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ELEMENTS AND METHODS FOR RISK ASSESSMENT OF AN ELECTRIC POWER TRANSMISSION SYSTEM

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Abstract. *Elements and methods for risk assessment of an electric power transmission system in terms of their influence on the environment are analyzed in the paper. Kinds and effects of the influence of the system on the ecological, social and technical systems are pointed out. According to the analysis of the elements for the assessment of a transmission system influence on the environment, a suggestion regarding the activities for overall risk assessment is made. Accident and cumulative risk are examined; analytical, statistical and fuzzy risk assessment methods are analyzed.*

Key Words: *Transmission system, environment, risk assessment, methods for risk assessment*

1. INTRODUCTION

High voltage systems for transmitting electric energy, i.e., transmission systems, during proper functioning and in the case of a disorder, represent a considerable risk factor for employees, for equipment and the environment in which they are situated. In order to evaluate the risks of a transmission system, it is necessary to take into consideration all the elements which need to be included in the assessment, and then, depending on the available input of data, to apply some of the assessment methods to quantify the risk.

Due to the large number of elements of the environment which are exposed to the influence of a transmission system, as well as the numerous and various effects of this influence, the risk for individual elements, i.e., systems, must be determined first, and then, through their aggregation, the overall risk of the transmission system can be determined.

2. SYSTEMS APPROACH IN THE ANALYSIS OF TRANSMISSION SYSTEM INFLUENCES ON THE ENVIRONMENT

In order to evaluate the risk of a transmission system for the environment, it is necessary to adopt a systems approach, which takes into consideration all the elements impor-

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tant for the assessment. Mutual influence between a transmission system and the environment may be represented by a block diagram shown in figure 1 [2].

The influence and effects of a transmission system on the environment depend on the relationships of its input elements. Namely, the elements of a transmission system, which are most often located in an urban environment and in green areas away from inhabited areas, with distinctive constructive characteristics of the equipment which is in the process of transmitting high voltage electric energy, represent risk factors in the environment and may affect the ecosystem, technical system and social system.

As a result of the influence of a transmission system on particular systems in the environment, different disturbances arise, which independently or together with the influences from other systems (technological factors, natural disturbance factors, etc) disturb its balance, and consequently, the balance of the environmental system.

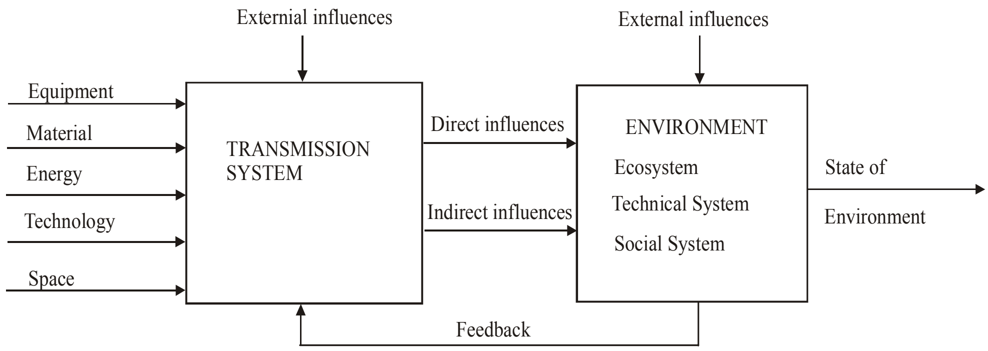

Fig. 1. Block diagram of the mutual influence between a transmission system and the environment

An electric energy transmission system influences those systems in the environment which are located in the field of influence of the factors that are dangerous for and/or harmful to them. These factors exist permanently or they appear from time to time in a transmission system. They cause degradation in the state of some of the systems in the environment and finally reduce their quality.

Degradation processes can be divided into two basic groups:

- Quick degradation processes, which bring about rapid changes of system characteristics due to a sudden change in the condition of any physical processes in a transmission system,
- Slow degradation processes, which cause a gradual change in the state of the environmental system, in which case degradation signs accumulate.

The first group of degradation processes is caused by certain accidental events in the transmission system (e.g. earth links), while the other group of processes is brought about by long-term exposure to dangerous and/or harmful factors (e.g. the influence of electromagnetic radiation on the environment). Therefore, there are basically two kinds of risk caused by a transmission system in the environment - accidents and cumulative risks.

