The description and evaluation of technical incident risk on the National Power Grid in the context of power safety growth

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Abstract. In the context of increasing the importance of power safety for national security, the security of power systems within the National Power Grid, must be an objective of major and constant interest for the national transmission and system operator. Evolutions in recent decades have shown the increase in vulnerabilities caused by: failure, destruction and/or disruption of technological infrastructures caused by acts of terrorism, natural disaster, negligence in service, work accidents of technical nature, technical incidents, criminal activities and lack of investment. For the critical analysis of the National Power Grid, 4 (four) possible risk scenarios with effects of instability of the power safety and with major effects on the national security were identified, described and evaluated: *Risk Scenario 1 – Technical Incident*, *Risk Scenario 2 – Damage: Technical Incident Sequence*, *Risk Scenario 3 – Damage: Natural Disaster*, *Risk Scenario 4 – Damage: Terrorist Attack*. The purpose of the paper is to describe and evaluate the Risk Scenario 1 – Technical Incident (which is most prevalent) on the power substations and to prevent potential disturbances in the safety of the power supply to consumer.

1 National Power Grid Generalities – NPG

1.1 The purpose of NPG

The purpose of NPG's existence is to ensure all safety, technical and economic requirements of consumers's supplying with electrical or thermal energy.

In order to do that, NPG must meet the following requirements:

- safety (security) in consumers's supplying;
- the quality of electricity;
- the economicity;
- external requirements.

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Fig. 1. The purpose and requirements of NPG

1.2 NPG statuses

NPG can be functionally found in one of the following status:

- normal operation status - N;
- exposed status (alarm) - E;
- critical status - C;
- damage status - D.

Fig. 2. Functional status of NPG: N – normal operation status; E – exposed status (alarm); C – critical status; D – damage status

Fig. 3. NPG status and transition from one status to another status: N – normal operation status; E – exposed status (alarm); C – critical status; D – damage status

1.3. NPG interconnection with neighboring power systems

NPG interconnection is one of the main ways to increase its reliability and safety, without affecting power independence.

These interconnections provide emergency assistance without the need of installing and maintaining of a strong power reserve.

International interconnections of Romanian NPG:

- Ukraine:
 - OHL 400 kV Roșiori – Mukacevo;
- Hungary:
 - OHL 400 kV Nădab – Bekescsaba;
 - OHL 400 kV Arad – Sandorfalva.
- Serbia:
 - OHL 400 kV Reșița – Pancevo 2;
 - OHL 400 kV Portile de Fier 1 – Djerdap.
- Bulgaria:
 - OHL 400 kV Țanțăreni – Koslodui;
 - OHL 400 kV Rahman – Dobrudja;
 - OHL 400 kV Stupina – Varna.
- Republic of Moldova:
 - OHL 400 kV Isaccea – Vulcănești.

Fig. 4. Transmission Electricity Map at the 400 kV and the interconnection with the neighboring power systems

1.4 Faults's typology (threats) in NPG operation

In NPG's, installations and power equipment running (power plants, electrical networks) it may occur different faults (threats) as follows:

- *current malfunctions*;
- *faults*;
- *incidents*:
 - *isolated*;
 - *associated*.
- *damages*.

Fig. 5. Faults NPG's running

1.5 Real functioning of the romanian NPG

In Romania, the responsibility for the safety and security of NPG running lies with the National Power Grid Company TRANSELECTRICA S.A.

NPG is interconnected to ENTSO-E (European Networks of Transmission System Operators for Electricity), which is the european transport system for European Union (Hungary, Bulgaria, North Ukraine) and the energy systems of Serbia, the Republic of Moldova.

Responsibilities of National Power Grid Company TRANSELECTRICA SA:

- **electricity transmission operator:**
 - exploitation of electricity transmission network infrastructure;
 - maintenance of electricity transmission network infrastructure;
 - development of electricity transmission network infrastructure;
 - on: 81 power substations and 8834,5 km. overhead lines;
 - through 8 power transmission branches and 5 subsidiaries (Opcom, Smart, Formenerg, Teletrans, Icemenerg).
- **system operator:**
 - leading management of NPG;
 - operational management of NPG.
 - with: EMS / SCADA Dispatch Infrastructure;
 - by: 1 National Dispatcher – ND and 5 territorial dispatchers – TD.
- **operator on the electricity market:**
 - electricity exchanges between Romania and the European Union;
 - electricity exchanges between Romania, Serbia, Ukraine and the Republic of Moldova.

