problems.

The mentioned designing problems are used to be characterised as mathematical base development. In a wider meaning this term comprises functional algorithms, automated programming tools and software complex testing. The functional programme scope usually comprises 50-70% from the software total scope. In the meaning of the mathematical software that is computation process organisation and functional control programmes as well as programming automated tools and programmes testing.

The main target assignment of the control programme testing is identification of operable availability fact according the requirements of the technical task as well as detection of errors and the adjustment of the complex in compliance with the customers needs.

Low voltage network development analysis technology constructional principles. The development dynamic optimisation model is structured in the dissertation as common decision taking technological risk (in the development analysis stage). The technology covers the following key groups: team of engineers, analytics who elaborate development options and its technical and economic motivation and background; b) information system with optimisation and evaluation programmes (procedures); c) key-persons (leaders) who take decisions in regard to construction object where and on what account. The necessity to create such technology is substantiated in the 1st and 2nd parts; it follows as a result of 1) existing network conditions and 2) technical and economic analysis significance under marketable conditions. The main assignment of decision taking technology is to prepare information in different level of management in order to motivate with objective facts but not only basing upon experts assumptions.

In the frame of such technology this working tool (low voltage network development optimisation model) should be suitable from the users point of view. The technology shall meet the following requirements:

l. Information architecture shall be unified;

2. The model of the analysed object input shall be simplified, easy handling and prompt;

3.The analysed object model shall be saved if updating information the key-person would be able to take decisions in decision implementation process;

4. The calculation/ computation period model shall be of multi-step, the number of steps up to 15; 5.The number of discrete alternative measures shall be sufficiently high - 30;

6. Development optimisation assignment input shall be operative;

7. In the optimisation result not only optimal option shall be acquired but also competitive options - up to 10 (if there are such);

8. The analysis of competitive options technical criteria and power supply reliability criteria shall be comprehensive, simple and of high-speed. 9. Information correction and adjustment shall be operable in rapid and handy way in the optimisation and analysis process.

10.The opportunity shall be available under uncertain conditions determine options sensitivity and risk matrices for diversified external factors forecasts;

