SOME ASPECTS OF EVALUATION OF LOSSES CAUSED BY ENERGY INTERRUPTION

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Abstract. Interruptions in the electric power, gas and heat supplies lead to various negative consequences for different categories of users. The results of systematization of the statistical data and structure of occurring damages are given in the paper. The survey of the existing approaches and methods of evaluating the components of damage for various categories of users is presented.

1. General view on the problem

In the general structure of losses caused by emergencies the significant place is occupied by the damages related to outage of different types of energy supply to users. In accordance with the data of the Electric Power Research Institute (EPRI), about 2 million companies in the USA lose 46 billion dollars a year due to loss of production in connection with power interruption and 6.7 billion dollars a year due to decrease in quality of the delivered electric power (direct damage) [1]. Similar assessments for the situation with interrupted gas supply of users in Great Britain amount to 7 billion pounds sterling or 0.8 % of GNP [2].

The analysis of failures in energy systems (power, gas, heat) reveals their general laws and completely confirms the systematic nature of occurrence such emergencies [3]:

– Most of power supply systems created at the end of fifties of the XX century was intended for mutual aid of operators in emergency. The modes, in which these systems work now, are beyond those provided at their designing, mainly in connection with liberalization of the market.

– Even the most insignificant event (for example, the line overload or breakage of wires by a tumbled down tree) can cause a heap of problems for the loaded power supply system.

– Failures in work of the emergency equipment and accident protection devices (frequently because of bad servicing) cannot prevent such situations; the existing automatic control system frequently appears unable to prevent emergency.

– Except for just technical factors, in all cases of occurrence and development of system failures the considerable role is played with human, economic, and situational factors, including a common lack of information on places of potentially possible failures and unavailability of the personnel capable of quickly reacting to an emergency.

The research carried out in work [3] demonstrates substantial mutual influences of the power and gas supply systems both in the normal functioning mode and in emergency situations. In elaboration of this research the effect of these systems on the state of the heat supply systems should be studied. This problem is of current interest for Russia where a share of centralized heat supply is about 70 %.

On the whole it is necessary to note that the problem of assessing the damage caused by interruptions in power supply is relevant to creation of the effective mechanisms for managing the risks of energy supply interruptions. Analysis of approaches to investigation of the structure of damages caused by interruptions in power, gas, and heat supplies of various categories of users and respective valuation methods was made in this work.

2. Some energy supply interruption statistics

Given below are some statistical data pertinent to interruptions in power, gas, and heat supplies. The statistics of interruptions in power supply is the most extensive one. Table 1 presents the data on the largest power failures.

Table 1. Large-scale power interruption

1965	January 28: delivery of electric energy on the territory of several states **of US Northwest** stopped. More than 2 million people remained without electricity for 2.5 h.
1977	Well-known «Night of Fear» in **New York**. The New York city stayed without power for two day due to a lightning hit in the electric transmission line; the caused damage amounted to over $300 million.
2003	August 14: industrial disasters occurred in a number of the largest cities of the east **coast of the USA and Canada**. Cutoff of electric power supply took place on the area of more than 24 thousand sq. km. This event affected more than 50 million people in the USA and Canada and led to shutting down over 100 power stations, including 22 nuclear reactors. The financial loss made about $6 billion.
2003	August 18: delivery of electric energy was stopped in the whole country, including the life-support objects, because of emergency switching-off of the power supply system **of Georgia**. Tens of thousands of passengers got stuck in cars of trains and at stations of the Tbilisi underground. In most of cities of Georgian water supply was interrupted.
2003	August 28: failure in power supply affected central and southeast areas **of London**. Trains on the central lines of the London underground stopped, passengers were evacuated from the elevators stopped between floors. The traffic of local trains was disrupted.
2003	Because of storming wind there was a short circuit in the 380-кV power transmission in the Swiss Alps. In different areas **of Italy** the electric power supply was interrupted for 5 to 16 h.
2005	July 25: there was a system failure in **Moscow**, as a result the electricity supply in most parts of the Russian capital and a number of cities of Moscow suburbs was disconnected. The transport network, many enterprises and commercial structures stopped, shops were closed. 72 % of Muscovites suffered from failure in electricity supply.
2006	November 4: When passenger liner *Norwegian Pearl* put to sea from the Ejms river **(Germany),** the scheduled switching-off of the 380-kV transmission lines was carried out for the liner passing under the line. However, during the redistribution of the electric power flows the automatic protection system of one of other lines caused a wave of switching-off in Germany, the countries of Benelux, France, Spain, Portugal, Italy, Morocco, Austria, and Croatia.