2 Identification, description and evaluation of the risk at NPG

2.1. Identification of possible risk scenarios with NPG instability effects

For the critical analysis of the National Power Grid, 4 (four) possible risk scenarios with effects of instability of the power safety and with major effects on the national security were identified:

- **Risk Scenario 1 – Technical Incident (Fig. 6, Fig. 7);**
- Risk Scenario 2 – Damage: Technical Incident Sequence;
- Risk Scenario 3 – Damage: Natural Disaster;
- Risk Scenario 4 – Damage: Terrorist Attack.

Fig. 6. Timing of phenomena and events in case of a Technical Incident 110 kV - 400 kV power substation

Fig. 7. Risk scenario 1 - Technical Incident: Lightning → Explosion → Fire → Interruption in Consumers's Electricity Supply

2.2 Risk scenario description 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY

Table 1. Risk Scenario on Power Substations from NPG

RISK SCENARIO ON POWER SUBSTATIONS FROM NPG TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY	
GENERAL DESCRIPTION	
Causes:	<div>- occurrence of electrical discharges; - the lack or malfunction of the lightning systems; - incorrect running of dischargers; - failure to comply with fire safety regulations; - failure to comply with occupational safety and health regulations; - non-use of IPE - individual protective equipment; - poor condition of power equipment; - lack of revisions of power equipment;</div>

	<ul style="list-style-type: none"> - the use of non-compliant power subassemblies; - lack of investments; - lack of power substation upgrades; - lack of specialized and/or trained maintenance personnel; - lack of specialized and/or trained operative personnel; - incorrect maneuvers (handling) by power substation personnel; - failure to communicate or poor communication with TED - Territorial Energy Dispatcher or DEN - National Energy Dispatcher; - lack/failure to comply/unawareness of national/european procedures in the event of serious incident or damage.
Effects:	<ul style="list-style-type: none"> - work accidents from an explosion that may cause fire (unitary or collective) fatal or incapacitated; - fire accidents at work (unitary or collective) fatal or incapacitated; - explosion reach (fire) to other power equipment in the area; - explosion reach (fire) to other external objectives (forests, houses, blocks, factories, etc.); - the disconnection of the equipment in question; - lack of consumers electric powering; - material damage resulting from lack of electricity; - major material damage happened because of other consumers interdependence.
Spatial dimension	- territorial area of electricity transport branches within National Power Grid Company Transelectrica SA.
Temporal positioning	- any time.
Event duration	- between 1 hour and 12 hours, depending on the intervention teams.
Evolution of the event	- the fire can trigger a series of other fires.
Intervention capacity	<ul style="list-style-type: none"> - it will intervene in the first phase with its own staff with specific attributions; - immediately notify ESI - Emergency Situations Inspectorate for fire insulation.

2.3 Risk scenario evaluation 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY

a) Establishing the probability

To establish the probability of occurrence, the following probability scale was adopted (tabel 2):

Table 2. Scenario 1: Tehnical Incident

SCENARIO 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY			
LEVEL / ASSOCIATED SCORE		DEFINITION OF PROBABILITY	PERIODS
	1. Very low	It has a very low probability of happening. Normal measures are required to monitor the evolution of the event.	over 13 years
	2. Low	The event has a low probability of occurrence. Efforts are required to reduce the probability and/or mitigate the impact produced.	10 - 12 years
	3. Medium	The event has a significant probability of happening. Significant efforts are required to reduce the probability and/or mitigate the impact.	7 - 9 years
X	4. High	The event is likely to happen. Priority efforts are	4 - 6 years

SCENARIO 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY			
LEVEL / ASSOCIATED SCORE		DEFINITION OF PROBABILITY	PERIODS
		required to reduce the probability and mitigate the impact.	
	5. Very high	The event is considered imminent. Immediate and extreme measures are required to protect the target, evacuate to a safe location if the impact imposes it.	1 - 3 years

b) Determining the gravity of the consequences of the proposed scenario

The gravity of the consequences is given by the worst level of vulnerabilities and levels of impact.