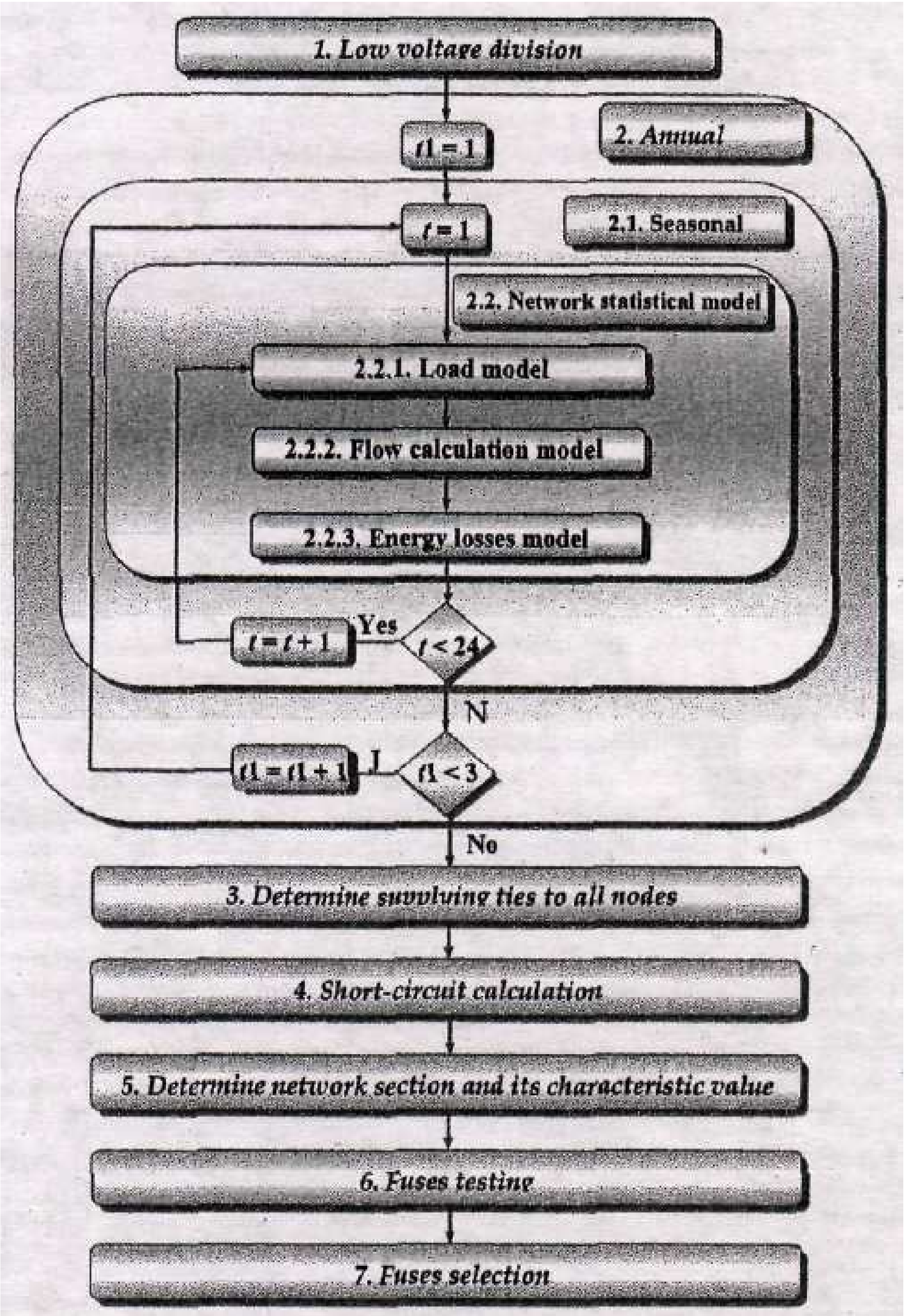
11.In the analysis results the selection probability shall be available in several ways - dependent on the management level it reaches.

12.The models shall ensure the opportunity to review 2 nominal voltage levels. The systems are interrelated with external databases.

The main systems units are:

- Data unit;
- Electric calculation unit, where all major parameters are calculated;
- Options benchmarking unit, where options formatting and economic criteria calculation are performed;
- Optimisation unit where optimal and competitive project/design options are selected;
- Analysis (decision-taking unit) where several forecasts are reviewed (load increment, interest rate percentage etc.) and sensitivity and risk analysis is performed.

Electric calculation structure of Low voltage network is shown in 4.1. pict.



4.1. The low voltage network electric calculation method structure

First of all low voltage division can be of independent role if loads deviations or due to other reasons the issues on division point alteration in the network shall be solved. At the database structure where one network object is supplied from one existing transformer substation.

But still the significance of Low voltage division is the effectiveness analysis of different options- Such measures or activities can be: the construction of new transformer substations or switchgear, wires replacement, new lines construction as well as the mentioned measures combination. In each such option usually there will be varied division areas. The low voltage network can be analysed (calculating power flows, voltage and energy losses, as well as short-circuits in such a case that is radial. Therefore the unit Low voltage division has a significant meaning in the analysis technology.

In parallel for software introduction distribution network the specialists training shall be conducted at Latvenergo Training Centre. The training courses are arranged for engineers and technical personnel of networks, transmission departments and design organisations. The trainees acquire the skill working with software LDM-VZ'01, for technical issues solution with economic approach to the item and capability to use software LDM-VZ'01 in current work. The targets of the courses are: to introduce the trainees with software LDM-VZ'01 potentials and applied technical and economic calculation methods; to train the trainees practically work with software LDM-VZ'01; render methodological assistance in the assignment solution of economic effectiveness analysis of the enterprise. The users training programme is worked out in compliance with LDM-VZ structure and analysis technology. For the objective achievement of the course introduction three days are required, hardware and software LDM-VZ'01 description (users manuals) for each trainee.

