



**UNIVERSITY OF PETROȘANI**  
**DOCTORAL SCHOOL**  
**DOCTORAL FIELD: INDUSTRIAL ENGINEERING**

# **DOCTORAL THESIS**

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**DOCTORAL FIELD: INDUSTRIAL ENGINEERING**

**RESEARCH ON THE CRITICAL ANALYSIS  
OF THE SARDANESTI POWER SUBSTATION  
REGARDING THE INDUSTRIAL SECURITY  
OF CONSUMERS IN THE OLTENIA COAL  
BASIN**

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# CONTEXT AND MOTIVATION OF THE RESEARCH

## The importance of the topic

In the modern era, electricity is the backbone of society. The functioning of essential services, critical infrastructure, industries and households depends on a safe and uninterrupted supply of electricity. In this context, the security of the consumer supply is of strategic importance, being a key component of the national energy security.

Electricity supply security involves the ability of the National Power System to provide electricity continuously, at appropriate technical parameters (stable voltage and frequency), with a minimum degree of interruptions and vulnerabilities. This includes both the availability of energy resources and the reliability of electricity transmission and distribution grids. Energy security must also take into account the resilience in the face of cyberattacks, terrorist attacks, sabotage, natural disasters or technical damage.

Electricity supply systems are subject to a wide range of risks, including: overshooting demand relative to supply, especially during peak periods or extreme weather conditions, technical failures of transmission and distribution equipment, cyberattacks, which may target the digital infrastructure of grid operators, extreme natural phenomena such as storms, earthquakes or fires, geopolitical instability and dependence on energy imports or critical components.

In order to guarantee the security of the supply to consumers, the implementation of modern policies and technologies, is essential: diversification of energy sources – the use of a balanced energy mix (hydro, gas, thermal, nuclear and renewable) reduces dependence on a single source, modernization of the transmission and distribution grids – by introducing the concept of „smart grid”, the grids become more efficient and resistant to disturbances, energy storage systems – high capacity batteries and other storage technologies can mitigate the fluctuations in supply, distributed energy generation – allows consumers to become prosumers, reducing pressure on central grids and rapid crisis response plans – alert systems, redundancies and reaction capacities can minimize the impact of interruptions.

The global energy transition brings new challenges and opportunities for security of supply. Digitization, the integration of intermittent renewable sources and the increase of electric mobility require flexible and intelligent solutions. At the same time, the decarbonisation of the National Power System must be accompanied by measures to maintain the reliability of the Power Transmission Grid. Emerging technologies such as artificial intelligence, blockchain or green hydrogen can play an important role in creating a safe, sustainable and resilient power system.

The security of the electricity supply to consumers is a national and global priority, which requires an integrated effort between governments, companies, communities and citizens. In a context of climate change, technological change and geopolitical instability, ensuring a robust and adaptable National Power System is essential for sustainable development and economic stability. Investment in infrastructure, research and coherent public policies will determine the capacity of society to respond efficiently to these challenges.

Power substations are strategic nodes in the Power Transmission Grid and the Power Distribution Grid that perform voltage transformation (very high voltage – high voltage – medium voltage – low voltage), protection and control of power flows and monitoring of grid parameters. Without the correct and continuous functioning of the power substations, end consumers can be affected by interruptions, voltage variations or even major damage.

Many power substations in the Power Transmission Grid were built in the '70-'80s and suffer from physical and moral wear, lack of automation and cybersecurity vulnerabilities. Their modernisation (refurbishment and optimisation) is essential for integrating renewable sources, managing variable consumption and ensuring resilience to climate change or geopolitical risks.

The topic addressed in this doctoral thesis "Critical analysis of the 220/110/20 kV Sardanesti power substation on the industrial security regarding energy objectives in the Oltenia Coal Basin", becomes very interesting, pragmatic and real, because the insecurity of the electricity supply of industrial consumers can lead to industrial insecurity, economic insecurity, societal insecurity and national insecurity, especially in the new context of world energy vulnerability.

This topic is of strategic importance, having direct implications on the quality of life of citizens, the functioning of institutions and the regional economic development. The critical analysis of the power substation not only identifies the vulnerabilities of the energy infrastructure, but also provides directions for a safer, more efficient and resilient system.