- Analysis of vulnerabilities and capabilities (tabel 3)

Table 3. Scenario 1: Tehnical Incident – Analysis of vulnarabilities and capabilities

SCENARIO 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY VULNERABILITIES AND CAPABILITIES	LEVEL
1. Location of the power substation (european critical infrastructure) from the safety point of view in the supply of electricity to consumers: - zonal, regional and national consumers; - national interconnection; - interconnection with neighboring power systems.	Very low
	Low
	Medium
	High
	Very high
2. Degree of specialization and training of fire intervention personnel	Very low
	Low
	Medium
	High
	Very high
3. Degree of specialization and periodic training of the operational personnel with attributions to restore the power supply process	Very low
	Low
	Medium
	High
	Very high
4. Equipping the power substation with fire extinguishing equipment	Very low
	Low
	Medium
	High
	Very high
5. Providing operational personnel with individual means and protective equipment	Very low
	Low
	Medium
	High
	Very high
6. Existence of safety work procedures for the power substation: - risk management; - crisis management; - emergency management; - health and safety work management.	Very low
	Low
	Medium
	High
	Very high
7. Status of the equipment and technological installations related to the electricity transmission process (lack of investments): - atmospheric overvoltage protection equipment (lightning strikes, landing gear);	Very low
	Low
	Medium

SCENARIO 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY VULNERABILITIES AND CAPABILITIES		LEVEL
<ul style="list-style-type: none"> - transformer equipment (transformers, autotransformers); - switching and protection equipment (circuit breakers, separators); - insulators, measuring transformers (voltage and current), etc. 		High
		Very high
8. Technical and human resilience: <ul style="list-style-type: none"> - the partial or total technical possibility of returning to the initial state; - the partial or total human chance of returning to the original state. 		Very low
		Low
		Medium
		High
		Very high

- Impact analysis (tabel 3)

Impact analysis is a management analysis at certain levels that identifies the impact of the loss of resources of a european critical infrastructure (national power substation).

The severity of all scenario impacts will be considered and then the level of severity of the hazard / threat consequences of the scenario considered.

The highest level of severity will be chosen.

Table 4. Impacts

IMPACTS	LEVEL	
Potential deaths	1. Very low	0 – 5
	2. Low	6 – 10
	3. Medium	11 – 15
	4. High	16 – 20
	5. Very high	> 21
Potential injured persons	1. Very low	0 – 20
	2. Low	21 – 40
	3. Medium	41 – 60
	4. High	61 – 80
	5. Very high	> 81
Potential damage or damage to on-site facilities providing the main utilities (electricity, communications)	1. Very low	temporary
	2. Low	significant damage
	3. Medium	average damage
	4. High	great damage
	5. Very high	very high damage
Potential loss or damage to material assets of those to whom services are provided by the relevant national critical infrastructure (public, commercial, private)	1. Very low	0 – 10% of VCI
	2. Low	11 – 20% of VCI
	3. Medium	21 – 30% of VCI
	4. High	31 – 40% of VCI
	5. Very high	over 41% of VCI
Potential loss or damage to the environment	1. Very low	0 – 20%
	2. Low	21 – 40%
	3. Medium	41 – 60%
	4. High	61 – 80%
	5. Very high	over 81%
Potential social impacts	1. Very low	0 – 10% of PT

IMPACTS	LEVEL	
	2. Low	11 – 20% of PT
	3. Medium	21 – 30% of PT
	4. High	31 – 40% of PT
	5. Very high	over 41% of PT
<i>VCI – Value Chain Insight; PT – People Trust</i>		

Table 5. Gravity of the consequences

LEVEL / ASSOCIATED SCORES		GRAVITY OF THE CONSEQUENCES
	1. Very low	The event produces a minor disturbance in the working process without material damage
	2. Low	The event produces minor material losses and limited activity disturbance
	3. Medium	Personal injury, and/or some loss of equipment, utilities, and delays in service providing.
X	4. High	Serious injury to personnel, significant losses of instalation equipment, delays and/or disruption of service provision.
	5. Very high	Consequences are catastrophic resulting in deaths and serious personal injury, major loss of equipment, instalations and facilities, and the cessation of service provision.

c) Calculation of risk level (Table 6)

In table 6 are presented the probability and gravity of the consequences and the calculated risk level.

Table 6. Probability / Gravity of the consequences

PROBABILITY	Very high 5					
	High 4				Scenario 1 FIRE	
	Medium 3					
	Low 2					
	Very low 1					
	0	Very low 1	Low 2	Medium 3	High 4	Very high 5
GRAVITY/CONSEQUENCES						

RISC LEVEL CALCULATED	
LEVEL	SCORES
Very low	1 – 3
Low	4 – 6
Medium	7 – 12
High	13 – 16
Very high	17 – 25

The risk is determined by multiplying the probability of producing a hazard with threats and the severity of its consequences.

