THE PROBLEM OF POWER INTERRUPTION:
LOSS ASSESSMENT AND INSURANCE

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Abstract
Analysis of power supply interruption for different category of consumers has been done. The method of the insurance tariff estimation of the risk of power interruption was designed. Estimations of the insurance tariff with reference to power supply interruption of the middle size town population has been executed.

Consequences of power supply interruption
In the general structure of losses caused by emergencies the significant place is occupied with the damages connected to outage of power supply of consumers. In accordance with data of Electric Power Research Institute (EPRI), about 2 million companies in the USA lose 46 billion dollars a year because of loss of production in connection with power interruption and 6,7 billion dollars a year – because of decrease in quality of the delivered electric power (direct damage) [1].

Consequences and the sizes of damages connected with power interruption are most in detail investigated in the case of large scale outages caused by system failures. The list and the brief description of the largest failures of power supply interruptions in the world are resulted in the Table 1.

Table 1. Some examples of large scale power interruption

1965	January, 28 submission of the electric power in territory of several states **of Northwest USA** has stopped. More than 2 million people have remained without the electric power for 2,5 hours.
1977	Well-known «Night of Fear» in **New York**. Because of hit of a lightning in electric transmission line New York city has been stay without power for two day, the damage for the sum over $300 million has been caused.
2003	August, 14 in a number of the largest cities of east **coast USA and Canada** there were industrial disasters. Switching-off of the electric power have taken place on the area more than 24 thousand sq. km. This event have been impacted more than 50 million in the USA and Canada and has led to a shutting-down over 100 power stations, including 22 nuclear reactors. The

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	financial losses has made about $6 billion.
2003	August, 18 because of emergency switching-off of a power supply system **of Georgia** submission of an electricity on all country, including objects of life-support has been stopped. Tens thousand passengers have got stuck in cars of trains of the underground and at stations of the Tbilisi underground. In the majority of cities of Georgia water supply was interrupted.
2003	August, 28 failure in power supply has impacted the central and southeast areas **of London**. There were stopped trains on the central lines of the London underground, passengers were evacuated from lifts stopped between floors. Local trains movement has been broken.
2003	Because of storming wind there was a short circuit on power transmission 380 кV in the Swiss Alps. In different areas **of Italy** the electric power supply was interrupted from 5 till 16 hours.
2005	July, 25 there was a system failure in **Moscow**, in result the electricity supply in the most part of areas of Russian capital and a number of cities of Moscow suburbs was disconnected. Transport network, many enterprises and commercial structures have stopped, shops were closed. 72 % of Moscow people have suffered from failure in electricity supply.
2006	November, 4 at exit in the sea on the river Ejms **(Germany)** passenger liner *Norwegian Pearl* scheduled switching-off 380 kV transmission lines for pass liner under the line was carried out. However at redistribution of the electric power flows the system of automatic protection of one of the next lines has caused a wave of switching-off in Germany, the countries of Benelux, France, Spain, Portugal, Italy, Morocco, Austria and Croatia.

As a rule, power interruptions lead to a wide spectrum of consequences in various areas of human activity. For example, consequences of the system's failure which have occurred in Moscow in May, 2005 have mentioned the following sectors of economy and an infrastructure: banks, authorities, stock exchanges, the industrial enterprises, communication, trade, transport, public health services, municipal services. The total losses from the accident was estimated in 1 billion 708 million 400 thousand Roubles (Moscow), and in the Moscow area — in 503 million 940 thousand Roubles. Other example of infrastructural consequences are faults in work of system of water supply owing to switching-off of the electric power in the USA and Canada in 2003.

Failures in power systems lead to development of emergencies of various scale: sub-local, local, territorial, regional, federal and transboundary. In Table 2 statistics of corresponding emergencies in Russia for the period with 2001 on 2005 is resulted.

Table 2. Statistics of emergencies in the Russian Federations caused by failures at electric power systems

Year	Total emergencies	Sub-Local	Local	Territorial	Regional
2001	16	5	10	1	0
2002	15	6	7	2	0
2003	12	5	4	3	0
2004	8	4	2	1	1
2005	13	12	1	1	0

The analysis of failures in power systems reveals their general laws and completely confirms the system nature of occurrence such emergencies [2]:

- The majority part of power supply systems was created at the end of 50th years of XX century counting upon mutual aid of operators in emergency. Modes in which these systems work now, are beyond, stipulated at their designing, mainly in connection with liberalization of the market.