State JSC Latvenergo employees training course "Low voltage and medium voltage network technical and economic analysis and optimisation programme LDM-VZ'01 is of 3 days duration period.

Topics for training programme	**Type of training**	**Number of hours**	**Day**
General characteristics of *LDM-VZ'01* programme.	Lecture	1	1
Programme *LDM-VZ'01* installation.	Practical works	1	1
Electric network database: a) objects; b) nodes, lines, transformers, commutation apparatus; c) Database *INDY* un *IRSIS* involvement.	Practical works	1	1
With programme *ZUDUMI-WGD'2000* formatted network object input *LDM-VZ'01*	Practical works	2	1

Topics for training programme	Type of training	Number of hours	Day
database.			
Electric network development model: a) Calculation period; b) Decision taking period; c) Calculation requirements.	Lecture Practical works	1 1	1
Scheme plan and measures/activities formatting.	Practical works	3	2
Options formatting.	Practical works	1	2
Options electric calculation: a)flows and voltage losses; b) short-circuit current; c) fuses testing and selection .	Practical works	3	2
Economic criteria: a) annual costs; b) discount expenses; c) pay-off period; d) NPV criterion e) IRR method.	Lecture Practical works	1 2	3
Options analysis under uncertain conditions: a) sensitivity analysis; b) risk analysis.	Lecture Practical works	1 1	3
Optimisation	Practical works	1	3
Test	Test of each individuals	1	3

Training methodology. The training course is arranged continuously combined lectures with theoretical technical and economic calculation issues with practical works. The lecturer has to be completely aware of the programme *LDM-VZ'01* and be able to respond to all questions of the trainees. Therefore the lessons are arranged as seminars.

5. THE RESEARCH OF LOW VOLTAGE DEVELOPMENT TECHNICAL ECONOMIC CHARACTERISTICS CURVES

In the fifth part the research methodology and research tool of low voltage development technical and economic characteristics curves- software DARJA is worked out as well aa experimental research results concluded. The specific recommendations are given for optimal initial states method application for low voltage network development optimisation.

The main demand in dissertation on low voltage optimisation methods is: in the result of optimisation the created options shall ensure electric energy quality to all clients.

The objectives/targets and assignments/tasks of researches are formulated on the basis criteria analysis. The criteria will be analysed from the point of view of dynamic optimisation process.

The criteria are divided into two main groups - economic and technical. The major economic effectiveness ratio are NPV (Net Present Value, IRR (Internal Rate of Return) and pay-off period.

In the promotion work low voltage network development optimisation is recommended, observing electric energy quality, utilising optimal initial states method (OIS). OIS method determines optimal development process utilising such recurrent equation:

$$f(t,e) = g(t,e)\cdot d_t + \min_{\{e(t-1)\subset e\}} f(t-1, e(t-1)), \qquad (5.1)$$

where *g(t,e)* - Target function in development step *t*, condition *e*.
d_t - discount coefficient in step *t*.

Optimising low voltage network, observing electric energy quality, in each development step *g(t,e)* calculation and its components;

$$g(t,e) = \sum C + \sum H = C_k + C_{O\&M} + C_{\Delta W} + H(1,t,e) + H(2,t,e), \qquad (5.2)$$

where *Ck* - Annual costs on capital investments

$$C_k = \sum_j^m K_j\,(a_{aM} + Int)/100; \qquad (5.3)$$

K_j - Capital investments on development activities realisation;
a_{aM} - Depredation coefficient, %;
Int - (interest rate,%);
$C_{O\&M}$ - Operation and maintenance costs;
$C_{\Delta W}$ - Electric energy losses costs;
H(1,t,e) - Penalty function, that observe non-admissible voltage losses;
H(2,t,e) - Penalty function, that observes lines and transformer overloading.

OIS method could apply in different way - using different algorithms.