As a rule, power supply interruptions lead to a wide spectrum of consequences in various areas of human activity. For example, consequences of the system’s failure, which occurred in Moscow in May, 2005, have affected the following sectors of economy and infrastructure: banks, authorities, stock exchanges, industrial enterprises, communication, trade, transport, public health services, and municipal services.

The total losses from the accident were estimated at 1 708 400 rubles (Moscow) and 503 940 rubles (Moscow Region).

The examples of gas supply interruptions are given in Table 2.

For a brief description of the greatest accidents in the Russian heat supply systems, refer to Table 3.

Table 2. Some examples of gas supply interruptions

February, 2004 Russia	4 of 5 lines of the Yamburg –Yelets-1 gas main became unserviceable as a result of destruction caused by breakdown. In 29 Russian regions gas supply was limited to15-50 % of the rated value.
December, 2007 Ukraine	Gas explosion with subsequent inflammation took place on the Urengoi – Pomary – Uzhgorod gas pipeline. Some 30 m of gas pipeline were damaged and a gas pipeline section of about 25 km was shut off. Several districts of the Vinnitsa Region were cut off from gas supply.
February, 2007 Russia	Gas explosion took place as a result of a crack in the Maikop - Sochi high-pressure gas main. For repair purposes gas supply to boiler houses of the city of Sochi was cut off. Gas supply interruption lasted for about 3 days.
March, 2007 Kazakhstan	In Alma-Ata gas supply was cut off in 333 private houses and 142 high-rise apartment buildings. The cut-off was caused by a break in the underground distribution gas pipeline.
May, 2007 Ukraine	Explosion took place on the Urengoi – Pomary –Uzhgorod gas main near the Stavishe compressor station of Boguslavsky District, Kiev Region. As a result of breakdown gas supply of 32 populated localities in the Kiev and Cherkassy Regions was interrupted.
February, 2008 South Ossetia	A great gas leak took place in the medium-pressure networks. gas supply of Tskhinval was terminated for 12 h.

Table 3. Statistic data on aftereffects of heat supply interruptions in 2006-2008.

Date and place of heat supply interruption	Duration	Air temperature , t °C	Cause of interruption	Number of victims, thou. persons
January, 2006 Khanty-Mansi Autonomous Area	9 days	-45 °C	Breaching of main pipeline (breakage point was found on the 4th day). Buildings were frozen up.	6.0
January, 2006 Krasnoyarsk Territory	7 days	-40 °C	Breaching of heating main	6.2
February, 2006 Archangelsk Region	7 days	-25 °C	Break of straight pipeline of heating network, 500 mm in diameter.	22.0
February, 2006 Electrostal Moscow Region	4 days	-25 °C	Short-time power supply cut-off, process failure in the boiler house operation. Breaching of heating main pipe due to hydraulic shock	38.8
December, 2006 Khabarovsk Territory	27 days	-30 °C	Heat supply system frozen up as a result of water pipeline breakdown	6.3
December, 2007 Yakutsk	1 days	-57 °C	Damage of heating main section	1.826
January, 2008	1 days	-30 °C	Breaching of heating main pipelines	137.0

Krasnoyarsk			(900 and 500 mm) on territory of district heating plant	
January, 2008 Novosibirsk	4 days	-24 ^oC	Voltage jump in electric networks, stoppage of pumps in boiler house. When changing over to the standby supply source, a hydraulic shock occurred in the heat supply system, which led to the breaching of heating main.	11.35
February, 2008 Ulan-Ude	5 days	-30 ^oC	Inflammation of electric cable at the district heating plant. 2 turbines and 4 of 5 operational boilers were disabled.	168.0

Even the qualitative analysis of presented statistical data shows that the aftereffects of interruptions in power, gas, and heat supplies are rather high, affect various spheres of economy, and have large-scale social consequences.

