Power network system reliability and methods of calculation.

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***Abstract* - Power supply reliability is one of the main criteria in estimation of power system networks. The decisions on radical changes in branch of electric power control and trade are still caused by essential monopolization, then reasoned with politicians, public, economic and technical factors and not less with international influence followed by ascendance to international alliances and wherewith connection of electric national network to the international grid. In order to prevent similar problems in a future it is necessary to elaborate new methods of power supply reliability assessment, which will use power network modernization and development. One of these methods is developed and examined in this paper. This reliability problems, which is devote modern, scientific and economic power system planning criteria and this calculation methods, review and assessment, is very actual.**

***Keywords* – Power system reliability, transmission and distribution power network, transmission power line, distribution power line.**

I. INTRODUCTION

As up to now only the Latvian power system has been a deficit system from the entire range of other Baltic power systems, Latvia is interested by joint efforts to increase electric power supply security and reliability. Cooperation and collaboration forms are being investigated for reliable operation of transmission and distribution networks and operative control, as well as maintaining opportunities to act on the electricity market in the Baltic Region observing reliability requirements in transmission and distribution network.

Of course economic development and growth of consumption in Latvia, demand introduction of new generating capacities, new transmission and distribution lines buildings, need to improve power system supply reliability methods and power system electricity market arrangement. In order to prevent similar problems in a future it is necessary to elaborate new methods of power supply reliability assessment and improve existing methods, which will use power network modernization and development. Reliability problems, which is devote modern, scientific and economic power system planning criteria and reliability calculation methods, review and assessment, is very actual. One of these methods is shown in this paper.

II. POWER SYSTEM RELIABILITY

Power system reliability – this is system basic functions performance ability – consumer's electric power supply without interruption with qualitative power energy. The major question of power system reliability investigation is generation, transmission and distribution reliability with its components (see fig.1).

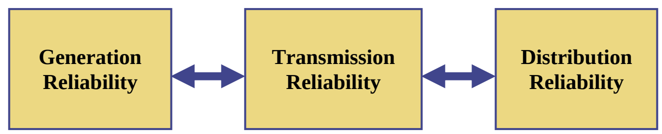

Fig.1. Main components of power system reliability.

III. GENERATION RELIABILITY IN LATVIA

Latvian power system is short of base load capacity. During last five years annually there is produced about 70% of total electrical energy resources in Latvia.

The total installed capacity of power plant generators in Latvia is considerably greater than peak load. But due to limited water storage size hydro power plants cannot operate with total installed capacity during twenty-four hours (except flood period), therefore can be operated only at peak load hours. During spring flood period, there is electricity export for the production of large hydro power plants.

Latvia with its cogeneration power plants, which are operated now on natural gas, to great extent are dependable on energy resources of Russia and cost elevation of energy resources (mainly natural gas) have affect to generation reliability.

If in near future new power station will not build, Baltic countries wait very rugged times. And not to permit this situation, Latvia build one gas station in Riga and in near future will build coal power station in Latvia Western region.

In order to avoid excessive flows of power that could endanger the reliability of transmission system in Latvia, the supply of electricity from Russia is to be reduced significantly after the closure of Ignalina NPP in the end of 2009.

Considering the government support for production of electricity from renewable energy sources, there is a

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considerable activity in development of new wind power station construction in the West of Latvia – in the seacoast of Baltic Sea. At present this activity confines to research work and obtainment of necessary license. According to estimates, if all of the wind generator projects are constructed, Latvia will have power from wind exceeding ≈2000MW. So providing the joint reliable operation of wind farms and two supporting them thermal power plants from one side Liepaja and another size Riga. Construction of a 330kV transmission arc in Kurzeme and a 400MW power plant, as well as developed strong connection with main power generating nodes of Latvia creates preconditions for building interconnections with neighboring countries. All this activities unequivocally will increase generation system reliable functioning.

