ASSESSMENT OF VULNERABILITY FROM NATIONAL POWER SYSTEM IN THE CONTEXT OF STRENGTHENING ENERGY RESILIENCE

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Abstract: A adaptable, resilient, safe and secure power system is essential for ensuring energy and national security, having a direct impact on a state's economy, social stability, and well-being through the following requirements: Ensuring continuity of power supply (a robust power system guarantees uninterrupted access to electricity for citizens, institutions, and industries, reducing the risk of disruptions caused by technical deficiencies, cyberattacks, or geopolitical instability); Energy independence and reduction of external dependence (a state that produces sufficient electricity from its own sources is less vulnerable to international market fluctuations and external pressures, while diversifying energy sources—renewable, nuclear, hydrocarbons—reduces import dependence and economic vulnerability); Security of power infrastructure (protecting electricity networks from physical and cyberattacks is essential for the normal functioning of society, and developing modern infrastructure—smart grids, electricity storage—ensures the resilience of the energy system); Economic stability and national development (an efficient power system supports industry, agriculture, and services, contributing to economic growth, while lower energy costs enhance economic competitiveness and attract investments); Environmental protection and energy transition (adopting renewable sources and clean technologies reduces dependence on fossil fuels and minimizes environmental impact, while increasing energy efficiency and reducing carbon emissions are essential for long-term sustainability); Strategic and geopolitical role (countries with significant energy resources have greater influence on the international stage, and regional energy cooperation can strengthen diplomatic and economic relations). A secure and efficient energy system is the backbone of national security, guaranteeing economic stability, strategic independence, and population protection. Investments in modern infrastructure, clean technologies, and diversification of energy sources are crucial for the energy future of any nation. The authors of this study have identified all elements of instability and insecurity within Romania's Power System, and they assessed the vulnerability Poor management of the transmission operator activity and risk of Natural Disaster, that could generate the Energy Crisis – black-out.

Keywords: assessment, vulnerability, national power system, energy resilience

1. INTRODUCTION

Romania is integrated into the European electricity transmission network, part of the European Network of Transmission System Operators for Electricity (ENTSO-E). International interconnections enable energy exchanges, optimisation of energy resources and contribute to system stability in the event of major variations in consumption or production. The structure of the National Power System is the set of interconnected components that ensure the production, transmission, distribution and consumption of electricity.

Electricity production in Romania is based on a combination of energy sources, and the energy landscape of the country has evolved over time, based on conventional and renewable energy sources. Romania has a diversified energy infrastructure, with power plants that use several energy sources, including nuclear energy, hydropower, fossil fuel energy (lignite, hard coal, natural gas) and renewable energy (wind, solar, biomass).

Electricity transmission is carried out through the National Power Grid, which plays a key role in the transmission of electricity from producers to distributors and is responsible for the safety and reliability of the National Power System. The structure of the power grid includes very and high voltage overhead power lines, power substations and dispatching.

The power infrastructure is composed of 81 power substations, of which 1 power substation at 750 kV (working at 400 kV), 38 power substation at 400 kV and 42 power substations at 220 kV. The distribution of electricity is carried out through the Power Distribution Network, which is an essential part of the national power infrastructure, responsible for the distribution of electricity to consumers. This network includes overhead power lines and power substations at 110 kV providing power to both urban and rural areas. [1-2].