3. Analysis of structure of damage

Irrespective of the kind of energy (electric energy, gas, heat energy), the structure of damage caused by interruptions in its supply includes the direct, downstream, and secondary aftereffects. Recording of the last component is advised by the UN Committee [4].

Referred to *direct damage* are the losses and damages occurred in the zone of action of negative factors, which resulted from the energy supply interruption. They include destructions, breakages, contamination, infection, etc. The following direct damage components can be singled out:

– social consequences (damage to life and health, deterioration of quality of life);
– damage to various types of property (nonrecoverable losses and expenditures for restoration of dwelling and infrastructure objects);
– expenditures for elimination of aftereffects of the power supply interruption.

The social component of direct damage includes non-recurrent and long-term compensatory payments related to kinds of losses suffered by inhabitants and in a general case can be classified on the basis of the scheme of possible consequences. Direct damage can also include expenditures for temporary evacuation from the accident territory (such a situation is possible if the power supply interruptions took place in the remote areas and particularly in winter time).

Downstream (indirect) damage from the accident is the damage in the form of losses, damages, benefits foregone, and additional expenses borne by inhabitants and economic agents outside the zone of action of negative factors occurred as a result of the accident and caused by disruptions and changes in the prevailing structure of economic ties and infrastructure. This component can be manifested both immediately after the power supply interruption and for a certain period of time. In a general case the following components can be singled out:

– reduction of output of products;
– reduction of productivity in the service industry;
– additional expenses in the social sphere and particular branches of economy;
– reduction of tax revenues on the territory where the power supply interruption took place.

Downstream damage can be assessed as a difference between the income from production of commodities and services prior to and after the power cut-off less the additional expenses arisen in the course of accident management and restoration.

Damage from secondary aftereffects has a more complicated origin and is essentially the result of the response of the whole system of socioeconomic relations in the country to the accident that has taken place. It should be emphasized that this component was not a mere sum of the direct and downstream damages. Damage from secondary aftereffects is the algebraic difference between the cost estimate of losses in all economy sectors and additional income in individual spheres of activity. The macroeconomic consequences can appear as a result of long-term wide-scale cascade accident, whose aftereffect affect several densely populated regions of the country and can comprise the following components:

- change of the GNP growth (decline) rate;
- change of the structure of import/export operations;
- reduction of the amounts of tax revenues;
- effect on the labor market.

In assessing the negative aftereffects of the power supply interruptions, a variety of peculiarities for each kind of energy supply considered herein.

Power supply interruptions are characterized by a possibility of negative aftereffects even in case of a very short cut-off of several industrial users and the absence of a possibility of large-scale accumulation of electric energy. At the same time power supply can be maintained during a certain period of time at the expense of using the standby sources. In case of system accidents they can entail large scales of aftereffects affecting practically all groups of users.

Gas supply interruptions primarily affect the groups of users employing gas as a raw material or it cannot be replaced with an alternative kind of fuel. Unlike the power supply, gas supply is characterized with a possibility of reducing (limiting) the delivery volume, which is associated with the use of underground natural-gas storages and reserve stocks of liquefied gas.

Heat supply interruptions mainly lead to damages suffered by utility users (inhabitants). Seasonal and regional factors are vital for assessing the damage value. Negative aftereffects may take place some time after the emergency cut-off, which is related to sluggishness of heat processes.

4. **Loss assessment**

The qualitative and quantitative assessment of the aftereffects caused by energy supply interruptions can be effected by various methods. These methods may include the use of interviews, forecasting of the sizes of damage caused by power supply interruptions with the use of statistic, computational, and expert assessments [5]. To forecast the number of power supply cut-offs and the scope of aftereffects, use is also made of simulation techniques. In worldwide practice the WTP (Willingness to Pay) and WTA (Willingness to Accept) methods are most frequently employed for forecasting the values of specific damage from power supply interruptions.

