Method of transmission power networks reliability estimation.

*ANTONS KUTJUNS, **ZIGURDS KRISHANS
*Riga Technical University, **Institute of Physical Energetic
Kronvalda boulevard 1, Riga, LV-1010
LATVIA

Abstract: - Power supply reliability is one of the main criteria in estimation of power system networks. There have been many power system blackouts during the last years, which have resulted interruption in power supply and big material loses in many countries all over the world. The same problems are in Latvia. Economic development and growth of consumption in Latvia, demand introduction of new generating capacities, new transmission 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, 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.

Key-Words: - Transmission power network, transmission power line, switchyard, power supply reliability.

1 Introduction

Methods for power system reliability evaluation have been developed over the past 30 years. Although research still continues in search of better models and methods but in general there is f substantial body of knowledge that can be used effectively for analysis and management of reliability related issues..

Depending on the scope, reliability analysis requires the simulation of the complete operational behaviour of the system to a certain extent including manual or automatic actions taken in response to component failures. Therefore reliability calculation is a much more sophisticated task compared to the conventional (n-1)- power-flow analysis. Suitable models to represent the components and the system are needed. We also need tools and data for making calculations using these models and the indices and methods for incorporating the output of these models and methods for appropriate applications.

Transmission power systems reliable operation is the important component of qualitative electric power supply. Consumers have already got used to reliable and continuous electric power supply and the most part of productions cannot exist without it.

The main thing, not only quickly and as much as possible with the minimal losses to repair the appeared damages, but also precisely to provide that. Substations to fulfil a very important function in transmitting power network work and reliable work and functioning of consumers depends on them in the big degree. Especially it is actual to big consumers in Latvia, which have very big problems from electric power non-delivery.

The Laboratory of Power System Simulation of the Institute of Physical Energetic Latvian Academy of Sciences and Riga Technical university worked in the project “The Network Reliability Optimization under Liberalized Electricity Market”. In this project new reliability calculation with undelivered energy methodology and software (Transmission network power supply reliability’s estimation software) is elaborated. Investigation results to put into practice in Latvian power system.

2 Reliability criteria

Switchyard reliability criteria are the following:

1. Probability of all connections synchronized disconnection
2. Probability of transit interruption
3. Probability of load disconnection
4. Probability of transit active status
5. Probability of load supply active status ***P***
6. Undersupply of energy ***W*** [MWh/a]
7. Costs of energy’s undersupply ***C*** [thous. €/a]

For switchyard estimation of reliability is necessary to take into account the failures of following elements:

1. Switchgears,
2. Busbar,
3. Disconnector,
4. Surge arrester,
5. Voltage transformer,
6. Current transformer.

7. Power auto transformer.
8. Power line.
9. Autotransformer relay protection.
10. Power line relay protection.

3 The main parameters of reliability of substation schemes

The main indicators identifying the scheme of distribution units in regard to reliability conditions are:

- probability of complete (100%) disconnection of substation;
- average frequency (50%) of disconnection of links (transformers, lines);
- probability of disconnection of two lines (faulted and non-faulted lines).

The power system reliability numerically characterizes probability of emergent conditions q and probability of operation conditions p, sum of which $p + q = 1$, but probability of operation conditions can be expressed as $p = 1 - q$. In evaluation process of reliability scheme is accepted that high reliability level has the scheme which $p \geq 0{,}9998$.

4 Power network reliability estimation with undelivered energy criteria

Block scheme of the method algorithm is shown in fig. 1.

Tehnology of calculation

The considered types of switchyard are divided into elements.

Definition – Rated element is a switchyard part, which is disconnected from power system by disconnectors as a fault clearance result.

Properties – Rated elements is a critical devices group, which is disconnected from power system, if only one device from this group has fault clearance;

Switchyard rated element example is showing in figure 2.

Asymptotic unavailability of element i calculated by formula:

$$U_i = N_{SW,i} \cdot \lambda_{SW} \cdot r_{SW} + N_{BB,i} \cdot \lambda_{BB} \cdot r_{BB} + N_{D,i} \cdot \lambda_D \cdot r_D + N_{SA,i} \cdot \lambda_{SA} \cdot r_{SA} + N_{VT,i} \cdot \lambda_{VT} \cdot r_{VT} + N_{CT,i} \cdot \lambda_{CT} \cdot r_{CT} + N_{LN,i} \cdot \lambda_{LN} \cdot r_{LN} + N_{LN(RA),i} \cdot \lambda_{LN(RA)} \cdot r_{LN(RA)} + N_{AT,i} \cdot \lambda_{AT} \cdot r_{AT} + N_{AT(RA),i} \cdot \lambda_{AT(RA)} \cdot r_{AT(RA)}$$