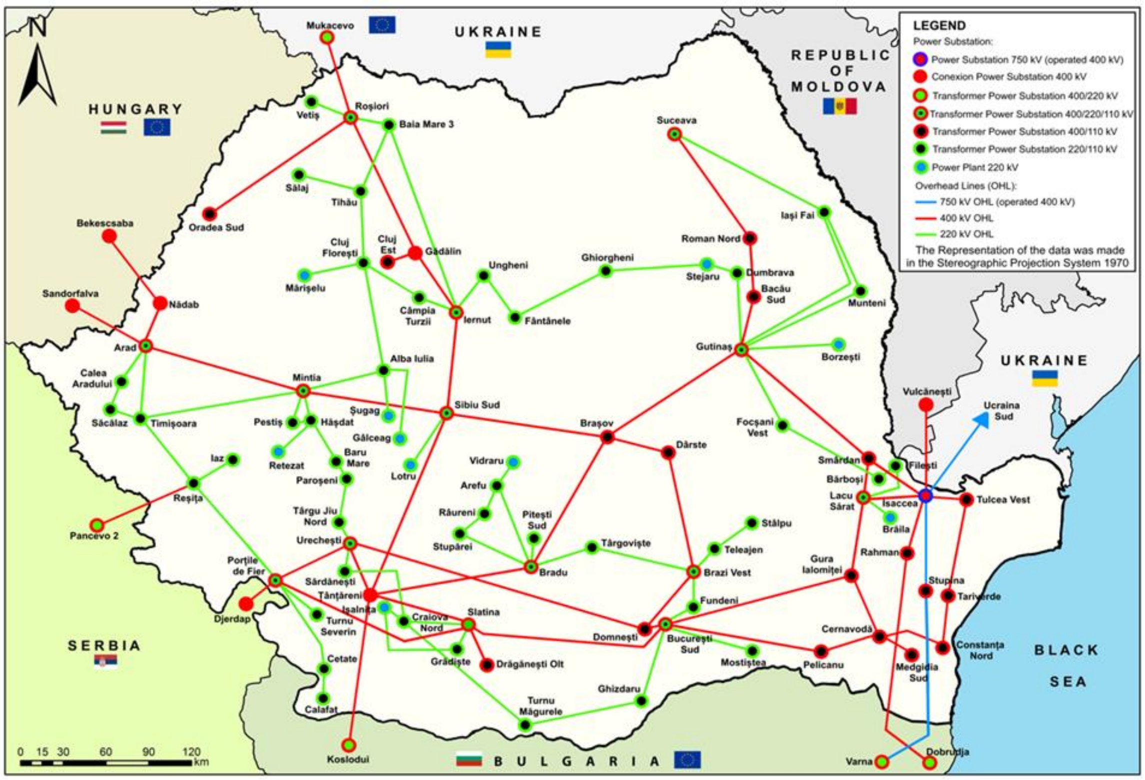

Figure 1. National Power System map.

Because The National Power System is vulnerable, it can be, at any time, the target of terrorist threats or attacks (bomb or cyber attacks), natural risks (calamities caused by nature) and anthropic risks (caused by man), which could endanger the proper functioning, or in the most unfortunate case, its total outage – black-out, generating a major crisis that could cause extreme damage to the citizen, society and state. [3].

The National Power System is the generator of critical infrastructures (power plants, power substations and overhead power lines), because it ensures the health and safety of the citizens by supplying all of the state systems, the industry and the national economy with electricity and has a substantial contribution to ensuring national security and well-being, as shown in figure 2. [4-6].

