Risk Assessment of Bulgarian Electricity Network under Natural Disasters

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Abstract. The electricity transmission and distribution networks are heavily affected from natural disasters. Electricity networks can also incur multiple or multi-risks, including their conjoint and cascading effects, or systemic risks. The aim this paper is to propose an approach for risk assessment of Bulgarian electricity transmission and distribution network under natural disasters. The proposed approach for risk assessment is based on guidelines and techniques of risk management standards ISO 31000:2009 and EN 31010:2010. Here, the risk assessment is the overall process of risk identification, risk analysis and risk evaluation. The risk assessment results can support the all key stakeholders to take more informed decision about effective protection of the electricity networks from natural disasters.

1. Introduction
In recent years, natural disasters have caused severe damage to the energy systems across the world [1], [2]. The electricity transmission and distribution networks are heavily affected [3], [4]. Thus, the number and duration of temporary power breakouts are increased [5], [6]. There is also a rise in the intensity and severity of these accidents [7]. Considering the importance of power supply for many systems that use energy, even minor breakouts can cause cascading consequences and intensify the initial negative impact [8], [9].

Although the electricity breakouts from natural disasters occur rarely, they are capable to cause significant disruptions in the Bulgarian economy and society due to the high degree of systemic interconnection. The energy system is strongly connected with other systems such as transport, water supply, communications, health care, and more. Therefore, power breakout for any duration can cause ubiquitous direct and indirect negative consequences. Therefore, modern economies and societies can properly function only with continuous power supply.

Natural disasters are difficult to avoid. For these reasons United Nations (UN), European Union (EU) and any governments develop strategies to disaster risk reduction in regard to the increased natural disasters [10], [11]. European Commission in the end of 2010 proposed official working paper “Risk Assessment and Mapping Guidelines for Disaster Management” [12].

The established trend of increasing natural disasters in the future is likely to lead to more damages of the electricity transmission and distribution networks, such as outcrop of cables because of erosion or damage to the transport infrastructure; increase of the losses on the power lines; increased of the damages to the overhead electrical infrastructure from extreme storms and winds; direct mechanical damages to the electricity network caused by a short circuit of power lines; indirect mechanical damage and short-circuits caused by the disruption of overhead lines due to fallen trees and debris; material damage (including falling) of overhead lines and pillars caused by ice, etc. [13], [14]
Nowadays, because of the possible losses mentioned above discussions and activities related to the protection of the electricity transmission and distribution networks from the impacts of natural disasters are especially topical. This requires strengthened cooperation between all key stakeholders: national governments, regional and non-governmental organizations, the business community, academia, development agencies, and financial institutions.

Protection of the electricity networks from natural disasters included risk assessment (to identify threats /natural disasters/, assess vulnerabilities, identify and quantify potential losses); risk preparedness, prevention, and mitigation (including technical and physical protection measures and planning, as well as organizational measures, capacity building, early warning, and internal controls); risk management (disaster management); reconditioning (backup supply and provisional repair); and risk recovery (reconstruction, financing, repairing, and restoring) [13], [14].

Protection of the electricity transmission and distribution networks is a challenging task due to the system complexity and the many elements included such as generators, transformers, and high- and low-voltage transmission and distribution lines. All these components are interdependent and include a large number of elements, such as interconnectors, edges, and nodes [15]. Each element can become vulnerable to existing and newly natural hazards. Electricity networks can also incur multiple or multi-risks, including their conjoint and cascading effects, or systemic risks.

The aim this paper is to propose an approach for risk assessment of Bulgarian electricity transmission and distribution network under natural disasters. The proposed approach for risk assessment is based on guidelines and techniques of risk management standards ISO 31000:2009 and EN 31010:2010.

2. Essence of the risk assessment process

Risk management standards ISO 31000:2009 “Risk management — Principles and guidelines” and IEC/ISO 31010:2010 “Risk management - Risk assessment techniques” are a useful tool in representing and logically organizing risk management process in a way that makes decision-making open to inputs from different stakeholders [16], [17].

The contribution of risk assessment to the risk management process according IEC/ISO “Risk management - Risk assessment techniques” is shown on Figure 1. Here, the risk assessment is the overall process of risk identification, risk analysis and risk evaluation.

![Figure 1. Contribution of risk assessment to the risk management process.](image)

It is necessary to point that the risk assessment may require a multidisciplinary approach since risks from natural hazards ordinary cover a wide range of causes and consequences.
Usually for the purpose of risk assessment from natural hazards the following term definitions are used [17], [18]:

- **Hazard** is a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

- **Natural hazard**: Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Natural hazard events can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent.

- **Exposure**: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

- **Vulnerability**: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. In probabilistic/quantitative risk assessments, the term vulnerability expresses the part or percentage of Exposure that is likely to be lost due to a certain hazard.

- **Risk** is a combination of the consequences of an event (Hazard) and the associated likelihood/probability of its occurrence.

- **Risk assessment** is the overall process of risk identification, risk analysis, and risk evaluation.