One of such types is energy object specific characteristics utilisation - OIS methods and heuristic methods hybrid.

Analytic and experimental researches in medium and higher voltage networks justify that technical and economic characteristics curves (both static and dynamic) of the energy object are conformed to definite consequences *g(t,e)= f(m)*, where *m* is number of realised measures or activities in the initial function f(m), reducing, having achieved minimal (optimal) value, but after it is only increasing. Based upon such consequences s, it is proved that optimal initial states s (OIS) occur only before function *g(t,e)* minimal value. That is, OIS group can be found with gradient method:

$$grad\, f(t,e(t,m)) = \max_{e(t,m-1)\subset e(t,m)} \left[f(t,e(t,m)) - f(t,e(t,m-1)) \right]. \qquad (5.4)$$

The research target is to prove in experimental way that also low voltage network development technical economic characteristics curves consequences could be represented by such theoretical model:

$$g(t,e) = A(e) + \frac{\chi(t)^k}{B(e)}, \qquad (5.5)$$

where *A(e)* - Quality criteria component that is dependable on load;

$\chi(t)$ - General characteristics curves value, that reflects system load;

B(e) - General system characteristics curves that is dependable on system structure and separate elements characteristics curves values (condition efficiency);

k - Constant factor.

In diversified dynamic programming assignments characteristics curves *A(e)* and *B(e)* values have different meaning - depending on economic and technical indicators that ensure system functioning, structure and description. *A(e)* mainly depends on capital investments and usually is of constant value. *B(e)* mainly characterises system reaction (losses reduction, reliability level and other characteristics values, which depends on loads and location in the system changes) and fulfilled measures. In the simple case *B(e)* characterises losses that occur, compensating electric energy losses. In such a case *k* = 2.

The main assignments for the set target achievement are:

1. Creation of fast research tool (software), with the help of which sufficiently large number of measures could be analysed for low voltage objects number.
2. From real 20767 Latvian low voltage objects the selection of particular objects group.

In the basis of research method is calculation on annual costs on capital investments, operation and maintenance & service costs, expenses on electric energy losses, penalty functions on non-admissible voltage losses and penalty functions on lines and transformers overloading. Voltage losses criteria (penalty functions) are calculated in the following way:

$$H(1,t,e)=\sum_{r\in R_n}\sum_{n\in M(r)} Au\cdot\left(\Delta U(n,r)-\Delta Ukr\right)^k, \quad (5.6)$$

where R_n - Normal modes set (72 modes);

M(r) - Group/set of nodes with non-admissible voltage losses in regime/mode *r*;

Au,k - indicators, with the help of which optimisation process could be regulated ; the values of constants to acquire in experimental way;

ΔU(n,r) - Voltage losses in node *n* in mode /regime *r;*

ΔUkr - Admissible voltage losses in low voltage networks.

Ties overloading criteria calculation (penalty function) is

$$H(2,t,e)=\sum_{r\in R_n}\sum_{i\in M(r)} A\cdot\left(Pl(i,r)-Plkr(i)\right), \quad (5.7)$$

where R_n - Normal regimes set in total (72 modes/regimes);

M(r) - Overloaded ties in set in regime/mode *r*;

A - indicator, with the help of which can be regulated optimisation process; constants values obtain in experimental way

Pl(i,r) - Voltage losses in node *n* in mode *r;*

Plkr(i) - Admissible flow in tie *i*.

The research tool shall correspond to the following basic principles:

1. To analyse many low voltage network objects in easy and fast way;
2. To set values for each calculation parameters Au, k and A;
3. To change *ΔUkr* value, losses costs, depreciation and interest rates;
4. In the calculation determine max *AU%* and energy losses per year *W* kWh/year;
5. In the result of calculation information shall be obtained on low voltage network technical economic characteristics curve design.

The observance of these requirements afford easy perform multiple optimisation methods researches and select the best.