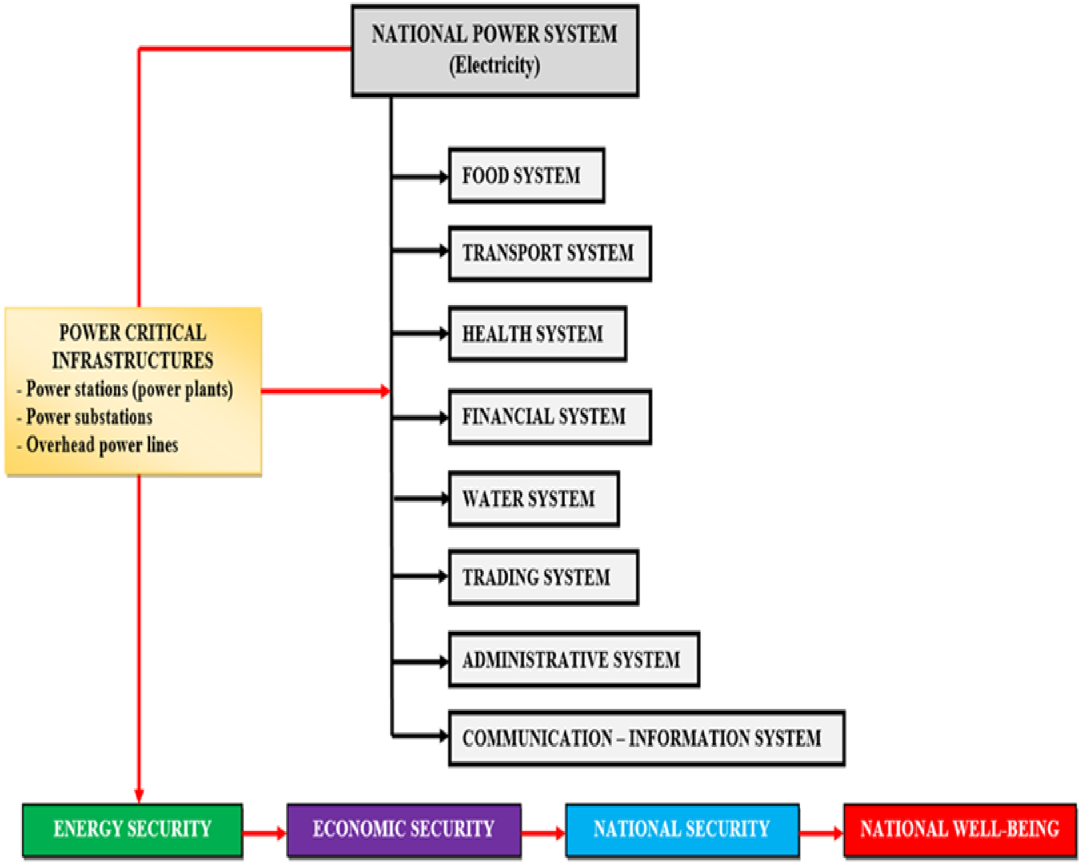

Figure 2. The dependence of state systems, economy and national industry on electricity.

2. ASSESSMENT OF VULNERABILITY

Vulnerability: Poor management of the transmission operator activity (exploitation, maintenance and development) of the Power Transmission Grid installations → Risk of technical incident (isolated/associated), technical disturbance or damage → Technological threat → Hazard of technologically instability (incident / damage) → black-out. [7-11].

Table 1. The causal analysis

The identified vulnerabilty	Identification of the generated source (dysfunction, deficiency, non-compliance)	The causal analysis
Poor management of the transmission operator activity (exploitation, maintenance and development) of the Power Transmission Grid installations.	Dysfunction	• lack, precariousness or non-compliance with exploitation procedures; • lack, precariousness or non-compliance with maintenance procedures; • lack, precariousness or non-compliance with development procedures

Table 2. Causes and effects

<table>
<tr><th>Causes</th><th>Effects</th></tr>
<tr><td>• short circuits of energetic equipment;
• loading of some main overhead power lines;
• loading of energetic equipment;
• precarious state of the energetic equipment;
• lack of investment in power substations;
• the system automatics within energetic groups not functioning;
• lack of energetic equipment revisions;
• non-refurbishment of the power substations;
• wrong configuration of the power substations;
• lack of specialised and/or trained operative staff;
• non-communication or poor communication with The Territorial Energy Dispatch and The National Energy Dispatch;
• unspecialised Territorial Energy Dispatch or National Energy Dispatch staff in times of crisis;
• lack of work procedures in stations during a crisis;
• lack of / non-compliance / ignorance of national/european procedures in case of serious damage (black-out);
• lack of training in the field of Risk Management;
• non-closure of the 400 kV ring of Romania – it becomes a vulnerability of The National Power System;
• the occurrence of electrical discharges;
• lack or incorrect operation of lightning rod installations;
• incorrect functioning of the unloaders;
• non-compliance of the fire safety standards;
• non-compliance with the Occupational Health and Safety standards;
• non-use of the personal protective equipment;
• precarious state of the energetic equipment;
• lack of energetic equipment revisions;
• use of non-compliant energetic subassemblies;
• lack of investments;
• non-modernization of the power substations;
• lack of specialized and/or trained maintenance staff;
• wrong manoeuvres performed by the operative staff from the stations.</td><td>• stopping the energy market between Romania and the EU
• stopping the energy market between Romania and Serbia, Ukraine, Republic of Moldova;
• non-supply with electricity the neighbouring and EU energy systems;
• non-supply with electricity the major consumers and the main overhead power lines within The National Power System
• the possibility of a local, regional or national black-out.
• work accidents resulting from the explosion which may cause fire (individual or collective) to be fatal or incapacitated;
• work accidents resulting from the fire (unitary or collective) to be fatal or incapacitated;
• the propagation of the explosion (fire) to other energetic equipment in the area;
• the propagation of the explosion (fire) to other external objectives (forests, houses, blocks, factories, etc.);
• the unexpected disconnection of the respective equipment;
• material losses resulting from lack of electricity;
• major material losses resulting from the interdependence of other consumers.</td></tr>
</table>