The paper addresses and analyzes the fundamental concepts related to the security of electricity supply, the risks associated with interruptions, the protection measures and future trends in the field of the National Power System.

### **The necessity of the topic**

The necessity for the "Critical analysis of the 220/110/20 kV Sardanesti power substation on the industrial security regarding energy objectives in the Oltenia Coal Basin", results from the following considerations:

- because the power substation is a national objective of strategic importance – national critical infrastructure, it must be analyzed, managed, monitored and assessed from the point of view of its stability, protection, security and resilience;
- the necessity for stability, protection, security and resilience of the power substation comes from the European obligation imposed by ENTSO-E (The European Network of Transmission System Operators for Electricity) and CNTEE Transelectrica SA (the national transmission and system operator);
- by identifying threats, hazards, risks and vulnerabilities to the power substation, different strategies regarding its safety and security can be generated;
- investments in infrastructure and specialized human resources become the central factor of the stability, safety and security of the power substation and implicitly of the National Power System;
- all the aspects listed above converge towards the dedication of scientific research towards industrial security and energy security and to become for economic decision-makers a pressing issue of ensuring national security and welfare and of sustainable development.

### **General objectives**

Defining methodologies and algorithms specific to the area of industrial security, energy security and implicitly national security, which include all operations and actions necessary to identify and assess all plausible risk scenarios that may threaten the safety and security of the Sardanesti power substation and the National Power Sector.

These methodologies and algorithms must be integrated into an Industrial Security Plan that must be mandatory for all operators, managers and owners of national and European critical infrastructures in the energy field.

## Specific objectives

- developing scientific research, expertise and assessments on identifying, assessing, stopping and/or eliminating all elements of instability, according to well-defined legislative frameworks;
- developing scientific research, expertise and assessments on the level of criticality of critical energy infrastructures;
- developing scientific research, expertise and assessments on the protection and security of all critical energy infrastructures within the National Power System;
- the thorough critical analysis of each power substation rated as national and/or European critical infrastructure;
- analysis of the evolutions of all technical damage and incidents until the source of the event is found;
- analysis of the evolution of all work accidents until the source of the event is found.

## Structure of the doctoral thesis

Following the thorough legislative, technical and security documentation and the collection of valuable information and data from various state authorities responsible for ensuring and increasing energy security, I have developed this doctoral thesis with the following procedural and selective structure:

1.	Foreword	– 1 page;	16 pages
2.	Content	– 4 pages;	
3.	List of abbreviations (42)	– 1 page;	
4.	List of figures (55)	– 2 pages;	
5.	List of tables (46)	– 2 pages;	
6.	Introduction	– 6 pages;	142 pages of scientific research
7.	Chapter 1	– 21 pages;	
8.	Chapter 2	– 73 pages;	
9.	Chapter 3	– 14 pages;	
10.	Chapter 4	– 22 pages;	
11.	Chapter 5	– 12 pages;	32 pages
12.	Annex 1	– 9 pages;	
13.	Annex 2	– 9 pages;	
14.	Annex 3	– 5 pages;	
15.	Bibliography (88)	– 9 pages.	

**The introduction** is dedicated to *the importance and necessity of the topic, general and specific objectives, the structure of the doctoral thesis and the degree of novelty and complexity.*

**Chapter 1**, entitled THE NATIONAL POWER SYSTEM – ENERGY AND NATIONAL SECURITY GENERATOR SYSTEM, is dedicated to presenting the importance of the National Power System in ensuring energy and national security.

It has the following structure: Definition, Composition, Structure (electricity generation elements, power grids and electricity consumers), Purpose and Requirements, States, Faults typology, Functioning, Strategic importance, Blackout risk and national resilience, Power Transmission Grid (importance, description, composition and security

and reliability) and Fundamental security notions (industrial security, security and protection of critical infrastructures and energy security).

The electricity produced in the National Power System and transported through the Power Transmission Grid (the backbone of the NPS composed of several critical energy infrastructures) is an essential pillar of the functioning of society, the economy, defense, intelligence and public order institutions of the state.