3. Elements for Transmission System Risk Assessment

A transmission system as a part of an electro - energetic system represents a danger factor both when functioning properly and when out of order, because it interacts with the ecosystem, technical system and social system.

The influences that appear during the proper functioning of the system come from the electromagnetic field and in case of a disorder, they are the result of overstrained waves, reverse jumps during atmospheric discharges, short circuits, earth links etc. The overall effect of a transmission system on the abovementioned systems in the environment is shown in figure 2.

The influence of a transmission system on the ecosystem includes influence on the soil, water resources, air, animals, birds and insects and vegetation.

1) The influence on the soil is manifested as:

- Soil erosion caused by vegetation cutting

Setting routes for long-distance power lines often demands going through forests. It is very important for the routes not to go through the forests planted to provide soil stability or to prevent the negative influence of wind. Soil erosion along the routes can cause secondary effects in electric energy transmission in the sense that it disturbs the stability of long-distance power line poles.

- Elimination of high quality agricultural areas

By violating and reducing agricultural areas, permanent material damage is done due to the loss of cultivable soil or due to crop damage.

- Soil contamination

In case of failure or fire in the transformers filled with transformer oil, soil contamination caused by the leaking, pouring out and spilling of oil may occur. Transformers which were once filled with very toxic polychlorated biphenyls are particularly dangerous.

2) Consequences of the influence on water resources are reflected in:

- Overground water pollution

It is brought about by direct pouring out of toxic cooling materials from electrical appliances into water currents or by penetration of contaminated underground waters.

- Underground water pollution

It occurs as a secondary consequence of soil contamination.

3) Damage to the air is manifested as:

- Air pollution

It is caused by fires in electric installations and toxic evaporations.

4) Consequences of the influences on animals, birds and insects:

Electromagnetic energy spreading uncontrollably from energetic appliances of a transmission system into the environment disturbs the natural surroundings, which brings about:

- Change of conditions in which animals, birds, insects and similar species survive and live,
- Animal migration caused by changes in their environment,
- Limitations and changes to animal and bird migration routes,

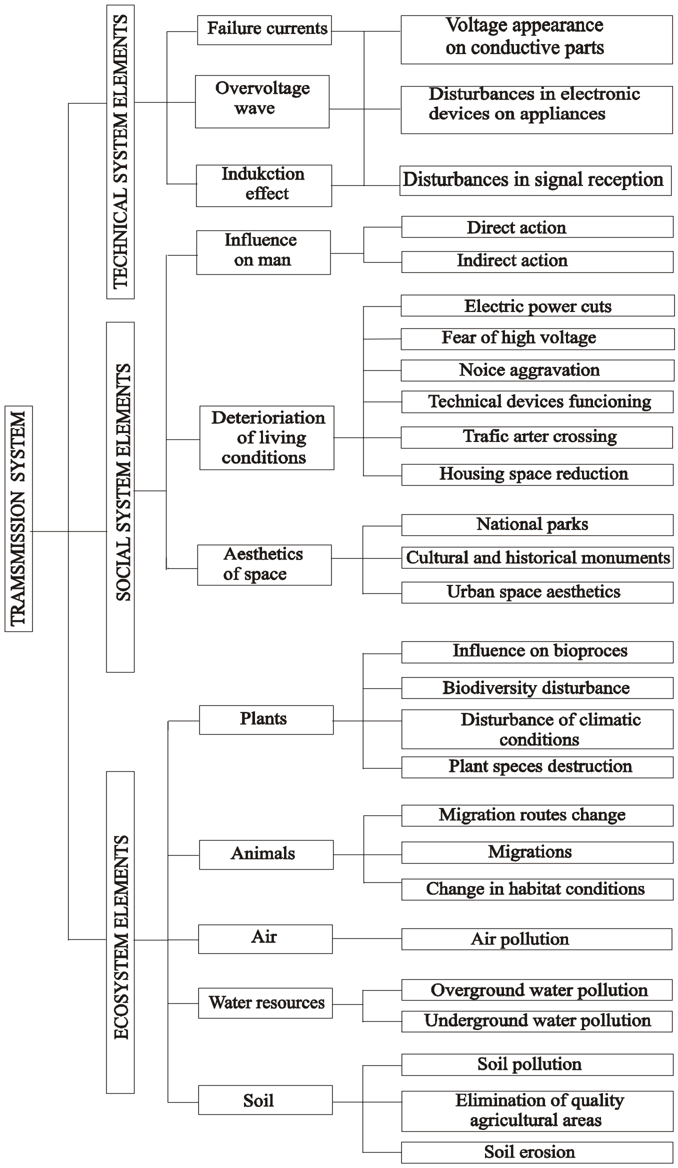

Fig. 2. Structural scheme of transmission system influence on system elements in the environment

5) The influence on vegetation is manifested as:
- Destruction of forests and other plant species,
- Change in climatic conditions of their habitats,
- Biodiversity disturbances,
- Influence on bioprocesses in vegetation.