A. The gravity analysis

Table 3. The gravitiy analysis

<table>
<tr><th>The Gravity Analysis</th><th colspan="2">Level</th></tr>
<tr><td rowspan="5">a) Non-closure of the 400 kV ring of Romania:
• lack of investments (non-refurbishment of the power substations, overhead power lines and new energetic objectives);
• unpredictability of the political system;
• the possibility of a local, regional or national black-out, generating the stopping of the energy market between Romania and the EU;
• economic insecurity generating national insecurity;</td><td></td><td>1. Very low</td></tr>
<tr><td></td><td>2. Low</td></tr>
<tr><td></td><td>3. Medium</td></tr>
<tr><td></td><td>4. High</td></tr>
<tr><td>X</td><td>5. Very high</td></tr>
</table>

b) The degree of specialization and periodic training of staff with attributions to restore the process of electricity supply: • operative staff; • maintenance staff; • security staff. c) Placing the power substation (critical european infrastructure) in terms of safety in supplying the consumers with electricity: • local, regional and national consumers; • national interconnection; • interconnection with neighbouring energetic systems. d) The degree of specialization and training of fire intervention staff; e) The degree of specialization and periodic training of the operative staff with attributions to restore the process of electricity supply; f) Equipping the power substation with fire extinguishing means and equipment; g) Equipping the operative staff with individual means and protective equipment; h) The existence of security work procedures for the power substation:: • the risk management; • the crisis situations management; • the emergencies situations management; • the security and health at work management. i) The state of equipment and technological installations related to the electricity transmission process (lack of investments): • equipment for protection against atmospheric overvoltage (paratransets, unloaders); • transformer equipment (transformers, autotransformers); • switching and protection equipment (switches, separators); • insulators, measuring transformers (voltage and current), etc.; • technical and human resilience: ➢ the partial or total technical possibility of returning to the original state; ➢ the partial or total human possibility of returning to the original state.		

B. The gravity level

Level		Gravity
	1. Very low	The event produces a minor disturbance in the activity, without material damage
	2. Low	The event causes minor material damage and limited disruption to activity
	3. Medium	Injuries to staff, and/or certain losses of equipment, utilities and delays in providing the service.
	4. High	Serious staff injuries, significant loss of equipment of installations and facilities, delays and/or interruption of service provision.
X	**5. Very high**	The consequences are catastrophic resulting in deaths and serious injuries to staff, major losses in equipment, installations and facilities and termination of service provision.

C. The impact analysis

Table 4. The impact analysis

The Impact analysis		Level	
Potential deaths (persons)	**X**	**1. Very low**	**0 – 5 people**
		2. Low	**6 – 10 people**
		3. Medium	**11 – 15 people**
		4. High	**16 – 20 people**
		5. Very high	**> 21 people**
Potential injured persons (persons)	**X**	**1. Very low**	**0 – 20 people**
		2. Low	**21 – 40 people**

		3. Medium	**41 – 60 people**
		4. High	**61 – 80 people**
		5. Very high	**> 81 people**
Potential losses or damage to on-site infrastructures providing the main utilities: electricity, communications, drinking water, natural gas (damage)		**1. Very low**	**temporary damage**
		2. Low	**considerable damage**
		3. Medium	**medium damage**
		4. High	**high damage**
	X	**Very high**	**very high damage**
Potential losses or damage to the material goods of those to whom services are provided by the critical national infrastructure in question: public, commercial, private (Income on Invested Capital)		**1. Very low**	**0 – 10% of IIC**
		2. Low	**11 – 20% of IIC**
		3. Medium	**21– 30% of IIC**
		4. High	**31 – 40% of IIC**
	X	**Very high**	**over 41% of IIC**
Potential losses or damage to the environment (%)		**1. Very low**	**0 – 20%**
		2. Low	**21 – 40%**
	X	**3. Medium**	**41 – 60%**
		4. High	**61 – 80%**
		Very high	**over 81%**
Potential social impacts (the Public Confidence)		**1. Very low**	**0 – 10% of PC**
		2. Low	**11 – 20% of PC**
	X	**3. Medium**	**21 – 30% of PC**
		4. High	**31 – 40% of PC**
		5.Very high	**over 41% of PC**