**Chapter 2**, entitled CRITICAL ANALYSIS OF THE 220/110/20 kV SARDANESTI POWER SUBSTATION, is dedicated to the critical analysis of the 220/110/20 kV Sardanesti power substation and represents the central core of this doctoral thesis.

It has the following structure: Presentation of the power substation, risk assessment methodology, prerequisites regarding risks and modeling of operating regimes (220 kV power substation, 110 kV power substation, 20 kV power substation, description of the methodology for assessing energy security risks, theoretical prerequisites regarding risks and theoretical notions regarding modeling of operating regimes: permanent and short circuit regime), Identification of threats, hazards and vulnerabilities (220 kV power substation, 110 kV power substation, 20 kV power substation), Energy security risk assessment (electricity supply risk assessment, technical failure risk assessment, natural disaster risk assessment, terrorist attack risk assessment and fire risk assessment AT 220/110/20 kV – 200 MVA) and Modeling of operating regimes (permanent regime and short circuit regime modeling).

The electricity distributed by the 220/110/20 kV Sardanesti power substation plays a decisive role in the security of supply to industrial consumers in the Oltenia Mining Energy Basin and The National Railway Company “CFR” – SA.

At the voltage of 220 kV (electricity transmission voltage), the power substation represents an important connection node between the 400/220/110 kV Urechesti power substation and the 220/110 kV Craiova Nord power substation.

At the voltage of 110 kV, the power substation ensures the supply of electricity to the following industrial mining objectives in the Oltenia Carboniferous Basin and CFR: Jilt, Dragotesti, Pinoasa, Rosia – Pesteana, SRA Pesteana, Turceni T01, Turceni T03, Turceni 05 and CFR: Plopsoru – CFR 1 and Plopsoru CFR 2.

The identification of threats, hazards and vulnerabilities was carried out for the following objectives: 220 kV power substation; 110 kV power substation; 20 kV power substation.

The energy security risk assessment was carried out through the following: electricity supply risk assessment; Technical Failure risk assessment; Natural Disaster risk assessment; Terrorist Attack risk assessment; Fire risk assessment AT 220//110/20 kV – 200 MVA

The modeling of the operating mode was carried out for the following regimes: permanent regime; short circuit regime.

**Chapter 3**, entitled DEVELOPMENT OF THE ENERGY SECURITY STRATEGY OF THE 220/110/20 kV SARDANESTI POWER SUBSTATION, is dedicated to the development of the Energy Security Strategy of the 220/110/20 kV Sardanesti power substation, composed of the three strategies related to the Identification of threats, hazards and vulnerabilities (220 kV power substation, 110 kV power substation and 20 kV power substation), energy security risk assessment (electricity supply risk assessment, Technical Failure risk assessment, Natural Disaster risk assessment, Terrorist Attack risk assessment, Fire risk assessment AT 220//110/20 kV – 200 MVA and the modeling of the operating regimes (permanent regime and short circuit regime).

It has the following structure: Strategy generated by identifying threats, hazards and vulnerabilities, Strategy generated by energy security risk assessment and Strategy generated by modeling operating regimes.

The three strategies generated (Strategy generated by identifying threats, hazards and vulnerabilities, Strategy generated by energy security risk assessment and Strategy generated by modeling of operating regimes) are the basis of the Energy Security Strategy of the 220/220/20 kV Sardanesti power substation and implicitly of the National Power System.

**Chapter 4**, entitled INDUSTRIAL SECURITY PLAN OF THE 220/110/20 kV SARDANESTI POWER SUBSTATION, is dedicated to the development of the industrial security plan that represents the totality of potential threats, hazards, risks and vulnerabilities with effect of instability and insecurity of the power substation.

It has the following structure: The role of the security plan of the owner /operator /administrator of the national/European critical infrastructure, Purpose and objectives, Drawing up, endorsement and approval, Confidentiality, Organizational structure, Legislative framework, Characteristics of the administrative-territorial unit within which the critical infrastructure is located, Operating systems, Description of infrastructure, facilities and equipment in the national/European critical infrastructure, Personnel, General aspects regarding the analysis of security risks, High-risk facilities and operations, Physical security of national/European critical infrastructure and access control, Information technology and communications networks, Document control, Security personnel related to national/European critical infrastructure, Security-related equipment and technologies, Communication technology, Mixed resources and tools, PSO review and update, Employee role and responsibilities, Key roles and responsibilities – Security personnel, Critical analysis (identification of threats, hazards and vulnerabilities, security risk assessment and operating regime modeling), Energy security strategy development, Final conclusions and Annexes.