In the frame of promotion work of 2004 I have elaborated software Darja. The software is worked out on the basis of low voltage network development optimisation programme *LDM-VZ'01* . The programme *LDM-VZ'01* ensures fulfilment of 1., 3. and 4. basic principles. The fulfilment of the first basic principle

LDM-VZ'01 database structure - database consists of many low voltage network calculation objects that are easy handling and available. Besides, the programme *LDM-VZ'Ol* can be used In combination with low voltage network technical analysis programme *ZUDUMI-WGD* (LOSSES) database Z/S *TĪKLS.* The programme ZUDUMI-WGD is applied for ail VAS *Latvenergo* distribution network calculations. The most part of transformer substations and switchgear are computerised. In my disposal during elaboration of promotion work in The Physical Energy Institute more than 300 network objects were analysed.

For the fulfilment of the third basic principle (change Δkr value, losses costs, depreciation and interest rate) data input entry windows are used Network parameters, Requirements and Basic indicators. For the fulfilment of the forth basic principle the programme block Electric calculations is used. The mentioned operations could be performed during the analysis process from the main Selection menu. In order to ensure the fulfilment of the second basic principle the main Selection menu is supplemented.

The penalty function coefficient Au and k as well as loading coefficient input is placed in the Selection Menu window).

Program's DARJA results output window differs from programme LDM-VZ'0l results output window by target function and penalty function output way. In experimental researches assuming that admissible voltage losses are 6% and 5%. Three different coefficients Au values are reviewed and analysed:

1. 0 - not observing penalty function;
2. 0,5 - observe average penalty function;
3. 2 - observe substantial penalty function.

The researched objects are located in distribution network enterprises DET, *CET* and *AET,* as well in rural areas and cities. The object parameters are changed within wide range (see. 5.1. tab.).

Table 5.1

The parameters range of the researched objects

Summary load , kW	3,48 - 111,99
0,4 kV line total length, m	1720 - 10768
Number of nodes	22 - 176
Number of ties/links	21 - 200
Number of nodes, kur $\Delta U > \Delta U_{kr}$ *	7 - 45

*- for admissible voltage losses values level ΔU_{kr} two values have been analysed: 6 and 5%.

In the research different measures are analysed focused on energy supply quality improvement:

1. Wires replacement, not changing wire type;
2. Replacement of overhead lines with suspended cables (AMKA);
3. Transformers replacement;
4. New TP construction

Based upon diversification of the researched objects, we could assume that the researched objects group is also characteristics objects selection group.

The summary of the results on the research of the groups is presented in Table 5.2.

Summary of the researches results

Object	*Criterion*	**Number of implemented measures**				**Penalty function**		
		0	**1**	**2**	**3**	**Au**	**k**	**A**
1. 1113	Max Δ U, %	9,9	9,78	6,25	5,99	-	-	-
	Δ W, кWh	3413	3592	3109	3092	-	-	-
	g (t,e)	0,15	0,71	1,28	1,52	0	2	0
		460,35	302,11	1,35	1,52	0,5	2	0
2. 1090	Max Δ U, %	13,08	13,08	12,33	5,78	-	-	-
	Δ W, kWh	5050	5012	4868	3807	-	-	-
	g (t,e)	6,35	6,46	6,88	7,27	0	2	0
		327,29	327,30	203,24	7,27	0,5	2	0
3. 1121	Max Δ U, %	7,09	1,42	1,42	-	-	-	-
	Δ W, кWh	5911	6028	2324	-	-	-	-
	g (t,e)	5,34	6,22	6,56	-	0	2	0
		9,8	6,22	6,56	-	0,5	2	0
4. 1044	Max Δ U, %	12,16	11,84	11,76	6	-	-	-
	Δ W, кWh	8601	8541	8538	8246	-	-	-
	g (t,e)	7,51	7,57	7,63	8,19	0	2	0
		401,61	327,87	314,49	8,19	0,5	2	0
5. 1308	Max Δ U, %	8,54	6,36	5,38	-	-	-	-
	Δ W, кWh	14259	12280	11859	-	-	-	-
	g (t,e)	1,94	1,96	2,02	-	0	2	0
		55,14	2,19	2,02	-	0,5	2	0
6. 1193	Max Δ U, %	7,98	6,72	5,46	-	-	-	-
	Δ W, кWh	9272	8242	8088	-	-	-	-
	g (t,e)	3,44	3,47	3,56	-	0	2	0