Forest resources are essential for the development and preservation of the global environment. By forest and plant destruction useful fauna is disturbed, oxygen production is reduced, and the filtration of air and water is limited. This also leads to climatic changes by increasing temperature extremes, the consequence of which is biodiversity disturbance and ecological balance violation.

6) The influence on the social system includes: space aesthetics disturbance, human living condition disturbance, and influence on man.

Space aesthetics disturbance is reflected in change of appearance and aesthetic effects:

- on national parks, resorts, landscapes etc,
- on cultural and historical monuments,
- on the urban environment.

Change in human living conditions:

Setting the elements of a transmission system in an urban environment and in the vicinity of traffic arteries brings about human living condition disturbances, which are manifested as:

- residential area reduction (passage of long-distance power lines through inhabited areas),
- traffic safety endangering,
- problems in technical device functioning,
- noise level increase,
- uneasiness and fear of high voltage in the vicinity,
- problems due to electric energy cuts.

Influence on man during the proper functioning and in case of a disorder can be:

- Direct influence: It occurs due to the electromagnetic field which is manifested in the electrocution of a human body and its discharge which produces a feeling of pain or stinging, along with the electricity flow through the human body which occurs by touching or failure.
- Indirect influence: It is manifested as: inductive vortex currents in the human body which may exceed values of the normal currents of heart and brain functioning, problems in a built-in cardio-stimulator (pacemaker) functioning; disorders similar to neurasthenic: headache, dizziness, fatigue, weakness, frequent perspiration, depression etc.

7) Transmission system influence on technical systems is reflected in the induction influence of the electromagnetic field, the appearance of over-voltage waves and failure currents that is manifested as:

- signal reception disorders (TV, radio, TT),
- electronic devices and measuring equipment disturbance,
- induction influence on neighboring telecommunication objects and equipment,
- discharge voltage and current occurrence on metal surfaces (constructions, pipelines, machines, etc).

4. Methods for Risk Assessment

Risk assessment is usually done on the basis of the expected risk value, which is the result of two things- the actual probability of the risk event taking place and the degree of the loss it causes in the system. As far as accident risks are concerned, risky events occur in the transmission system, and the effects (i.e. loss) are manifested in the transmission system as well as in the environmental systems, while with cumulative risks only the initial events occur in the transmission system, while both the risk events and the effects appear in the living environment.

According to the definition of the expected risk rate, the basic risk indicators are:

- the probability of risk event occurrence, Pre;
- the mathematical expectation of the loss which occurs as the consequence of the risk events during the given time intervalτ, Mτ [G].

Apart from the basic indicators, the following indicators can also be used:

- intensity of the risk-events occurrence
- average time of system functioning - until/between risky events
- the level of the economic investment in the prevention of risk events and/or the reduction of losses if these events occur.

4.1 Analytical risk assessment

Analytical determination of risk indicators requires thorough knowledge of the structure of the system, the intensity of the initial events and the indicators of the reliability of the system elements which occur in the chain of risk events. On the basis of such data, one can determine: the probability of the system moving into a state of danger $P_0(t)$, the state of risk $P_r(t)$, and the state of failure $P_{sf}(t)$ for each causal chain.

Probability of the *i-th* type of risk event is determined through the following formula:

$$P_{re,i(t)} = P_{0,i(t)} P_{r,i(t)} P_{sf,i(t)} \tag{1}$$

and the intensity of the same type is determined as follows:

$$\omega_{re,i(t)} = \omega_{ie,i(t)} P_{re,i(t)} \tag{2}$$

where $\omega_{ie,i}$ represents the intensity of the initial event causing the *i-th* type of risk event.