[h/100y] (1)

where

$\lambda_j \ldots \lambda_{sp}$ - switchgears and others critical devices failure parameters [num./y]; (handbook value)
$r_j \ldots r_{sp}$ - switchgears and others critical devices repair time [h]; (handbook value)
$N_{j,i}$ - number of switchgears in element i;
$N_{k,i}$ - number of busbar location in element i;
$N_{a,i}$ - number of disconnectors in element i;
$N_{pn,i}$ - number of surge arrester in element i;
$N_{sp,i}$ - number of voltage transformer in element i;
$N_{st,i}$ - number of current transformer in element i;
$N_{AT,i}$ - number of autotransformer in element i;
$N_{LN,i}$ - number of power lines in element i;
$N_{AT(RA),i}$ - number of autotransformer relay protection in element i;
$N_{LN(RA),i}$ - number of power line relay protection in element i;

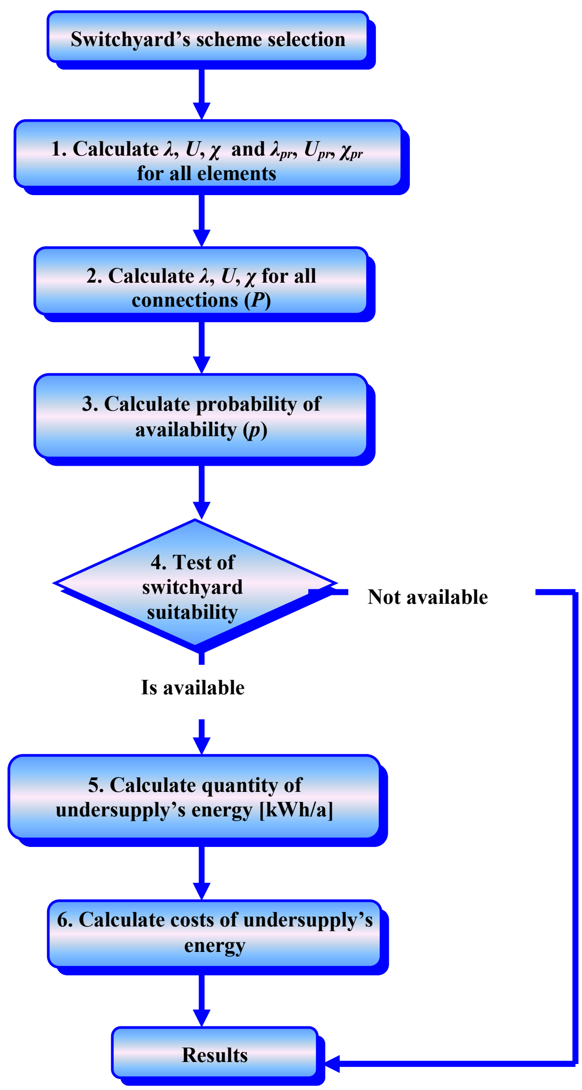

Fig.1. Reliability criterion estimation algorithm block scheme;
λ - failure rate, χ - probability of unavailability position, U – asymptotic unavailability parameter.

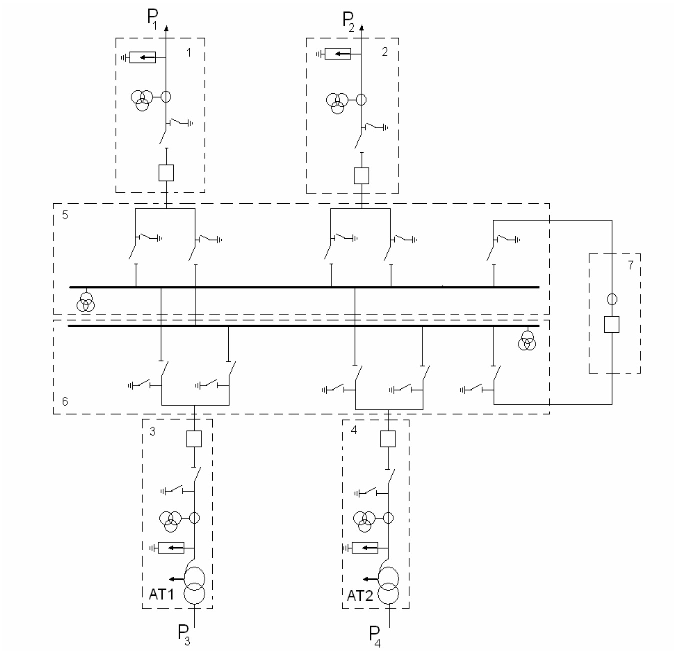

Fig.2. 330 kV switchyard (double-busbar scheme configuration) division into *rated element*