IV. TRANSMISSION NETWORK RELIABILITY

The transmission of electric energy is a significant link in the whole process of power supply to consumers or distribution companies. The existing transmitting network and it equipment will satisfy predicted growth of capacities and a current consumption the nearest ten years. In future is necessary to reconstruct and modernize high voltage substations and power stations primary schemes and connect electric networks of Latvia and Baltic States with European networks.

Reliability and security of electric power supply integrates reliable operation of power supply circuit and operation reliability of electric equipment. The target and operation sphere of transmission system operator is to determine the measures, undertakings or assignments which would guarantee required power supply reliability and promote adequate EU internal electricity market functionality. The undertakings shall be substantiated by adequate generating capacity level, appropriate balance of demand and supply and adequate interstate connection level for internal market development. Implementing all these undertakings many requirements and regulations are to be observed: non-interrupted electric energy supply, transparency of regulations and legislation, significance of cross-borders cooperation, necessity to maintain and upgrade electric networks as well necessity to keep sufficient reserve capacity in electric power plants and electric networks.

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V. LATVIAN DISTRIBUTION NETWORK RELIABILITY

Latvian Distribution System Operator faces new challenges and have to become an efficient and dynamic provider of electric power distribution services to its customers, improve efficiency of distribution and reduce operating costs and maintenance costs whilst providing customers with a reliable power supply. Key challenges involving the initiatives are to deliver quality and cheep electric energy, ensure excellence in customer care, and create a work environment that encourages teamwork and innovation. With the implementation of the initiatives, dramatic improvements in the performances in all the areas were observed which enabled the company to orient the core business operations with information systems and world-class practices for sustainable reforms.

In accordance with operator technical policy the main dispatcher service tasks are to organize distribution network operative work, saving the structure of the operative guidance of two levels – region and local, to implement IT applications in distribution network; such a distribution automation, Geographic Information System (GIS), Distribution Management System (DMS), Supervisory Control and Data Acquisition (SCADA) platforms. SCADA refers to a system that enables an electric utility to remotely monitor, coordinate, control and operate distribution components, equipment and devices in a real-time mode from remote locations with acquisition of data for analysis, and planning from one central location.

DMS platform is a program for the operative personnel of utilities to monitor and operate their medium and low voltage distribution networks. GIS is the computer based methodology to collect, store, and control, retrieve and analyze data.

After restructuring of the Latvian distribution network – consolidations of 7 distribution network districts, separation of distribution and realization business processes, dispatch control modernization and optimization, are an actual question. After introduction new model structure in correlation on the operative work, as one from main challenges is the optimization of local dispatchers certain tasks such as their disengagement from the inoperative functions, including from the customers calls. Call Center (CC) were developed to support call distribution, capturing the caller line identification, priority customer handling, reduce average electric supply restoration time, lighten dispatchers daily tasks.

For information exchange quality improvement between CC and dispatch centers (DC) there is developed distribution network electric supply outage system (STEPS).

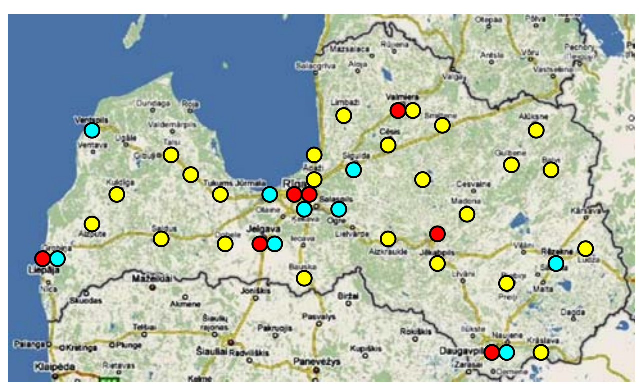

Fig.2. Current DC points in distribution network.

CC operator registers customer's information in the STEPS Faults module for the automatic information exchange between CC and DC dispatchers and will be replaced by GIS Call Register module, but STEPS Outage module provides a registration of all 0,4kV – 20kV networks outages in a certain order.