Object	Criterion	Number of implemented measures				Penalty function		
		0	1	2	3	Au	k	A
		12,29	4,79	3,56	-	0,5	2	0
7. 1311	Max Δ U, %	10,57	7,21	4,65	-	-	-	-
	Δ W, кWh	22582	18440	17036	-	-	-	-
	g (t,e)	1,79	1,7	1,61	-	0	2	0
		279,64	6,8	1,61	-	0,5	2	0
8. 1029	Max Δ U, %	12,65	5,65	2,37	-	-	-	-
	Δ W, кWh	24867	16507	14531	-	-	-	-
	g (t,e)	1,65	2,44	2,5	-	0	2	0
		2370,72	3,02	2,5	-	0,5	2	0
9. 4262	Max Δ U, %	9,17	6,14	4,64	-	-	-	-
	Δ W, кWh	2883	2826	2806	-	-	-	-
	g (t,e)	4,69	4,89	5,19	-	0	2	0
		78,73	6,87	5,19	-	0,5	2	0
10. 2214	Max Δ U, %	10,56	5,23	4,36	-	-	-	-
	Δ W, кWh	22,018	17928	17506	-	-	-	-
	g (t,e)	3,54	8,00	8,17	-	0	2	0
		1220,8	8,02	8,17	-	0,5	2	0

Based upon the summary table we can conclude on the following assumptions:

1. The characteristic curve of the low voltage target function g (t,e)if not observed penalty function, is of U-type curve.
2. The characteristic curve of low voltage target function g (t,e) if observed penalty function is also of U-type curve.
3. In low voltage network if penalty function is not observed, technically applicable options are not obtained.
4. For all objects if Au- 0,5 and k-2, with the OIS method we obtain technically applicable options with minimal expenses.

THE CONCLUSIONS

1. The analysis of low voltage network justifies that low voltage network development optimisation programme shall incorporate such tasks, as:

- Regular analysis of the existing conditions - in order to identify bottle-neck places and major problems;
- New users optimal connection;
- Optimal network reconstruction - wide replacement, new lines and substations construction;

- Modernisation - wider use of self-supporting cables (AMKA), transformers replacement;
- Ensure admissible voltage losses and admissible lines and transformers loading;

At present low voltage networks are characterised by substantial voltage losses. In low voltage networks 50% of transformer substations voltage losses surpass admissible level.

The major assignment of low voltage network reconstruction and modernisation activities is to ensure the performance of such measure or type of activities scope that reduce electric energy distribution costs price and/ or provide electric energy quality.

2. The analysis justifies that in the foreseeable perspective low voltage loads could increase. Therefore for the low voltage network development optimisation programme the dynamic optimisation shall be performed observing load increment and load increment probable characteristics. The loads are changed both in regard to quantity and quality. Due to the implementation of new modern electrical appliances and equipment the loads diagrams and curves arc changed in principle - these became denser.
3. Approximately 60-70% of electric energy cost price forms the entire costs structure of electric networks - for electric energy transmission and distribution, but only 30-40% - costs for electric energy production and import. It could be assumed that our electric networks are designed and constructed for one and a half times more capacious load and energy consumption, then at present these are underloaded and therefore there no any problems seemed. Unfortunately, this is not like that. The theory has justifies that in network with 70% load cost price is by 15% higher than in optimal network. The existing network conditions are hampered by the fact that network design was envisaged for other structure of consumption and location than now it functions that consequently causes higher consumption costs - 25-30%. Besides, many existing transformers are operated with substantial losses and also other equipment does not meet the modern technical requirements. Therefore, the issue of network reconstruction and modernisation is the most actual and urgent. But still this issue cannot be focused for the sake of the goal itself. The major assignment is to realise such measures and activities that decrease cost prices of transmission and distribution.
4. Network technical and economic analysis and optimisation shall be done on regular and operative basis. Changing the situation previously taken decisions are to be corrected if it gives economic effect. Based on the experience of developed countries the initial economic analysis is a very significant stage for rational decision taking - decisions taken in the stage of activities analysis and planning already by 85% determine total costs for the entire economic life cycle;