- Even the most insignificant event (for example, the overload of a line or breakage of wires by the tumbled down tree) can cause weight of problems for the loaded system of power supply of the big extent.
- Failures in work of the emergency equipment and accident protection devices (frequently because of bad servicing) can not prevent with such situations; the existing system of automatic control frequently appears unable to prevent emergency.
- Except for only technical factors, in all cases of occurrence and development of system failures the considerable role is played with human, economic and situational factors, including the common lack of information on places of potentially possible failures and unavailability of the personnel quickly to react to an emergency.

Estimation of insurance tariffs and liability limits

As shows experience of developed countries, one of the most perspective mechanisms of management of considered risk is insurance. Calculation of insurance tariffs and liability limits is essentially possible if dependence between frequency of events and consequences as economic damage (distribution "frequency - losses") is known. If the estimation of the distribution is executed for events, which can be identified as insurance events within the framework of the contract of insurance power interruption there are problems of definition of acceptable liability limits, franchises, the insurance tariff and other characteristics of the insurance policies.

Insurance of the damage caused by electric power interruption, can be carried out within the framework of contracts of property or liability insurance. In case of liability insurance, the tariff of insurance reflects the size of a payment of the insurant (the power companies) to the insurer (the insurance companies), the liability carried out within the framework of established limits.

At calculation of the net - rate “the principle of a standard deviation” which declares equality of size of the payments collected for full term of insurance, to the expected size (i.e. to average value) claims, combined with “the risk charge”, proportional to a standard deviation from average value more often is used. Using of the risk charge is dictated by necessity of maintenance of stability of activity of the insurer, i.e. reduction of ruin probability [3].

The size of the of insurance rate is defined for the integrated categories of consumers (the population, industrial consumers, services) in view of the reasons caused by power outage. Settlement formulas are below resulted by the example of the population.

The size of damage caused by power interruption essentially depends on duration of switching-off of consumers. The average damage from outages of the population supply, caused *δ-th* the reason (equipment failure , natural disaster, actions of the third parties, etc.), on all intervals of duration of power interruption is estimated according to expression:

$$\overline{Y}^{(pop,\delta)} = \frac{\sum_{\tau} Y_{\tau}^{(pop,\delta)} q_{\tau}^{(pop,\delta)}}{\sum_{\tau} q_{\tau}^{(pop,\delta)}} \quad (1)$$

where $Y_{\tau}^{(pop,\delta)}$ - damage in population customers, caused by power interruption with duration τ, initiated by δ-th reason, Rouble/year; $q_{\tau}^{(pop,\delta)}$ - frequency of power interruption with duration τ, initiated by δ-th reason, event/year.

The estimation of frequency of power interruption n $q_{\tau}^{(pop,\delta)}$ can be carried out on the basis of an index of system reliability of power supply *SAIFI* (System Average Interruption Frequency Index), reflecting an average of breaks in power supply in a year on one consumer. In case the number of contracts of insurance of the consumers caused by the reason *δ,* coincides with number of consumers it is possible to count that $q^{(pop,\delta)}$ is equal $SAIFI^{(pop,\delta)}$.

The liability limit of power company for interruption in electricity supply the population caused *δ-th* by the reason on one event, is established with use of value of the maximal duration of a outage τ^{max} and estimated on the basis of the formula:

$$L^{(pop,\delta)} = R_{\delta} y_{\tau^{\max}}^{(pop)} N^{(pop)} \omega_{\tau^{\max}}^{(pop)}, \qquad (2)$$

where $y_{\tau^{\max}}^{(pop)}$ - average specific damage at one consumer at one outage by duration τ_{max}, Rouble/year/event; $N^{(pop)}$ - a population consumers of the electric power, people.; $\omega_{\tau^{\max}}^{(pop)}$ - the share of the population injured of a interruption by duration τ_{max}.

The liability limit of power company for electricity interruption supply the population caused by set of the reasons (insurance risks), is estimated on the basis of the formula:

$$L^{(pop)} = \mu^{(pop)} \sum_{\delta} L^{(pop,\delta)}, \qquad (3)$$

where $\mu^{(pop)}$ – factor of a variation of insurance compensation of damage to the population. If the standard deviation of size of the damage caused by power interruption in supply of the population on *δ-th* reason is known, factor of variation μ is assessed by the formula:

$$\mu^{(pop)} = \frac{\sqrt{\sum_{\delta}\left[\left(\bar{Y}^{(pop,\delta)}\right)^2 N^{(pop)} q^{(pop,\delta)}\left(1-q^{(pop,\delta)}\right) + \left(R^{(pop,\delta)}\right)^2 N^{(pop)} q^{(pop,\delta)}\right]}}{\sum_{\delta} \bar{Y}^{(pop,\delta)} N^{(pop)} q^{(pop,\delta)}} \qquad (4)$$