Fig. 3. Proposed DC points in distribution network.

VI. RELIABILITY MODELLING OF DISTRIBUTION NETWORK

In liberalized markets, an optimized asset management should consider the reliability of supply and power quality aspects as well as the reduction of maintenance and capital costs. This is of great importance for operators of distribution system, since distribution system have a significant influence on both quality and costs of power supply. In this area of conflict between supply quality and cost effectiveness, a comprehensive asset management procedure provides technical and economical information on the equipment and on the entire network especially for distribution networks that form the basis for planning and entrepreneurial decisions.

Efficiency of distribution networks reliability assessment strategy is based on reliability indices. Customer reliability indices such as interruption frequency, interruption duration, not supplied energy and interruption cost are dependent on network structure, switching devices, information and protection equipment, the possibility of switching and emergency supply and on post fault management. For reduction of interruption duration automatic and remote control equipment control level is promoted, that provide the rapid electric supply restore of involved customers where it helps to improve electric supply restore time. Apart from the fault clearing strategy the influence of other features such as network structure or network technology - switches, protection system, fault locators, substation automation system - on system reliability has to taken into account as well.

Table 1: Interruptions frequency in Latvia distribution network by 1 million km or 1 million pcs.

6-20 kV distribution lines	7,42
6-20 kV distribution cables	13,37
Substations 20-10-6/0,4 kV	0,72
Equipment	3,24

Distribution networks are depended on the influence of meteorological conditions and mechanical faults therefore electric supply reliability indices could be different even in a close geographical territory.

One of the most important points in distribution networks is social and economic reliability assessment. Therefore it is necessary to take in account not only customer, distribution system operator interruptions costs but also influence on society. In the load model there is taken in the account not supplied energy and the peak and average loads by customer sectors. In the reliability model there is taken in an account interruption frequency, interruption duration, and sum of involved customers in one interruption. In the interruptions cost model there is taken in an account direct and indirect costs by customer sectors and distribution system operator interruption prevention costs – staff costs, material costs. Customers are divided in four sectors – residential, industrial, agricultural and commercial.

For social and economical reliability model firstly it is important to know system data including network configuration, reliability, load and customer data. Second step is the formulation of load, reliability and interruptions cost models and after that third step is the collection of all three models in one set in which is possible take in the account load, customer and reliability data depending on time. Reliability improving options step is the list of all possible distribution system operator investments. In this step there are investments in maintenance, reliability, operation costs, and costs of implementation new systems. The last step is social and economic reliability model where is compared and evaluated reliability improving options with it impact to distribution system reliability. For instance, if customer call centre does not imply lower total cost than this reference, it should not be implemented (Fig.4).

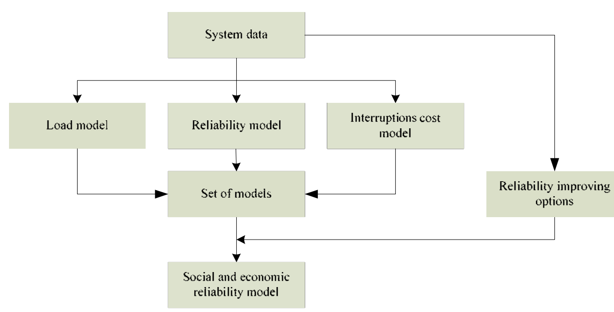

Fig.4. Structure of distribution networks reliability modeling

Two approaches to reliability model of distribution systems are normally used: historical assessment and predictive assessment. Historical assessment involves the collection and analysis of distribution system outage and customer interruption data. It is essential for electric utilities to measure actual distribution system reliability performance levels and define performance indicators in order to assess the basic function of providing cost effective and reliable power supply. Historical assessment generally is described as measuring the past performance of a system by consistently logging the frequency, duration, and causes of system component failures and customer interruptions. Predictive reliability assessment, combines historical component outage data and mathematical models to estimate the performance of designated configurations.