Element *i* probability of disability

$$\chi_i = \frac{U_i}{8760} \text{ [a.u.]}. \quad (2)$$

Table 1
330kV switchyard (double-bus bar scheme configuration) parameters of a rated element (fragment)

i	$N_{SW,i}$	$N_{BB,i}$	$N_{D,i}$	$N_{SA,i}$	$N_{VT,i}$	...	λ, h/y	U, h/y	χ, a.v.
1.	1	0	1	1	1	…	0,0126	0,141	0,000 016
2.	1	0	1	1	1	…	0,0126	0,141	0,000 016
3.	1	0	1	1	1	…	0,0101	0,116	0,000 013
4.	…	…	…	…	…	…	…	…	…

1. block. For all elements failure mathematical expectation λ, asymptotic unavailability *U* and probability of unavailability position χ are calculated. The calculation is made for the emergency failures and to maintenance position.

2. block. Calculate:

1) Connections ***P1***, ***P2***, ***P3*** … probability of disability χ_{P1}, χ_{P2}, χ_{P2}, … and asymptotic unavailability U_{P1}, U_{P2}, U_{P3} …;
2) Two connections ***(P1+P2)***, ***(P3+P4)***, … synchronous probability of unavailability position $\chi_{(P1+P2)}$, $\chi_{(P3+P4)}$, … and asymptotic unavailability $U_{(P1+P2)}$, $U_{(P3+P4)}$, ….

The formulas, developed earlier, and the first block rated results are used for each switchyard type.

Table 2
Example of 330kV switchyard (double-bus bar system) second block calculation (fragment)

Number of element	χ calculation formula, a.u.	U calculation formula, h./y	χ, a.u.	U, h./y
P1	$\chi_{P1} = \chi_1 + \chi_5$	$U_{P1} = \chi_{P1} \cdot 8760$	0.000032	0.284
P2	$\chi_{P2} = \chi_2 + \chi_5$	$U_{P2} = \chi_{P2} \cdot 8760$	0.000032	0.284
P3	$\chi_{P3} = \chi_3 + \chi_6$	$U_{P3} = \chi_{P3} \cdot 8760$	0.000030	0.259
…	…	…	…	…
P1+P2*	$\chi_1 \cdot \chi_2 + \chi_5$	$\chi_{P1+P2} \cdot 8760$	0.0000163	0.143002
P3+P4*	$\chi_3 \cdot \chi_4 + \chi_6$	$\chi_{P3+P4} \cdot 8760$	0.0000168	0.143001
…	…	…	…	…

* - think, that the second element is repairing, but the 1 element has a fault.

3. block – calculation of availability's probability. The formulas, developed earlier, are used for each switchyard type calculation. (See Table 3).

Table 3
Example of 330kV switchyard third block calculation

Nr.	Name	p formula, a.u.	p, a.u.	U, h./y
1.	All connections synchronized disconnection	$p = 1 - \chi_{P1+P2}$	0.999983675	0,228
2.	Transit interruption	$p = 1 - \chi_{P2}$	0.999968	0,367
3.	Load disconnection	$p = 1 - \chi_{P3+P4}$	0.999983675	0,228

4. block – suitability's test. As the suitability's criteria $p \geq 0,9998$ is used.

5. block – calculation of not supplied energy.

The not supplied energy calculated by the formula (for example, take the load equal 50MW):

$$W = P \cdot U_{P3+P4} \cdot k_{gr} = 50 \cdot 0,143 \cdot 0,59 = 4,22 \text{ [MWh]} \quad (3)$$

where k_{gr} - rated coefficient, which observes load graph, accepting, that failures can take place during a year (see table 4).

$$K_{gr} = \frac{(1600 + 4200 \cdot 0,7 + 2960 \cdot 0,2)}{8760} = 0,59 \quad (4)$$

Table 4. Rated coefficient parameters.

Mode Nr.	Name	Tre, h/y	P, a.u.
1.	Maximal	1600	1
2.	Medium	4200	0.7
3.	Minimal	2960	0.2

6. block – calculation of energy's undersupply costs. If specific costs *c* = *10€*/kWh, then energy's undersupply costs are:

$$C = c_{und} \cdot W = 10 \cdot 4,22 = 42,2 \text{ thous.€/year} \quad (5)$$

In the ultimate result having selected switchgear and equipment type with different options and having calculated for all these situations reliability with undelivered load criterion, the most acceptable option is selected and the rest options are considered as invalid and unacceptable.

In order to calculate costs of undersupply energy C, in many countries specific costs of undelivered energy c_{und} are used of electric network due to power supply interruption caused total costs proportion against to undelivered electricity in kWh.