**Chapter 5**, entitled CONCLUSIONS, ORIGINAL CONTRIBUTIONS, LIMITATIONS OF THE STUDY AND FUTURE RESEARCH DIRECTIONS, is dedicated to developing the Conclusions, Original Contributions, Limitations of the study and Future Research Directions.

It has the following structure: Conclusions (specific and general), Original contributions (from the point of view of bibliographic research and analysis of the current stage of the addressed topic, from the point of view of establishing research objectives, from the point of view of theoretical research, from the point of view of practical and applied contributions and from the point of view of dissemination of results), Limitations of study and Future research directions.

### **Degree of novelty**

Approach, critical analysis, gradual and processual identification and assessment based on new knowledge, methodologies and algorithms in the field of energy engineering, industrial security, energy and critical infrastructure.

### **Degree of complexity**

The necessity and knowledge of interdisciplinary, multidisciplinary and transdisciplinary knowledge from several areas of national economy and industry: industrial

security, energy security, critical infrastructure protection and resilience, occupational security, electrical and energy engineering, etc.

# CONCLUSIONS, ORIGINAL CONTRIBUTIONS, LIMITATIONS OF THE STUDY AND FUTURE RESEARCH DIRECTIONS

## CONCLUSIONS

### Specific conclusions

*Chapter 1*, entitled THE NATIONAL POWER SYSTEM – ENERGY AND NATIONAL SECURITY GENERATOR SYSTEM, is dedicated to presenting the importance of the National Power System in ensuring energy and national security.

The electricity produced in the National Power System and transported through the Power Transmission Grid (the backbone of the NPS composed of several critical energy infrastructures) is an essential pillar of the functioning of society, the economy, defense, intelligence and public order institutions of the state.

*Chapter 2*, entitled CRITICAL ANALYSIS OF THE 220/110/20 kV SARDANESTI POWER SUBSTATION, is dedicated to the critical analysis of the 220/110/20 kV Sardanesti power substation and represents the central core of this doctoral thesis.

The electricity distributed by the 220/110/20 kV Sardanesti power substation plays a decisive role in the security of supply to industrial consumers in the Oltenia Mining Energy Basin and The National Railway Company “CFR” – SA.

At the voltage of 220 kV (electricity transmission voltage), the power substation represents an important connection node between the 400/220/110 kV Urechesti power substation and the 220/110 kV Craiova Nord power substation.

At the voltage of 110 kV, the power substation ensures the supply of electricity to the following industrial mining objectives in the Oltenia Carboniferous Basin and CFR: Jilt, Dragotesti, Pinoasa, Rosia – Pesteană, SRA Pesteană, Turceni T01, Turceni T03, Turceni 05 and CFR: Plopsoru – CFR 1 and Plopsoru CFR 2.

The identification of threats, hazards and vulnerabilities was carried out for the following objectives:

- 220 kV power substation;
- 110 kV power substation;
- 20 kV power substation.

The energy security risk assessment was carried out through the following:

- electricity supply risk assessment;
- Technical Failure risk assessment;
- Natural Disaster risk assessment;
- Terrorist Attack risk assessment;
- Fire risk assessment AT 220//110/20 kV – 200 MVA

The modeling of the operating mode was carried out for the following regimes:

- permanent regime:
  - *active and reactive power losses;*
  - *voltage drops;*
  - *circulation of currents;*

- *circulation of powers;*
- *overvoltages;*
- *autotransformer loading;*
- *total losses.*
- short circuit regime:
  - *short circuit on 220 kV bar;*
  - *short circuit on 110 kV bar;*
  - *short circuit all nodes.*

Interpretation of results:

**A. Identification of threats, hazards and vulnerabilities**

Following the critical analysis of the 220/110/20 kV Sardanesti power substation, the following threats, hazards and vulnerabilities were identified:

- Following the critical analysis of the 220/110/20 kV Sardanesti power substation, 14 following threats, hazards and vulnerabilities were identified:
  - poor condition of energy equipment;
  - lack of investment in the power substation;
  - lack of energy equipment revisions;
  - non-optimization of the power substation;
  - poor configuration of the power substation;
  - wrong maneuvers performed by the station's operational personnel;
  - lack of specialized and/or trained operational personnel;
  - lack of communication or poor communication with the Territorial Energy Dispatcher, or the National Energy Dispatcher;
  - lack, non-compliance and/or ignorance of work procedures in case of disruption, damage or blackout;
  - lack of training or poor training in the field of Risk Management;
  - lack of training or procedures regarding Critical Infrastructure Protection Management;
  - lack of a Security Liaison Officer on Critical Infrastructure;
  - lack of Security Plan at the Operator;
  - lack of a strategy regarding the energy security of the power substation.
- Following the critical analysis of the 220 kV Sardanesti power substation, 6 threats, hazards and vulnerabilities were identified:
  - failure to supply the 220 kV power substation via the 220 kV Urechesti – Sardanesti OHL;
  - failure to supply the 220 kV power substation via the Craiova Nord - Sardanesti OHL;
  - non-supply, non-functioning or untimely disconnection of AT 220/110 kV – 200 MVA;
  - low reliability of the 220 kV power substation – simple busbar system;
  - overloads of the 220 kV Urechesti – Sardanesti OHL and the 220 kV Craiova Nord – Sardanesti OHL;
  - overload of AT 220/110 kV – 200 MVA.

The identified elements of instability (threats, hazards and vulnerabilities) may have the following effects::

- enormous material damage resulting from lack of electricity;

- enormous material damage resulting from the interdependence of other systems;
- the possibility of a local, regional or national blackout;
- energy insecurity;
- economic insecurity;
- national insecurity.

- Following the critical analysis of the 110 kV Sardanesti power substation, 1 threat was identified:
  - non-supply, non-functioning or untimely disconnection of AT 220/110 kV – 200 MVA.

The identified threat may have the following effects:

- failure to supply industrial consumers (mining operations and Romanian Railways – CFR) at 110 kV voltage:
  - 110 kV OHL Jilt;
  - 110 kV OHL Dragotesti;
  - 110 kV OHL Pinoasa;
  - 110 kV OHL Rosia – Pesteana;
  - 110 kV OHL SRA – Pesteana;
  - 110 kV OHL Plopsoru – CFR 1;
  - 110 kV OHL Plopsoru – CFR 2;
  - 110 kV OHL Turceni T01;
  - 110 kV OHL Turceni T03;
  - 110 kV OHL Turceni T05;
- enormous material damage resulting from lack of electricity;
- enormous material damage resulting from the interdependence of other systems;
- the possibility of a local, regional or national blackout;
- energy insecurity;
- economic insecurity;
- national insecurity.

- Following the critical analysis of the 20 kV Sardanesti power substation, 1 threat was identified:
  - non-supply, non-functioning or untimely disconnection of AT 1 110/20 kV – 16 MVA and AT 2 110/20 kV – 16 MVA.

The identified threat may have the following effects:

- failure to supply industrial consumers at 20 kV voltage:
  - 20 kV OHL Turceni;
  - 20 kV OHL Cocoreni;
  - 20 kV OHL MHC 1;
  - 20 kV OHL MHC 2;
  - 20 kV OHL SI CHE;
  - TSI 1 (internal services);
  - TSI 2 (internal services);
- enormous material damage resulting from lack of electricity;
- enormous material damage resulting from the interdependence of other systems;
- the possibility of a local, regional or national blackout;
- energy insecurity; economic insecurity; national insecurity.

It is proposed that urgent measures be taken to stop, mitigate or assume the threats, hazards or vulnerabilities identified in the 220/110/20 kV Sardanesti power substation, by the management of the transmission company or by decision-makers in the energy field, because the lack of electricity in industrial areas can cause major damage to the national economy through enormous financial losses, which through a domino effect can spread economic and national insecurity.