The calculated risk is 16 (probability 4 x gravity 4) therefore there is a high risk of producing the chosen scenario.

d) Risk treatement (table 7)

To reduce the risk,the next steps are required to cover the following vulnerabilities and/or improve the following capabilities:

Table 7. Risk treatment

VULNERABILITY AND/OR CAPABILITY	PROPOSED MEASURES
Degree of specialization and training of fire intervention personnel	- training and retraining courses for emergency situations; - simulations of interventions (very short time) in case of fires.
Degree of specialization and periodic training of the operative personnel with attributions to restore the power supply process	- combined training and retraining courses; - events and incidents analysis, etc.; - installations's checking on the operating line and performing preventive maintenance.
Equipping the power station with fire extinguishing equipment	- Equipping with individual means of fire extinguishing
Equipment and technological installations related to the electricity transmission process status (lack of investments)	- major investments in high performance equipment

After applying the risk reducing measures we have the next results (table 8):

Table 8. Risk reducing measures

SCENARIO 1: TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY VULNERABILITY	IDENTIFIED	AFTER THE MEASURES APPLICATION
<ul style="list-style-type: none"> - Degree of specialization and training of fire intervention personnel - Degree of specialization and periodic training of the operative personnel with attributions to restore the power supply process - Equipping the power substation with fire extinguishing equipment 	1. Very low	1. Very low
	2. Low	2. Low
	3. Medium	3. Medium
	4. High	4. High
	5. Very high	5. Very high

e) Recalculating the consequences gravities (table 9)

Table 9. Recalculating the gravity of the consequences

LEVEL / ASSOCIATED SCORES	GRAVITY OF CONSEQUENCES
1. Very low	The event produces a minor disturbance in the development of activity without material damage.
2. Low	The event produces minor material damage and limited activity disturbance
X 3. Medium	Personal injury, and / or some loss of equipment, utilities, and delays in providing the service.
4. High	Serious injury to personnel, significant loss of instalations and facilities equipment , delays and / or disruption of service provision.
5. Very high	Consequences are catastrophic resulting in deaths and serious injuries to staff, major loss of equipment, instalations and facilities, and cessation of service provision

f) Risk level after reduction measures applying (table 10)

The risk is given by the product between the probability of producing a hazard and threats and the severity of its consequences. The calculated risk is 12 (probability 4 x gravity 3) therefore there is a medium risk of producing the chosen scenario.

Table 10. Probability / Gravity of the consequences

PROBABILITY	Very high 5					
	High 4			Scenario 1 FIRE		
	Medium 3					
	Low 2					
	Very low 1					
	0	Very low 1	Low 2	Medium 3	High 4	Very high 5
GRAVITY/CONSEQUENCES						

RISK LEVEL CALCULATED	
LEVEL	SCORES
Very low	1 – 3
Low	4 – 6
Medium	7 – 12
High	13 – 16
Very high	17 – 25

3 Conclusion

After the completion of evaluation SCENARIO 1 - TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY, the following facts were determined (table 11):

- to establish the probability of the event to happen, it was selected the **scale 4 probability (high)**;
- **level 4 (high)** was selected for the severity of the consequences;
- the calculated risk is **16 (high risk)**;
- after the risk reduction measures have been applied, the severity of the consequences has been recalculated and **level 3 (medium)** has been selected;
- the recalculated risk is **12 (medium risk)**.

Table 11. Risk scenario 1

RISK SCENARIO 1 TECHNICAL INCIDENT: LIGHTNING → EXPLOSION → FIRE → INTERRUPTION IN CONSUMERS'S ELECTRICITY			
LEVEL	SCORES	CALCULATED RISK	RECALCULATED RISK
VERY LOW	1 – 3		
LOW	4 – 6		
MEDIUM	7 – 12		12
HIGH	13 – 16	16	
VERY HIGH	17 – 25		

To reduce the risks, the following measures were selected in order to diminish the vulnerabilities and to improve the next capabilities (table 12):

Table 12. Proposed measures

VULNERABILITY AND/OR CAPABILITY	PROPOSED MEASURES
Degree of specialization and training of fire intervention personnel.	- emergency training and retraining courses; - simulation of interventions (very short time) in case of fires.

VULNERABILITY AND/OR CAPABILITY	PROPOSED MEASURES
Degree of specialization and periodic training of the operational staff with attributions to restore the power supply process.	- combined training and retraining courses; - events and incidents analysis etc .; - installations's checking on the operating line and performing preventive maintenance
Equipping the power station with fire extinguishing equipment	- equipping with individual means of fire extinguishing.
Equipment and technological installations related to the electricity transmission process status(lack of investments).	- major investments in high performance equipment.

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