If the standard deviation of size of the damage caused by electricity supply of the population on *δ-th* reason is not known, value of factor of a variation μ, is evaluated by the formula:

$$\mu^{(pop)} = 1{,}2\frac{\sqrt{\sum_{\delta}\left[\left(\bar{Y}^{(pop,\delta)}\right)^2 N^{(pop)} q^{(pop,\delta)}\left(1-q^{(pop,\delta)}\right)\right]}}{\sum_{\delta} \bar{Y}^{(pop,\delta)} N^{(pop)} q^{(pop,\delta)}} \qquad (5)$$

Base value of the net - rate of the tariff of liability insurance of power interruption in supply the population caused by the reason *δ,* is defined under the formula:

$$a_0^{(pop,\delta)} = \frac{\bar{Y}^{(pop,\delta)}}{L^{(pop,\delta)}} q^{(pop,\delta)} \qquad (6)$$

where $\bar{Y}^{(pop,\delta)}$ - average value of damage caused by interruption in supply of the population caused by the reason *δ*, Roubles; $L^{(pop,\delta)}$ - a liability limit for damage caused by power interruption by the reason *δ*, Rouble; $q^{(pop,\delta)}$ – frequency of outage caused by the reason *δ*, event/year.

In case the standard deviation of size of damage of the population caused by interruption in power supply on *δ-th* reason is known the estimation of risk charge is carried out under the formula:

$$\Delta a^{(pop,\delta)} = a_0^{(pop,\delta)}\alpha(\gamma)\sqrt{\left[1-q^{(pop,\delta)}+\left(\frac{R^{(pop,\delta)}}{\overline{Y}^{(pop,\delta)}}\right)^2\right]\frac{1}{N^{(pop)}q^{(pop,\delta)}}}\ , \qquad (7)$$

where $\alpha(\gamma)$ - factor which values are determined depending on a required level of solvency of the insurance company γ; $R^{(pop,\delta)}$ - a standard deviation of damage of the population caused by power supply interruption by *δ-th* reason, Rouble; $N^{(pop)}$ - a population.

In case the standard deviation of size of damage at the population caused by electricity supply interruption, is not known, the estimation of the risk charge is carried out under the formula:

$$\Delta a^{(pop,\delta)} = 1{,}2a_0^{(pop,\delta)}\alpha(\gamma)\sqrt{\frac{1-q^{(pop,\delta)}}{N^{(pop)}q^{(pop,\delta)}}} \qquad (8)$$

Example of calculation of tariffs of insurance of damage caused by interruption in power supply of the population.

By the technique stated above calculation of tariffs of insurance is executed. At calculations it is supposed, that insurance of consumers is made irrespective of the reason of the outages (all calculations are made for the generalized reason of electricity supply interruption).

Calculation of tariffs is executed for town Kaluga (Russia). The population of Kaluga with suburbs – 500 thousand persons. Frequency of power interruption for the given settlement supposed $q^{(pop)} = SAIFI^{(pop)} = 1{,}3$ (event/year on 1 consumer).

Distribution of frequencies of power interruption of the population by duration factor of a variation τ (event/year on 1 consumer), received on the basis of the analysis of the statistical data for the countries of Northern America and the Western Europe, is resulted in Table 3 [4].

Table 3. Distribution of power interruption frequencies for population

Outage duration	Power interruption frequency, event/year on 1 consumer ($*10^{-2}$)
From 1 to 20 min	10,01
from 20 min to 1 hour	11,44
From 1 to 2 hours	30,03
From 2 до 4 hours	32,89
From 4 to 6 hours	21,45
From 6 hours to 1 day	14,3
More than 1 day	2,86
Not defined	7,15

Distribution of specific damages from power supply interruption by duration τ (Rouble/year on 1 consumer), is resulted in Table 4.

Table 4. Distribution of loss caused by power supply interruption of the population

Outage duration	Losses, Rouble/year on 1 consumer ($*10^2$)
From 1 to 20 min	0,12
from 20 min to 1 hour	0,65
From 1 to 2 hours	9,01
From 2 до 4 hours	9,47
From 4 to 6 hours	12,61
From 6 hours to 1 day	30,24
More than 1 day	13,04
Not defined	8,47

The rating of average damage caused by power supply interruption of the population, on all duration intervals, designed under the formula (1), makes 1069,5 roubles on one consumer.

Also the rating of liability limit of the power company for power interruption of the population is executed. Calculations are made for the generalized reason of power interruption, index R_δ=1 used in the formula (2) (a share of outages caused by the reason δ). The option value $\omega_{\tau_{\max}}^{(pop)}$ of a share of the population injured of outage by duration $\tau_{\tau max.}$, is appreciated by results of the statistical data and equals 57,5 %.