Due to the principle of risk event occurrence in the system [1], the probability of occurrence of at least one risk event is determined by the formula:

$$P_{re(t)} = 1 - \exp(-\sum_{i=1}^{m} \omega_{rd,i} \tau) = 1 - \exp(-\omega(t)\tau) \tag{3}$$

where: m represents the number of different types of risk events, and $\omega(t)$ - the intensity of risk events.

The formula for the mathematical expectation of the value of the loss is:

$$M_\tau[G] = \sum_{i=1}^{m} \frac{g_i}{m} \tag{4}$$

where: g_i represents the expected loss during the realization of the *i-th* type risk event.

The expected risk value based on formulas (3) and (4) is:

$$R = (1 - \exp(-\omega(t)\tau)) \sum_{i=1}^{m} \frac{g_i}{m} \tag{5}$$

4.2 Statistical risk assessment

The statistical assessment of risk indicators is possible only if there is a statistically significant set of information about risk events. The assessment of risk events probability $P_{rd}(\tau)$ and the mathematical expectation of their number $M_\tau[x]$ is carried out by using the principle of large numbers, i.e. the Chebishi and Bernuli theorem [1].

According to Chebishi's hypothesis, with a large number of systems (N) of the same type to explore, the arithmetic average has a tendency towards their mathematical expectation.

$$M_\tau[X] = \frac{1}{N}\sum_{i=1}^{N} x_i(\tau) \tag{6}$$

In (6), x_i (τ) represents the number of realized risk events in the *i-th* system during a period of timeτ.

On the basis of Bemuli's hypothesis, the frequency of different events under certain circumstances has a tendency of becoming a probability:

$$P_{re(\tau)} = \frac{1}{m}\sum_{k=1}^{m} x_k(\tau) \tag{7}$$

In case that the amount of information is insufficient, it is necessary to determine the credibility of the assessment, or the deviation of the real values P_{re} (τ), $M_\tau[X]$, i.e. from the values determined by the formulas (6) and (7).

A statistically insufficient amount of data is the consequence of a small number of systems of the same type and/or a small number of the registered risk events in them. The problem of infrequency can be overcome, to a certain extent, by forming homogenous groups of systems, i.e. groups similar in causes and effects of the risk events and which have similar values.

Each increase in the validity of the results demands a larger amount of data or a longer period of research; however, as these conditions cannot always be fulfilled, the statistical interval assessment is beginning to be more widely used.

Statistical interval judgment implies determining the value interval of the indicator $P_{re}(\tau)$ or $M_\tau[X]$, which would contain the unfamiliar values of these parameters, with the demanded credibility. The credibility of the interval values is related to the length of the interval as follows:

$$P(V_u < V < V_l = \int_{V_u}^{V_l} f_{px}(x,n)dx = \gamma \tag{8}$$

where V_u and V_l represent the upper and lower limits of the grades of the observed values; $V \in \{P_{re}(\tau),\ M_\tau[x]\}$; $f_{px}(x,n)$ – statistical distribution of the probability of values x; $n = \{N\ m\}$ – the extent of research; γ – the coefficient of credibility.

Statistical interval judgment does not provide the exact value of the risk indicators, but offers only an interval of possible values, their value depending on the demanded credibility of values (γ) and on the form of the statistically determined function of grade distribution (f_{px}).

4.3 Fuzzy risk assessment

The necessity of the use of the approximate initial data, due to the lack of the exact data, caused the application of the results of the possibility theory in the area of risk analysis and assessment. Namely, representing the grade interval in the form of fuzzy values and numbers represents a promising way of solving the problems caused by the lack of a sufficient amount of valid data, which is quite common in modern systems.

The methods of the possibility theory and the fuzzy set theory as its integral part slowly entered the area of risk assessment, due to the subjectivity involved in the process of determining the membership functions of the linguistic variables. Today, there exist formulated rules for transferring familiar distribution of accidental probability value to its equivalent membership functions. The application of these rules provides objectivity in the formulation of membership functions on the scale of probability, loss and risk [2].

The fuzzy method includes the use of linguistic variables for the description of various events and losses. Risk events are ranked according to the probability of occurrence: highly improbable, slightly probable, moderately probable, highly probable, extremely probable, as shown in table 1.