- **Risk identification** is the process of finding, recognizing and describing risks.

- **Risk analysis** is the process to comprehend the nature of risk and to determine the level of risk.

- **Risk evaluation** is the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable.

- **Risk criteria** are the terms of reference against which the significance of a risk is evaluated.

- **Consequences** are the negative effects of a disaster expressed in terms of human impacts, economic and environmental impacts, and political/social impacts.

- **Hazard assessments** determine the probability of occurrence of a certain hazard of certain intensity.

According EN 31010:2009 [17] in situations where the likelihood of occurrence of a hazard of certain intensity can be quantified investigators refer to the term probability of occurrence. When the extent of the impacts is independent of the probability of occurrence of the hazard, which is often the case for purely natural hazards, such as earthquakes or storms, risk can be expressed as [16]:

\[
Risk = \text{probability of occurrence} \times \text{hazard impact}
\]

or

\[
R = f(P \times C),
\]

where \( R \) is the risk; \( P \) – the probability of occurrence of the natural hazard; \( C \) – the consequences (natural hazard impact).

Risk matrix is very helpful in the risk assessment process. In particular the risk matrix or so-called consequence/probability matrix is a means of combining qualitative or semi-quantitative ratings of consequence and probability to produce a level of risk.

The format of the risk matrix depends on the context in which it is used. The scale used may have 5 or more points. The matrix may be set up to give extra weight to the impact or to the likelihood, or it may be symmetrical.

Usually in risk assessment process the risk matrix 5x5 is used (Figure 2).

Here the **Probability levels** (Relative likelihood) are graded as “Very low”, “Low”, “Medium”, “High” and “Very high”.

**Consequences** (Relative impact) are also graded as “Very low”, “Low”, “Medium”, “High” and “Very high”.

The **Risk levels** \( R \) are defined as “Low”, “Medium”, “High” and “Very high”.

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3. Risk identification of the Bulgarian electricity network from natural disasters

According to the above definition, risk identification is the process of finding, recognizing and describing risks. In cases where the risk is induced by natural disasters, then the process of risk identification requires descriptions of all potential natural hazards, which cause these disasters.

In this paper, the risk identification of Bulgarian electricity transmission and distribution network requires descriptions of the natural hazards occurring on the territory of the country.

The predominant natural hazards on Bulgarian territory are identified as follows:

- Geological processes and phenomena: Earthquakes; Slope failures (landslides, landslips, creep, falls, flows, subsidence); Mud-rock flows (seli); Erosion and abrasion; Storm surge.
- Hydrological processes and phenomena: Floods; Dry periods; Snow flows and glaciations; Icings.
- Meteorological processes and phenomena: Strong wind; Extreme temperatures; Freezings, Drought, Tornado phenomena; Dust storms; Hailstorms; Wet snow; Fog (coastal, evaporation, radiation, valley, upslope); Thunderstorm; Silver thaw; Wild land fire.

It can be pointed some representative examples of identified risks from natural disasters for the Bulgarian electricity network as follows:

- Losses from transmission of electricity due to extremely high temperatures (including hot days and heat waves).
- Damage to the electricity transmission and distribution network from icing due to extremely low temperatures (including cold days and cold airwaves).
- Flooding of the electricity transmission and distribution network (including electricity substations) leading to power breakouts and/or higher capital costs for equipment repairs due to more rainfall and high humidity.
- Droughts that cause soil downgrades, damaging underground electricity transmission and distribution network.
- Strong winds and storms damage the electricity transmission and distribution network (for example, from fallen trees), leading to power breakouts and/or higher capital costs for repairs of the equipment.
- Landslides also damage the electricity transmission and distribution network, resulting in power breakouts and/or higher capital costs for equipment repairs.
- The power lines could exceed the established maximum temperatures in the technical documentation and violate the requirement for a minimum distance from the earth's surface due to thermal expansion, which could lead to a power breakout.

4. Risk analysis of the Bulgarian electricity network from natural disasters

The essence of the proposed approach is consists in the determination of the levels of risk for the electricity transmission and distribution network as a whole and/or its individual elements from the natural disasters in a given geographic region for a certain time interval. Here, according to the definition the risk analysis is the process to determine the levels of risk.
In this study, it is considered that the natural hazard that causes the corresponding natural disaster has four levels of intensity. Furthermore it is necessary to note that the adequate risk analysis requires producing distinct risk matrices for each intensity levels of the natural hazard. Usually it is considered the following four levels of the natural hazard intensity: (1) Low hazard intensity, (2) Medium hazard intensity, (3) High hazard intensity, (4) Very high hazard intensity (Table 1).

| Relative intensity | Hazard intensity levels, $H$ |
|--------------------|-----------------------------|
| (4)                | Very high hazard intensity  |
| (3)                | High hazard intensity       |
| (2)                | Medium hazard intensity     |
| (1)                | Low hazard intensity        |

In this case, the risk is defined as follow:

$$R = \sum_{k=1}^{4} R_k$$  \hspace{1cm} (1)

where $R_k$ is the determined risk corresponding to $k$ intensity level of natural hazard, $k=1,...,4$. The risk $R_k$ is obtained by following product

$$R_k = P_k \cdot C_k \hspace{1cm} k=1,...,4$$  \hspace{1cm} (2)

where $P_k$ is the occurrence probability of the natural hazard with $k$ intensity level; $C_k$ is the consequences caused by action of the of the natural hazard with $k$ intensity level.