Two classical approaches exist for relating the socioeconomic costs to the risk index. These are the direct cost and the indirect cost methods. Direct costs are loss production, product spoilage, paid staff unable to work, unavailable transportation, risk to injury, uncomfortable building temperature and loss of leisure time and fear of crime. Indirect costs are changes of business plans, looting, legal and insurance costs and changes in business patterns. Three approaches exist for assessing interruptions costs – analytical methods, blackout case studies and customer surveys. The various analytical methods analyze the interruption costs from a mainly theoretical economic perspective. The blackout case study method implies conducting a case study of a particular interruption, often a major blackout. Commonly, the case study aims to include both direct and indirect costs of the outage. The customer survey methods focus on the customer valuations of the interruption cost. The strength of the method is that customers are in the best position to know their own costs.

VII. THE METHOD OF RELIABILITY CALCULATION IN POWER NETWORKS

During the latest time period all the discussions were focused on energy market, less attention is paid to the reliability aspects in power systems. The power supply reliability directly affects the consumers and can cause tremendous economic and material losses due to reliability aspect. In Latvia great attention is being drawn to the criteria of reliability: investigations, researches and practical simulation studies. We prepare to calculate power system reliability with conventional load non-supply criterion. In the calculation process of reliability criteria of power network interruptions or disconnections are reviewed by one and by two simultaneously. In the result of interruption:

- one or more nodes could be without electric supply,
- overload in other power lines could occur.

Network reliability calculation block diagram you can see in fig.5.

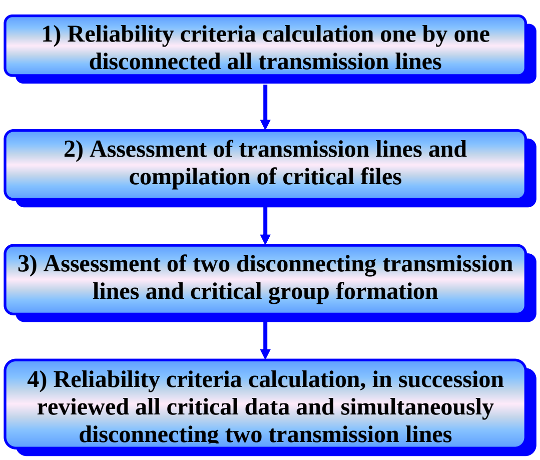

Fig.5. Network reliability calculation block diagram.

For the modes calculations of transmission network consistent load duration curves are applied.

First of all in blocks 1 and 4 the nodes are identified which in the result of disconnection power supply is lost in all load modes and the following items are calculated: 1) time of interruption, 2) no delivered electric energy and 3) no supply costs. If line tripping does not cause one or more nodes disconnection from the supply source it should be checked whether the line tripping causes congestion of ties of un-disconnected line.

For reduction of calculation time in blocks 2 and 3 limited interruptible electric lines group is formed.

1st block. In the 1st block, disconnecting in succession all lines, first should be tested or checked whether load is disconnected. If load is disconnected, then calculated undelivered energy amount W_{L_i} :

$$W_{L_i} = \sum_{re=1}^{rem} U_{re,L_i} \cdot P_{re} \text{ [kWh]},$$

where
re - mode ordinal number;
rem - number of modes;
P_{re} - mode's re disconnected load;
L_i - disconnected transmission line;
$U_{re,Li}$ - line L_i fault prevention time in mode re (asymptotic unavailability parameter);

$$U_{re,L_i} = \frac{\lambda_{L_i} \cdot DL_{L_i} \cdot r_{L_i} \cdot Tre_{re}}{100 \cdot 8760};$$

where
λ_{Li} - number of failure per year per 100 km line *Li* [failure/100 km per year];
DL_{Li} - transmission line *Li* length [km];
r_{Li} - transmission line *Li* duration of repair [h];
Tre_{re} - mode *re* duration [h].