Table 1. The criteria for the assessment of risk event frequency

Rank	Risk event	Meaning	Probability of risk event
1	Highly improbable	Impossible event	$< 10^{-6}$
2	Slightly probable	Relatively small number of risk events	$(1 \div 5)10^{-5}$
3			$(5 \div 9)10^{-5}$
4	Moderately probable	Occasional occurrence of risk events	$(1 \div 3)10^{-4}$
5			$(3 \div 6)10^{-4}$
6			$(6 \div 9)10^{-4}$
7	Highly probable	Repeated risk events	$(1 \div 5)10^{-3}$
8			$(5 \div 9)10^{-3}$
9	Extremely probable	Almost inevitable risk events	$(1 \div 10)10^{-2}$
10			$> 10^{-1}$

The limits of the interval of probability for specific kinds of events are determined on the basis of the class of liability, and therefore subjective assessment [7].

The losses are ranked according to the seriousness of the effects: minimum, small, moderate, high, and extremely high, by subjective expert assessment as shown in Table 2.

Input parameters - risk events and loss - are transferred by means of fuzzification to fuzzy variables of the corresponding degree of membership. Their analysis is carried out by the use of the basic linguistic rule and fuzzy-logical operations with the purpose of obtaining the classification of the risk and the value of risk and the value of membership in every class of risk.

The basic linguistic rule describes the risk for each combination of input variables. Generally, this rule may be represented in the "if- then" form and is easily applied by means of *fuzzy* conditional statements. An example of the basic linguistic rule used for risk assessment is given in Table 3 [8]. These rules are subjectively defined and based on experience.

Table 2. The criterion of loss assessment [2]

Rank	Loss	Meaning
1	Minimum	No relevant influence on system performances and the living environment
2,3	Small	Irrelevant deviations of the performances of the system and small influence upon the environment
4,5,6	Moderate	Considerable deviations of the performances and a small influence on the environment
7,8	High	Failure of a part or the whole system, without harming the people or the environment
9,10	Extreme	The potential defunct influences the safety and the balance of environment, or ecological balance.

Table 3. Example of the basic linguistic rule

		RISK EVENT				
	RISK	Highly impossible	Slightly probable	Moderately probable	Highly probable	Extremely probable
	Minimal	Irrelevant	Minimal	Small	Small	Moderate
L	Small	Minimal	Small	Small	Moderate	Significant
O	Moderate	Small	Small	Moderate	Significant	Significant
S	High	Small	Moderate	Significant	Significant	Very significant
S	Extremely high	Moderate	Significant	Significant	Very significant	Very significant

The rules can be applied by the use of min- max conclusions for transforming numeric conclusions into linguistic variables. The membership functions of the rules are assigned the smallest degree of membership functions of the premise. Fuzzy output can be the result of more than one rule. In that case, the membership function of the outcome equals the highest membership function of the rule. The result of this process is fuzzy risk conclusion. It can be used in this form for determining the risk on a level higher than the observed one by applying the rule of aggregation of the fuzzy conclusions [6], or by the process of defuzzification.

From the set of fuzzy conclusions, the value which expresses the degree of risk is formed by the process of defuzzification. For these purposes, the Weighted Mean of Maximum method is used.

5. Conclusion

Based on the analysis of the elements for the assessment of the influence of a transmission system on the environment, it can be concluded that the necessary conditions for integral risk assessment still do not exist.

For this assessment it is necessary:

- to make possible the use of uniform norms and standards;
- to establish mechanisms of influence on all the elements in the environment

- to establish the influence zone of dangerous/harmful factors
- to establish the monitoring of parameters important for assessment
- to make influence and effect quantification;
- to define the unfavorable effect assessment methodology;
- to define the partial risk aggregation procedure.

In that way prevention engineering would become a part of the technology of electric power production and transmission, and the abovementioned parameters would be of immediate use in the process of electric power system risk management.

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ELEMENTI I METODI ZA OCENU RIZIKA SISTEMA ZA PRENOS ELEKTRIČNE ENERGIJE

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U radu se analiziraju elementi i metodi za ocenu rizika sistema za prenos električne energije sa aspekta uticaja na životnu sredinu. Ukazuje se na vrste i efekte uticaja ovog sistema na ekološki, socijalni i tehnički sistem. Na osnovu analize elemenata za ocenu rizika prenosnog sistema na životnu sredinu, dat je predlog prethodnih aktivnosti neophodnih za ocenu integralnog rizika. Razmatraju se udesni i kumulativni rizici i analiziraju analitički, statistički i fazi metodi ocene rizika.

Ključne reči: *Prenosni sistem, životna sredina, ocena rizika, metodi ocene rizika*