In this context, the critical analysis of power substations in the context of identifying elements of instability becomes an essential national security issue and makes this work of real interest and a model for other power substations listed as critical infrastructures.

### ***B. Energy security risk assessment***

The following risks were assessed:

#### **1. Electricity supply risk assessment**

Following the assessment of the security risk of the electricity supply of the 220/110/20 kV Sardanesti power substation, the results were as follows:

Likelihood: 4 (remains constant)  
Gravity: 5  
Risk level: 20 → Very High Risk  
Gravity Recalculation: 3  
Risk level 12 → Medium Risk  
Recalculation:

It can be seen that following the assessment of the security risk of the electricity supply of the 220/110/20 kV Sardanesti power substation, the risk level with the value 20 (very high risk) turned into the value 12 (medium risk).

It is proposed to develop a strategy for energy security and stability of the 220/110/20 kV Sardanesti power substation and implicitly of the National Power System.

#### **2. Technical Failure risk assessment**

Following the Technical Failure risk assessment of the 220/110/20 kV Sardanesti power substation, the results were as follows:

Likelihood: 2 (remains constant)  
Gravity: 5  
Risk level: 10 → Medium Risk  
Gravity Recalculation: 3  
Risk level 6 → Low Risk  
Recalculation:

It can be seen that following the Technical Failure risk assessment of the 220/110/20 kV Sardanesti power substation, the risk level with the value 10 (medium risk) turned into the value 6 (low risk).

It is proposed to develop a strategy for energy security and stability of the 220/110/20 kV Sardanesti power substation and implicitly of the National Power System.

#### **3. Natural Disaster risk assessment**

Following the Natural Disaster risk assessment of the 220/110/20 kV Sardanesti power substation, the results were as follows:

Likelihood: 1 (remains constant)  
Gravity: 5  
Risk level: 5 → Low Risk  
Gravity Recalculation: 4  
Risk level 4 → Low Risk  
Recalculation:

It can be seen that following the Natural Disaster risk assessment of the 220/110/20 kV Sardanesti power substation, the risk level with the value 5 (low risk) turned into the value 4 (low risk).

It is proposed to develop a strategy for energy security and stability of the 220/110/20 kV Sardanesti power substation and implicitly of the National Power System.

#### 4. Terrorist Attack risk assessment

Following the Terrorist Attack risk assessment of the 220/110/20 kV Sardanesti power substation, the results were as follows:

Likelihood: 3 (remains constant)  
Gravity: 5  
Risk level: 15 → High Risk  
Gravity Recalculation: 4  
Risk level 12 → Medium Risk  
Recalculation:

It can be seen that following the Terrorist Attack risk assessment of the 220/110/20 kV Sardanesti power substation, the risk level with the value 15 (high risk) turned into the value 12 (medium risk).

It is proposed to develop a strategy for energy security and stability of the 220/110/20 kV Sardanesti power substation and implicitly of the National Power System.

#### 5. Fire risk assessment AT 220//110/20 kV – 200 MVA

Following the Fire risk assessment AT 220//110/20 kV – 200 MVA of the 220/110/20 kV Sardanesti power substation, the results were as follows:

Likelihood: 2 (remains constant)  
Gravity: 5  
Risk level: 10 → Medium Risk  
Gravity Recalculation: 3  
Risk level 6 → Low Risk  
Recalculation:

It can be seen that following the Fire risk assessment AT 220//110/20 kV – 200 MVA of the 220/110/20 kV Sardanesti power substation, the risk level with the value 10 (medium risk) turned into the value 6 (low risk).

It is proposed to develop a strategy for energy security and stability of the 220/110/20 kV Sardanesti power substation and implicitly of the National Power System.