In such a case undelivered electric energy amount will be equal to undelivered electric energy amount in the specific line $W_{und} = W_{Li}$.

If load is not disconnected from the network, it should test whether there is or not overload in other lines L_i, if there such - it defines:

$$\Delta P_L = P_{S_{L,re}} - P_{\max L} \text{ [kW]},$$

where
$P_{S_{L,re}}$ - power flow in transmission line L mode re;
$P_{\max L}$ - admissible load in power line L.

It is assumed that to provide network normal operation overloaded lines L_i in interruption time load is reduced by ΔP_L.

The amount of electric energy undelivered in line L_i at disconnection time is calculated by formula:

$$W_{L_i} = \sum_{re=1}^{rem} \sum_{L \in M_{re,L_i}} \Delta P_L \cdot U_{re,L_i} \text{ [kWh]},$$

where M_{re,L_i} - mode *re* line L_i at disconnection time overloaded electric lines totally.

The 1st block algorithm scheme is shown in Fig.6.

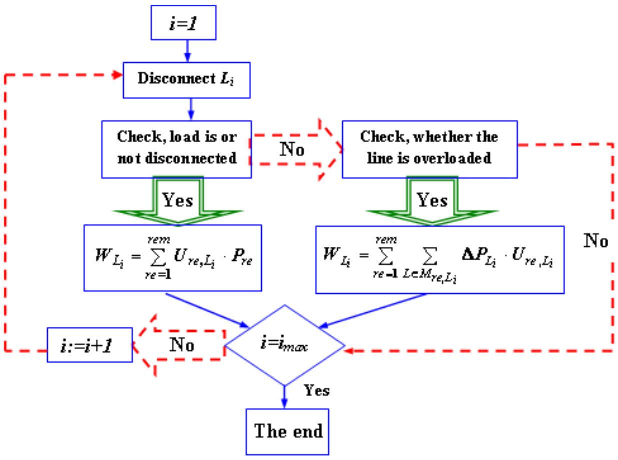

Fig.6. The 1st block algorithm block scheme.

To all lines undelivered electric energy is

$$W_{und} = \sum_{L_i = M_i} W_{L_i} .$$

Costs of undersupply energy:

$$C_{und} = c_{und} \cdot W_{und}$$

where c_{und} – undelivered electric energy specific costs [€/kWh].

2nd block. In the 2nd block power lines are selected according to these criteria:

$$K^*_{L,re} = \sum_{L \in M} Tre_{re=1} \cdot \chi_L \cdot P_{S_{L,re=1}} \text{ [MWh]},$$

where

L	–	transmission line ordinal number, $L \in M$;
M	–	disconnected transmission lines group;
re	–	modes ordinal number $re=1$;
$Tre_{re=1}$	–	mode $re=1$ (maximal loads, local power plants are not in operation) duration [h/year];
$P_{S_{L,re=1}}$	–	transmission line L flow in mode $re=1$ [MW];
$\chi_L = \dfrac{\lambda_L \cdot DL_L \cdot r_L}{100 \cdot 8760}$	–	interruption probability of transmission line L;
λ_L	–	specific number of failures per 100 km of lines per year;
DL_L	–	electric transmission lines L length [km];
r_L	–	electric transmission line L fault prevention duration [h].

3rd block. In the 3rd block two simultaneously interrupted electric transmission lines are reviewed. It is assumed, that in the reliability calculation we should observe only such electric transmission lines pairs, which have highest probability values of simultaneous interruption. In the 3rd block selection simultaneously interrupted electric transmission lines according the following criteria:

$$K^*_{L\{i,j\},re} = \sum_{L \in M} Tre_{re=1} \cdot \chi_{L\{i,j\}} \cdot P_{S_{L\{i,j\},re=1}} =$$

$$\sum_{L \in M} Tre_{re=1} \cdot \chi_{L\{i\}} \cdot \chi_{L\{j\}} \cdot P_{S_{L\{i,j\},re=1}}$$

[MWh],

where $\chi_{L\{i,j\}}$ – transmission lines simultaneous interruption probability.