but in the stages of project elaboration, construction and operation and maintenance could effect only by 15%,

The highest necessity to solve reconstruction and modernisation issues relates to low voltage networks. At present the loads deviations are very irregular, in many regions loads decrease but in other it rapidly increase. In low voltage networks probable load characteristics shall be considered.

5. Feasibility of each project is evaluated taking into consideration more criteria, from which the major ones are technical need and economic effectiveness. Technical need or necessity motivation is the project correspondence to basic principles of the energy company policy and requirements.

One part of the acquired benefits is in monetary value, but there are benefits that are difficult to express by monetary value. But still ii is required to realise optimisation steps.

The measures/activities are to be evaluated using method, which is called energy object life-cycle concept. The capital investments effectiveness is evaluated observing operation & maintenance and service costs and costs associated with faults and emergency situation prevention and others costs.

Designing construction object it is not sufficient to analyse costs only one year considered. The costs are to be analysed for the entire life cycle of the equipment operation or object functioning.

The major economic effectiveness ratios are Net Present Value, Internal Rate of Return and pay-off period.

Net present value indicator observes discounting or monetary value reduction in time (according discount rate). NPV value is represented in monetary value.

Obtaining dynamic models benchmarking options, optimising reviewed energy object at the average data (forecast data). In the optimisation result up to ten best competitive options are obtained. Further on " researcher" referring to own experience he could reduce or supplement this group. For the optimal option selection the matrix cost method is used. Matrix rows (in dynamic models) correspond to forecasts, but columns - to options. In the matrix the respective target functions are recorded.

The economic analysis in correspondence with methodology shall be made for the entire life-cycle period of the object (in electric networks - 20-25 years).

The development process of project elaboration shall be taken gradually:

1. observing external information details;
2. using output information in previous stages for specific objects taken decisions (horizontal information flow)
3. using supplemented information on previous system compliance (vertical information flow).

6. The requirements put forward for optimisation development models:

- Optimisation is to he with discreet variables;

- Optimisation is to be multi-step (time);
- In optimisation process load increment is to be observed and economic ratios changes in time;
- In optimisation process the entire depreciation period (20-25 years) is to be reviewed;
- Technical restraints;

  1) voltage losses;
  2) presence of non-connected load
  3) lines and transformers loading;

- selection criterion is summary discounted costs within the calculation period;
- in the optimisation process many and diversified alternatives are to reviewed and analysed : TF construction, transformers replacement, wires replacement use of other line types (suspended cables), alteration of network configuration and new loads connection.
- For all options electric calculations are to be made;
- In the result of optimisation more competitive technically reliable options are to be obtained;
- The optimal option is to selected taking into consideration ambiguity character of information.

7. The compliance to these requirements is selection criterion of optimisation methods. In promotion work two such methods are compared.

  - Artificial neurons network method;
  - Evolution algorithm method (EA);
  - Montekarlo method;
  - Optimal initial states method;

  In order to achieve the best optimisation results I have selected OIS method based upon the following requirements:

1. It corresponds to the setneeds;
2. There is substantial experience on network optimisation assignments solution;
3. There is opportunity to utilise existing LDM group software programmes.

8. In dissertation development dynamic optimisation model is used as a tool for the integrated decision taking technology (in the stage of development analysis). The technology incorporates: a) engineers, (group) analyst, who develop development options and its technical and economic basis, b) information system with optimisation and evaluation software (procedures), c) key-persons who take decisions what and how to construct.