D. The impact level

Level		**Impact**
	1. Very low	The event produces a minor disturbance in the activity, without material damage
	2. Low	The event causes minor material damage and limited disruption to activity
	3. Medium	Injuries to staff, and/or certain losses of equipment, utilities and delays in providing the service.
	4. High	Serious staff injuries, significant loss of equipment of installations and facilities, delays and/or interruption of service provision.
X	**5.Very high**	The consequences are catastrophic resulting in deaths and serious injuries to staff, major losses in equipment, installations and facilities and termination of service provision.

E. The identification of the involved infrastructures

Table 5. Involved critical equipments

The identification of the involved critical equipment	Notes
• overhead power lines; • (auto) transformers of high power; • switches, separators • compensation coils, reactance coils, quenching coils; • current and voltage transformers (measuring devices); • unloaders, fuses (protective devices); • conductors, insulators.	

F. The interdepepencies analysis

Table 6. Interdepencies analysis / Critical infrastructures or system

The interdepencies analysis	Critical infrastructures or systems
• the drinking water supply system; • the natural gas system; • the oil system; • the mining system; • the nuclear system; • the economic system; • the transport system; • the information system; • the financial and banking system; • the industrial system, etc..	• aqua pipelines, pumping stations, etc.; • gas pipelines, pumping stations, etc.; • oil pipelines, pumping stations, etc.; • coalmines; • nuclear power plants, hydro power plants, thermo power plants, etc.; • airports, airplanes, train stations, trains, highways, ports, ships, etc.; • banks; • industrial systems, etc..

G. The calculation of the vulnerability level

GRAVITY						
	Very high 5					**Scenario**
	High 4					
	Medium 3					
	Low 2					
	Very low 1					
	0	**Very low 1**	**Low 2**	**Medium 3**	**High 4**	**Very high 5**
				IMPACT		

Note: The vulnerability level is given by the product between the gravity level and the impact level

The calculated vulnerability has a value of 25 (gravity 5 x impact 5) therefore the production of the chosen scenario has a VERY HIGH vulnerability level

CALCULATED VULNERABILITY LEVEL		
LEVEL		**SCORE**
	Very low	**1 – 3**
	Low	**4 – 6**
	Medium	**7 – 12**
	High	**13 – 16**
X	**Very high**	**17 – 25**

H. Proposed recommendations

Table 7. Proposed recommendations

The vulnerability	Proposed recommendations
Non-closure of the 400 kV ring of Romania	• major investments in the national and european critical insfrastructure; • the predictability (safety) of the political system; • accessing european funds regarding the security of the critical european infrastructures.
The degree of specialization and periodic training of staff with attributions to restore the process of electricity supply	• training and refresher courses for the operative, maintenance and security staff; • the assessment of the events, incidents, etc.;

	• control of installations on the operating line and carrying out preventive maintenance.
The degree of specialization and training of fire intervention staff	• training and refresher courses in the field of emergency situations; • simulations of interventions (very short time) in case of fires
Equipping the power substation with fire extinguishing means and equipment	• equipping with individual fire extinguishing means and equipment
The state of equipment and technological installations related to the electricity transmission process (lack of investments)	• major investments in performant equipment.