The specific costs c_{und} are framed in the result of perennial observations. Using the undelivered specific costs the information on interrupted load and interruption duration shall be available. These values can be easily calculated in distribution networks as in case of fault one or more load buses or nodes are tripped. Unfortunately at present Latvian conditions the specific costs of undelivered electricity are not known. The foreign researches state that specific costs of undelivered electricity c_{und} depending on users comprise 0,5–100€/kWh. In Latvia such investigations and research have not been done yet.

Due to that big (qualified) consumers in power supply systems in the world and Europe, draw the big attention and interest to questions about "power supply reliability" and "nondelivered electric energy". Investigate work characteristics of consumers, their structure, consequences after switching-off of consumption, etc. Consumers to be indignant big discontent that they are not protected. Power supply systems pay very small penalties for undersupply of energy, though production losses are much higher, and quantity of nondelivered electric energy to consumers very big. Therefore research will proceed and very big work ahead.

5 Conclusions

1. The schemes of electric power plants and substations are of great importance in the reliability provision of electric power supply.
2. In paper presented 330 and 110 kV substations switchyards reliability estimation method is apply for power transmission networks in Latvia. The schemes and diversity of the existing transmission network switchyard hampering reliability calculation process have been analysed. The method estimates transmission network reliability with criterion of undelivered energy.
3. The calculation of reliability of transmission network with criteria of undelivered energy allows assessing probability of disconnection of certain lines and connections and providing the opportunity to evaluate material loss that would be caused to the consumers in case of undelivered energy.
4. The elaborated methods, which is presented in paper, is applied in the dynamic optimisation software *LDM-AD* created by Mathematical Modelling Laboratory (EMML) of the Academy of Science Physical Energy Institute of the Republic of Latvia according to the order-assignment of public utility AS *Latvenergo* (Latvian power company). The program performs reliability analysis of transmission network substations and switchyards operation and electric power supply reliability and security analysis.

This work has been partly supported by the European Social Fund within the National Programme “Support for the carrying out doctoral study programm’s and post-doctoral researches” project “Support for the development of doctoral studies at Riga Technical University”.

References

[1] Bhavaraju,M.P. *Role of a Composite System Reliability Model in Adequacy Assessment* // IEEE Power Engineering Society Winter Meeting, 2002.

[2] Singh C., Billinton R. System Reliability Modeling and Evaluation. (1997) London: Hutchinson Educational.

[3] Под ред. Воропая Н.И. *Надежность систем энергетики* Новосибирск: Наука (1999).

[4] Billinton, R., Fotuhi-Firuzabad, M., Bertling, L. *Bibliography on the Application of Probability Methods in Power System Reliability Evaluation* 1996-1999 // IEEE Transactions on Power Systems, 2001, Vol. 16.

[5] J. Backes, H.-J.Haubrich, A. Montebaur, H.-J. Koglin, M. Schwan, A. Sorg. W.H, Weilssovv. M. Zdrallek, U. Zimmermann, O. Bertoldi, C. Tagliabue. Service Reliability in a Competitive Market. Tools, Criteria and New Approaches for Risk Management and Monetary Evaluation. 38th CIGRE Session. JS 37/38/39, Paris, 2000.

[6] *Latvenergo* annual report, 2006.

Biographies

Antons Kutjuns was born in Daugavpils, Latvia, on September 12, 1978. He received the BSc, MgSc degrees from Riga Technical University, in 1999 and 2002 respectively. He is presently a PhD student in Riga Technical University, at the Institute of Power Engineering.

From 1998 to 2006 he is dispatcher in the Joint Venture of Estonia-Latvia-Lithuania Baltic Power Systems Control Centre Ltd. From 2006 he is electrical engineer in Latvian High Power System Dispatch Centre. His main research interests include Power System Reliability and Liberalized Electricity Market. He is an author of 22 papers.

Zigurds Krishans was born in Riga, Latvia, on May 1, 1930. He graduated as Civil Electrical Engineer from Latvian State University (1954) and received his Ph.D. degree (1961) from Kiev Polytechnical Institute, USSR and Doctor of Sciences (1984) from Moscow Power Engineering Institute, USSR. He is a Professor (1994) at the Institute of Physical Energetics, Latvian Academy of Sciences and Riga Technical University and the Head of the Laboratory of Electric Power System Simulation (1969) at the Institute of Physical Energetics. Prof. is the Vice President (1992) of the Baltic Association of Electric Power System Researchers. His main research interests include Methods for Mathematical Modelling of Electrical Networks and Systems; Methods for Development of Power Systems Planning; Dynamic Optimisation Methods and Decision Systems. Prof. is an author of more than 180 papers, including 10 books.