The need to realise such technology is based upon: 1) the network existing conditions and 2) technical economic analysis significance under marketable conditions. The major assignment of decision taking technology is to prepare information for different levels managers - in such a way that it would be supplemented with objective facts but not only with experts assumptions.

9. Such technological working tool (low voltage network development optimisation model) shall be easy handling from the user point of view. This should meet the following requirements:

1. The information architecture shall be unified;
2. The input (entry) model of the analysed object shall be simple, easy and fast;
3. In the analysed model object shall be available for saving in the system, to specify the measures in the decision taking process;
4. The model calculation period shall be multi-steps, steps number up to 15;
5. The number of discreet alternative measures shall be sufficiently high - up to 30.
6. The entry of development optimisation task shall be operative (fast);
7. In the result of optimisation not only optimisation option shall be obtained but also competitive options - up to 10 (if there are such);
8. The competitive options technical criteria and power supply criteria analysis shall be full-scale, simple and fast operable;
9. Information adjustment and correction in analysis and optimisation process shall be capable to perform in easy and fast way;
10. or information under ambiguous conditions the opportunity shall be ensured to determine options sensitivity and risk matrix for diversified external factors forecast;
11. The analysis results shall be capable to select in different ways - depending on to what managers' levels these shall be submitted.

10. OIS method could be applied in different ways - applying diversified algorithms. One of such approaches is energy object specific features utilisation - OIS methods and heuristic methods hydride.

The analytic and experimental researches in medium and higher voltage network identify that energy objects economic characteristic curves (diagrams) both statistical and dynamic) are conformed to definite consequences, g (t,e) - f(m) where m is number of realised measures of initial function f(m), decreased, reaching minimal (optimal) value, after it only increased.

Based upon such consequences it is approved that optimal initial states s (OIS) are identified only before function g (t,e) minimal values. That is OIS group can be identified with more rapid gradient method.

The research target is to prove in experimental way that also low voltage network development technical economic characteristic consequences could be described with this theoretical model.

The major assignments for the set target achievement are:

1. Fast operable research instrument (tool -software) with which could analysed sufficiently large low voltage objects number.

2. From real 20767 Latvian low voltage objects characteristic objects selection.

11. In the promotion work in the frame of the year 2004 the software "Darja" was elaborated. The software is elaborated on the basis of low voltage network development optimisation programme LDM-VZ'01.
In the experimental researches we assume that the admissible voltage losses are 6 and 5%. Three several Au coefficients values are reviewed:

1. 0 - do not observing penalty functions;
2. 0,5 - observing average penalty function.

The researched objects are located in distribution network enterprises DET, CET and AET as well as in rural areas and cities. The object parameters are changed within wide margins: summary load (kW): 3,48-111,990; 4kV line total length (m): 1720-10768; nodes numbet;22-176; ties/links number : 21-200, where : *&U>AU$_{kr}$:7-45%.*

In the research different type of power supply quality improvement measures are reviewed and analysed:

1. Replacement of wires not changing wires type;
2. Replacement of overhead lines with suspended cables (AMKA);
3. Transformers replacement;
4. New TP construction.

Based upon the analysed objects diversification we could consider that within the analysed objects there are particular objects selection group.

12. In the results of research and analysis the following conclusions are to be set:

1. The characteristics curve of Low voltage network target function g (t,e) if penalty function is not observed is of U-shape curve.
2. The characteristics curve of low voltage network target function g (t,e,) if penalty function is observed also is of U-shape curve.
3. In Low voltage network I penalty function is not observed technical operable options are not obtained.
4. In all objects if Au =0,5 and k-2 with OIS method technically operable options with minimal costs are obtained.

13. In the frame of promotion work the training methodology is developed.

The training objectives:

- To give an introduction course to the trainees on opportunities of programme LDM-VZ and application of technical and economic calculation methods;
- To give practical course on programme LDM-VZ;
- To render methodological assistance to network enterprise on economic effectiveness analysis task performance.