The WTP and WTA methods consist in maximizing the funds the individual is ready to pay in order to avoid the damage or, accordingly, in minimizing the value, which the subject is ready to accept as compensation for the inflicted damage. The choice between these methods is related to determination of the property rights, which are not precisely defined in actually arising situations. In principle, the WTP and WTA methods are the development of the notion of equilibrium (market) prices of commodities and services (including damage risks), which have no market. A sufficiently detailed analysis of assessment of the aftereffects caused by power supply interruptions with the aid of the WTP and WTA methods is done in work [6] where the assessments of the values of specific damage performed for the conditions of the USA and West European countries are systematized. The averaged assessments of specific damage obtained with the aid of these methods versus duration of power supply interruption for various categories of users are shown in Figures 1 - 3.

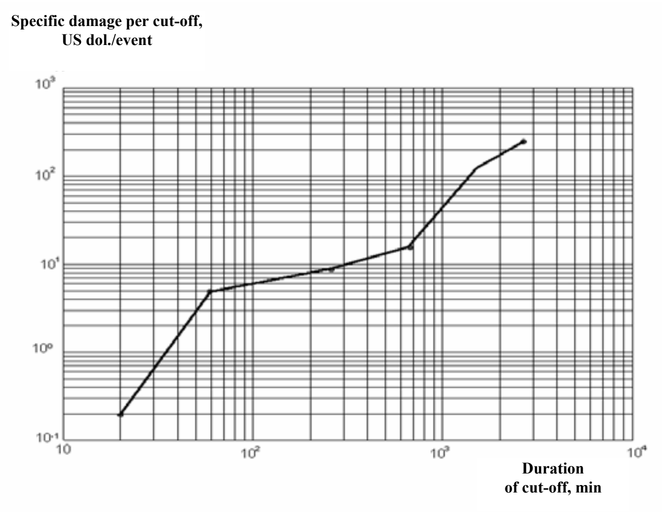


Figure 1. Specific damage versus duration of interruption in power supply of population

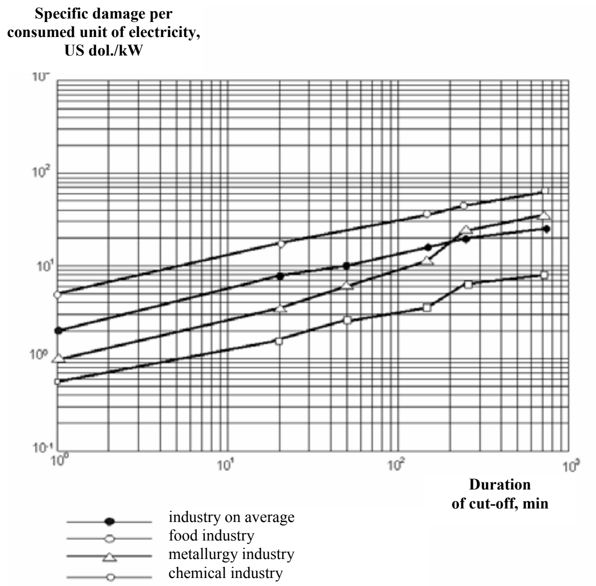


Figure 2. Specific damage versus duration of interruption in power supply of industrial users

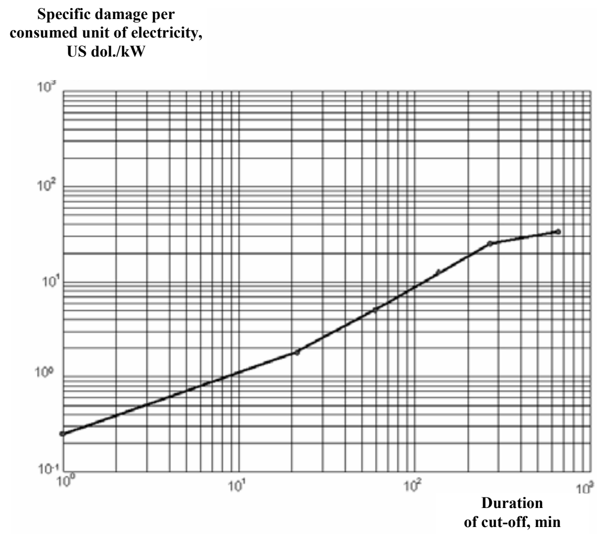


Figure 3. Specific damage versus duration of interruption in power supply for service industry enterprises