The selected set is assumed as two elements interruption critical group.

4th block. In the 4th block is continued the 3rd block initiated network reliability criteria calculation. Reliability criteria are calculated by algorithm in succession simultaneously disconnecting two transmission lines. The 4th block scheme we can see in fig.7.

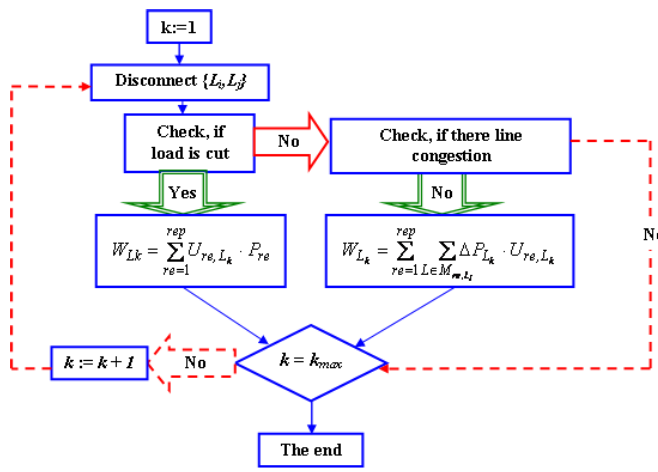

Fig.7. The 4th block algorithm block scheme.

Where L_k – simultaneously interruptible transmission lines pair $k - L_i$ and L_j.

In the reliability calculation of this criterion only highly loaded electric transmission lines is selected, transmission line interruption probability χ_L is calculated and therefore criteria K is calculated. Such transmission lines group is formed and named as critical lines group. After we was calculate undelivered energy at this criteria, we can calculate costs of undersupply energy. This criterion is necessary in order to select critical lines group and thus reducing calculation time. Due to huge scope of calculation, essential calculation problems could appear, because, disconnecting lines by two, sizeable combination number presented.

This criterion is to regard as conventional load non-supply. This corresponds to electric transmission line $L \in M$ in mode $re=1$ to repair duration (asymptotic unavailability parameter U) [h], multiply by flow in line. In the reliability calculation of this criterion only theses electric transmission lines should be taken into consideration which transmission line flow is $P_{S_{L,re=1}}$, transmission line interruption probability χ_L and therefore criteria K^* are the highest values. Such transmission lines group is marked with value M and is named as critical lines group. This criterion is necessary in order to select critical lines group and thus reducing calculation time. Due to huge scope of calculation, essential calculation problems could appear, because, disconnecting lines by two (2), sizeable combination number presented. For instance, if there are 100 elements (transmission lines), then $C_n = \frac{n(n-1)}{1 \cdot 2} = \frac{100 \cdot 99}{1 \cdot 2} = 4950$ combination number for one mode, but if we have minimum three modes (for example three Baltic countries) which are to be calculated, calculation time is increase.

According the theoretical calculation results is clear that Latvian transmission network need to develop in future. Transmission network development will increased power supply reliability in Latvia and Baltic area, and this plan is provide projects of new HV power lines construction with European non European power systems.

VIII. CONCLUSIONS

- Main power system reliability components are: generation reliability, transmission and distribution reliability;
- Need to construct new power stations to increase Latvian generation reliability and energy independency;
- The transmission of electric energy is a significant link in the whole process of power supply to consumers or distribution companies;
- Calculating and estimating reliability by conventional non-supply criterion K, we have to select the most significant and the most loaded lines, in order to decrease calculation scope.
- Transmission and distribution new power lines construction and old object reconstruction will increase power system reliability.

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X. BIOGRAPHIES

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