Let amount of insurance policies corresponds with the population $N^{(pop)}$ - 500 thousand. Then, the liability limit of the power company assessed by the formula (2) will make 54,6 million roubles.

As a liability limit of the power company value of the maximal damage which has arisen as a result of power interruption at all insured consumers is accepted. Net - rate of the tariff of liability insurance for the population, assessed by the formula (6) makes 0,63 %.

As it is not enough accessible statistical data for calculation of size of a standard deviation of size of damage a rating of the risk charge it is feasible under the formula (8). Let the insurance company with solvency probability γ = 0,95, then factor $\alpha(\gamma)$ = 1,645; and value of the risk charge will make 0,12 %. Accordingly, value of the net - rate of the insurance tariff will make 0,75 %.

Fig. 1 shows dependence of the net - rate of the insurance tariff on amount of insurance policies. Analyzing the received dependence, it is possible to see, that at increase in amount of insurance policies, predictably, the insurance tariff is reduced.

Fig. 2 shows the behavior of the net - rate of the insurance tariff at change of index SAIFI - an average power interruption in a year on one consumer.

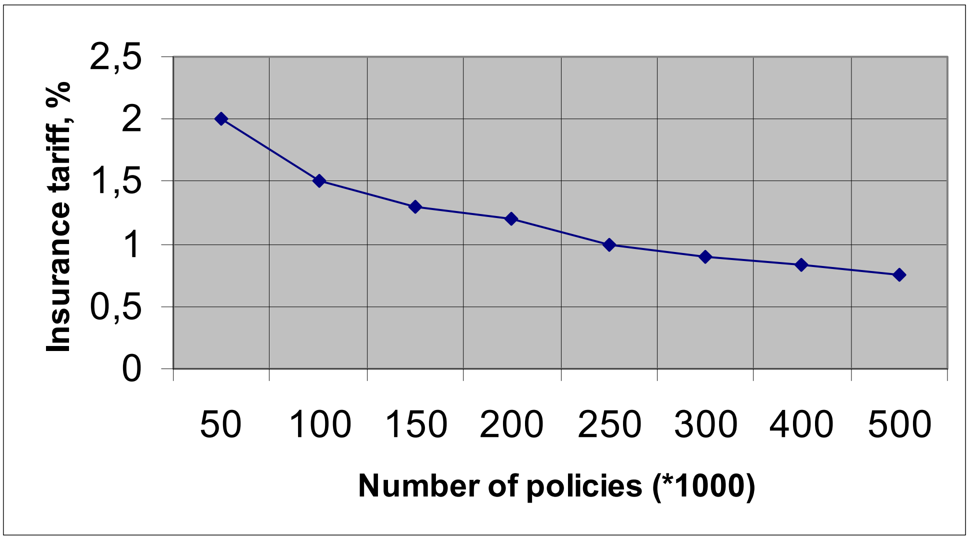

Fig. 1. Dependence of the net - rate of the insurance tariff on amount of insurance policies

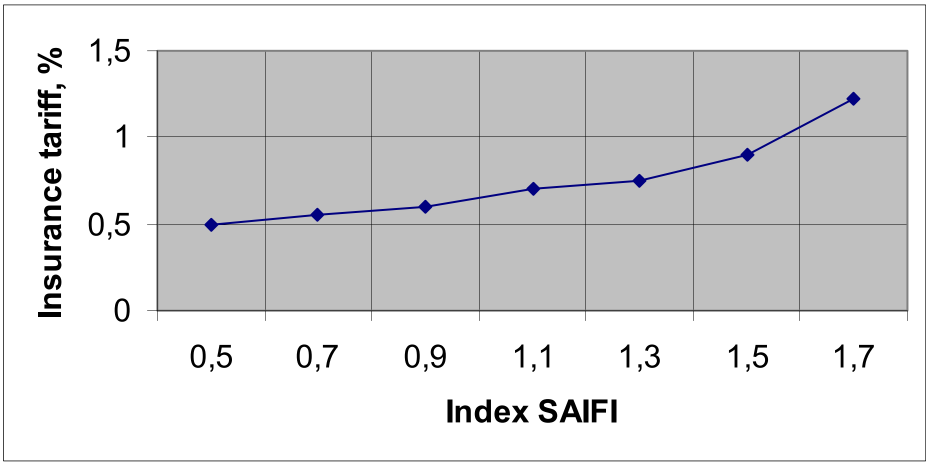

Fig. 2. **Dependence of the rate of the insurance tariff for the population from change of index SAIFI**

Analyzing the received dependence, it is clear, that at increase in index SAIFI, i.e. at increase in an average of power interruption in a year on one consumer value of the insurance tariff increases. Basically, it means, that increase of reliability of power supply leads to reduction in insurance tariffs.

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