As for the damage assessments, the number of works covering this subject is rather small. The aftereffects of gas supply interruptions for industrial users in Great Britain are discussed in the fullest form in [2]. Figure 4 shows the bar chart of aggregate direct and downstream losses caused by gas supply interruptions for industrial users.

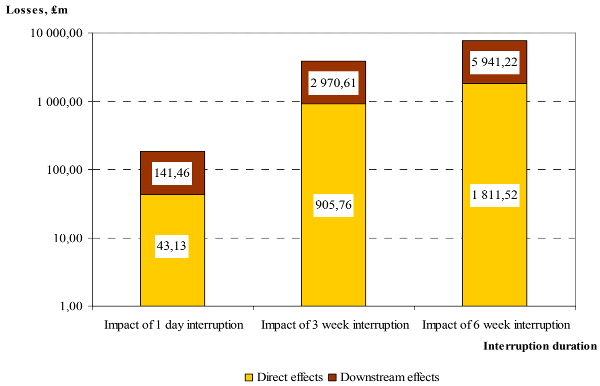
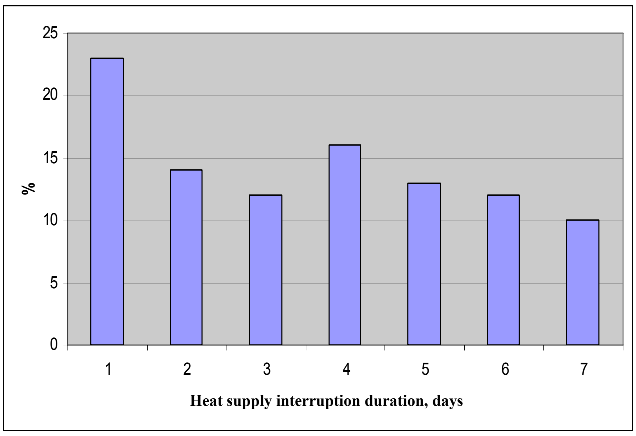


Figure 4. Assessment of direct and downstream losses caused by gas supply interruptions for industrial users for various interruption durations

As has been mentioned above, the damage assessments in case of heat supply interruptions have been previously carried out in fragments, but, like in power and gas supply interruptions, the damage value will be substantially affected by the duration of the users' cut-off. The result of systematizing the heat supply interruption durations in case of large-scale accidents in Russian heat networks during 2005-2007 is shown in Figure 5.



Interruption duration: 1 –1-2 days; 2 - 3-4 days; 3 - 5-6 days; 4 - 7-8 days; 5 - 9-10 days; 6 - 10-20 days; 7 - over 20 days.

Figure 5. Heat supply interruption duration

5. Conclusion

The work provides the analysis of the problem of assessing the damage caused by interruptions of various kinds of energy supply (power, gas, heat) for various categories of users.

The performed analysis of the statistical data has shown that that energy supply interruptions lead to large-scale consequences for various categories of users. Also demonstrated is the necessity of taking into account the specific features of formation of negative aftereffects for each kind of energy supply under consideration.

The factors affecting the values of damage caused by energy supply interruptions have been analyzed. It is shown that duration of energy supply interruptions most strongly influences on the values of arising damages.

The analysis of approaches to assessment of damages has shown that the methods of assessing damage caused by power supply interruptions are developed in greater detail. The aspects of assessing the damage caused by gas and centralized heat supply interruptions have been insufficiently studied.

Further development of the quantitative assessment of damage is essential for substantiating the most effective methods of reduction of risks of energy supply interruptions for various categories of users.

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