The values of the consequences are expressed in monetary terms (USD, Euro, etc.). The consequences can be defined as: the value of non-earned revenue corresponding to the amount of unsold electricity or the value of the alternative costs for repair or recovery of the damaged network elements.

The calculated value of consequences $C_k$ and the given value of the probability $P_k$ for occurrence of the natural hazard with $k$ intensity level in the considered time interval are substituted in (2) to calculated corresponding risk level $R_k$.

Than using (1) it is calculated the total risk assessment $R$ of a monitored object (whole electricity transmission and distribution network or its individual elements) from the natural disasters in a given geographic region) from natural hazard with four intensity levels for a certain time interval.

Each of the resulting risk levels $R$ and $R_k$, $k=1,...,4$ can be presented as a distinct risk matrix as the proposed on Figure 2.

First from Table 2 it can be determined the particular level of the probability $P_k$ by using predefined range of each of the five levels. The constants $IP_i$, $i=1,...,5$ are previously defined on the base of the real data or expert knowledge.

Second by analogy with the probability from Table 3 it can be determined the particular level of the consequences $C_k$ by using predefined range of each of the five levels. The constants $IC_i$, $i=1,...,5$ are previously given.

Third from Table 4 for each of the resulting risk assessments $R$ and $R_k$, $k=1,...,4$, can be determined the particular risk levels by using predefined range of each of the four levels. The constants $IR_i$, $i=1,...,4$ are previously given.

The proposed risk assessment with these determinations of the particular risk levels $R$ and $R_k$, $k=1,...,4$, leads to more effectiveness of the risk management about natural hazards.
Table 2. Relative likelihood / Probability levels

| Relative likelihood | Probability levels, $P_k$ | Probability value intervals |
|---------------------|---------------------------|-----------------------------|
| (1)                 | Very low probability      | $IP_4 < P_k$                |
| (2)                 | Low probability           | $IP_3 < P_k \leq IP_4$      |
| (3)                 | Medium probability        | $IP_2 < P_k \leq IP_3$      |
| (4)                 | High probability          | $IP_1 < P_k \leq IP_2$      |
| (5)                 | Very high probability     | $P_k \leq IP_1$             |

Table 3. The Consequences levels

| Relative impact | Aggregated loss / Consequences levels, $C_k$ | Consequence value intervals |
|-----------------|---------------------------------------------|-----------------------------|
| (1)             | Very low probability                        | $IC_4 < C_k$                |
| (2)             | Low probability                             | $IC_3 < C_k \leq IC_4$      |
| (3)             | Medium probability                          | $IC_2 < C_k \leq IC_3$      |
| (4)             | High probability                            | $IC_1 < C_k \leq IC_2$      |
| (5)             | Very high probability                       | $C_k \leq IC_1$             |

Table 4. The Risk levels

| Risk levels, $R$ or $R_k$ | Risk value intervals |
|---------------------------|----------------------|
| Very high risk            | $IR_4 < R_k$         |
| High risk                 | $IR_3 < R_k \leq IR_4$ |
| Medium risk               | $IR_2 < R_k \leq IR_3$ |
| Low risk                  | $R_k \leq IR_2$      |

5. Risk evaluation of the Bulgarian electricity network from natural disasters
The risk evaluation is carried out by comparing the determined risk levels according Table 4 with specific risk criteria to decide whether the risk is acceptable or inadmissible.
It is necessary to ensure the sustainability of Bulgarian electricity network to natural disasters because it is part of the national critical infrastructure.
For this reason, the network needs to be maintained and exploited, following building standards, regulations and good practices. The risk assessment shall be carried out taking into account: the parameters of the electricity network, the characteristics of the potential natural disasters, the peculiarities of the geographical region, the historical and forecast data available. The results are compared with defined criteria for safety and adaptation of the electricity network and its elements.

6. Conclusion
The risk assessment of electricity network as an essential part of risk management from natural disaster is a significant problem of the present day. This paper propose an approach for risk assessment of Bulgarian electricity transmission and distribution network under natural disasters. It is considered that the natural hazard that causes the corresponding natural disaster has four levels of intensity. The proposed approach for risk assessment is based on guidelines and techniques of risk management standards ISO 31000:2009 and EN 31010:2010. Here, the risk assessment is the overall process of risk identification, risk analysis and risk evaluation. The risk assessment results can support the all key stakeholders to take more informed decision about effective protection of the electricity networks from natural disasters.

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