Table 8. The identified vulnerability after the proposed recommendations

The identified vulnerability after the proposed recommendations	Identified		After the proposed recommendations	
a) Non-closure of the 400 kV ring of Romania; b) The degree of specialization and periodic training of staff with attributions to restore the process of electricity supply; c) The degree of specialization and training of fire intervention staff; d) The degree of specialization and periodic training of staff with attributions to restore the process of electricity supply; e) Equipping the power substation with fire extinguishing means and equipment; f) Locating the power substation (european critical infrastructure) in terms of safety in supplying electricity to consumers g) Equipping the operative staff with individual fire extinguishing means and equipment; h) The existence of work procedures in the security field for the power substation; i) The state of equipment and technological installations related to the electricity transmission process (lack of investments); j) Technical and human resilience.		**1. Very low**		**1. Very low**
		2. Low		**2. Low**
		3. Medium	**X**	**3. Medium**
		4. High		**4. High**
	X	**5. Very high**		**5. Very high**

I. The recalculation of the vulnerability level

GRAVITY						
	Very high 5			**Scenario**		
	High 4					
	Medium 3					
	Low 2					
	Very low 1					
	0	**Very low 1**	**Low 2**	**Medium 3**	**High 4**	**Very high 5**
				IMPACT		

Note: The vulnerability level is given by the product between the gravity level and the impact level

The calculated vulnerability has a value of 15 (gravity 5 x impact 5) therefore the production of the chosen scenario has a MEDIUM vulnerability level

CALCULATED VULNERABILITY LEVEL		
LEVEL		SCORE
	Very low	1 – 3
	Low	4 – 6
X	Medium	7 – 12
	High	13 – 16
	Very high	17 – 25

3. CONCLUSIONS

After assessment of Vulnerability: Poor management of the transmission operator activity (exploitation, maintenance and development) of the Power Transmission Grid installations → Risk of technical incident (isolated/associated), technical disturbance or damage → Technological threat → Hazard of technologically instability (incident / damage) → black-out, result is next:

- The calculated vulnerability has a value of 25 (gravity 5 x impact 5), therefore the production of the chosen scenario has a VERY HIGH vulnerability level;
- After proposed recommendations: The calculated vulnerability has a value of 15 (gravity 5 x impact 5) therefore the production of the chosen scenario has a MEDIUM vulnerability level.

Major Conclusions

A. Systemic Vulnerability and organizational risk:

- Poor management practices—such as inadequate maintenance planning, lack of asset monitoring, or delayed infrastructure development—create systemic weaknesses in the transmission grid;
- These weaknesses accumulate over time, increasing the likelihood of cascading failures during high-demand or fault conditions;
- The vulnerability is organizational as much as technical: it arises from governance, oversight, and resource allocation failures.

B. Increased Probability of technical incidents:

- Inefficient or irregular preventive maintenance leads to the degradation of critical components (transformers, lines, substations);
- Fault detection and response systems become less reliable, allowing minor faults to escalate into major disturbances;
- Technical incidents may occur in isolation or in combination with external stressors (weather, cyberattack, supply-demand imbalance).

C. Risk Amplification through Interconnection:

- Because the transmission grid is highly interconnected, local failures can propagate regionally or nationally, causing widespread disturbances;
- Inadequate operational coordination between transmission and distribution operators amplifies the propagation of technical issues;
- Such propagation can result in frequency and voltage instability, which, if uncontained, culminates in a blackout scenario.

D. Technological threat and instability:

- Poor management translates into a technological threat—a latent hazard within the infrastructure;
- The result is technological instability, where the system operates near its technical limits without sufficient resilience margins;
- This instability undermines the reliability and security of electricity supply, affecting economic, industrial, and social continuity.

E. Potential consequences:

- Blackouts or large-scale outages due to cascading failures;
- Damage to critical infrastructure (equipment burnout, insulation failures);
- Economic losses, safety hazards, and loss of public trust in the grid operator;
- Regulatory and reputational impacts on the transmission operator due to failure to meet reliability standards.

F. Strategic implications:

- Strengthening asset management systems, risk-based maintenance, and real-time condition monitoring is essential;
- Establishing a robust governance and accountability framework within the transmission operator reduces management-related vulnerabilities;
- Integration of resilience planning, redundancy, and emergency response protocols minimizes the impact of incidents and prevents blackouts.

Poor management of transmission system operations constitutes a critical vulnerability that can transform minor technical issues into major technological hazards, leading to instability or total system blackouts. Addressing this vulnerability requires both organizational reforms and technological reinforcement to ensure sustainable, secure, and resilient power transmission.

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