### ***C. Simulation of operating regimes***

The following operating regimes were simulated:

#### A. Modeling of the permanent regime

After the simulation of the permanent regime of the 220/110/20 kV Sardanesti power substation using the Paladin DesignBase program, the following results were obtained:

a) *Active and reactive power losses:*

- Scenario 1 – 0.283 MW and 97.884 MVA;
- Scenario 2 – 0.132 MW and 97.885 MVA;
- Scenario 3 – 0.131 MW and 96.888 MVA.

b) *Voltage drops:*

- Urechesti 220 kV OHL: 0.00 %;
- Craiova Nord 220 kV OHL: – 5.83 %;
- AT 220/110 – 200 MVA: 0.64 %;
- Dragotesti 110 kV OHL: – 5,83 %;
- Pinoasa 110 kV OHL: – 0.94 %;
- Plopsoru – CFR 1 110 kV OHL: – 1.09 %;
- Plopsoru – CFR 2 110 kV OHL: – 5.98 %;
- Rosia-Pesteană 1 110 kV OHL: – 0.68 %;
- SRA-Pesteană 2 110 kV OHL: – 5.88 %;
- Jilt 110 kV OHL: – 0.66 %;
- Turceni T01 110 kV OHL: – 0.67 %;
- Turceni T03 110 kV OHL: – 0.65 %;
- Turceni T05 110 kV OHL: – 5.87 %;
- T 110/20 (1) – 16 MVA: – 0.64 %;
- T 110/20 (2) – 16 MVA: – 0.64 %.

c) *Circulation of currents:*

- AT 220/110 kV – 200 MVA: 0.025 kA – 2 % loading;
- T 110/20 (1) – 16 MVA: 0.063 kA – 4 % loading;
- T 110/20 (2) – 16 MVA: 0.063 kA – 4 % loading.

d) *Circulation of powers*

- AT 220/110 – 200 MVA: – 39.81 MW; 0.01 losses;
- T 110/20 (1)–16 MVA: – 20.81 MW; 0.01 losses;
- T 110/20 (2)–16 MVA: – 19.81 MW; 0.01 losses;
- Urechesti 220 kV OHL: 0.00 MW; 0.00 losses;
- Craiova Nord 220 kV OHL: 0.00 MW; 0.00 losses;
- Dragotesti 110 kV OHL: 0.00 MW; 0.01 losses;
- Pinoasa 110 kV OHL: 99.33 MW; 0.02 losses;
- Plopsoru–CFR 1 110 kV OHL: 0.00 MW; 0.01 losses;
- Plopsoru–CFR 2 110 kV OHL: 0.00 MW; 0.01 losses;
- Rosia-Pesteană 1 110 kV OHL: 0.00 MW; 0.00 losses;
- SRA-Pesteană 2 110 kV OHL: – 19.98 MW; 0.00 losses;
- Jilt 110 kV OHL: 0.03 MW; 0.00 losses;
- Turceni T01 110 kV OHL: 10.00 MW; – 5.30 losses;
- Turceni T03 110 kV OHL: 0.00 MW; – 5.30 losses;
- Turceni T05 110 kV OHL: 40.00 MW; – 57.61 losses.

e) *Overvoltages:*

- Urechesti 110 kV OHL: 95.0% over;
- Craiova Nord 110 kV OHL: 95.0% over;
- Dragotesti 110 kV OHL: 95.0% over;
- Pinoasa 110 kV OHL: 95.0% over;
- Plopsoru–CFR 1 110 kV OHL: 95.0% over;

- Plopsoru–CFR 2 110 kV OHL: 95.0% over;
  - Rosia-Pesteană 1 110 kV OHL: 95.0% over;
  - SRA-Pesteană 2 110 kV OHL: 95.0% over;
  - Jilt 110 kV OHL: 95.0% over;
  - Turceni T01 110 kV OHL: 95.0% over;
  - Turceni T03 110 kV OHL: 95.0% over.
- f) *Autotransformer loading:*
- AT 220/110 – 200 MVA: 12.22 – 3%;
  - T 110/20 (1) – 16 MVA: 11.12 – 3%;
  - T 110/20 (2) – 16 MVA: 10.27 – 3%.
- g) *Total losses:* 1.935 MW and – 208.922 MVAR.

### B. Modeling of the short circuit regime

After the simulation of the short circuit regime of the 220/110/20 kV Sardanesti power substation using the Paladin DesignBase program, the following results were obtained:

- a) *Short circuit on 220 kV bar:*
- Buss bar 2, 3P fault: A = 8670 Ik; B = 8670 Ik; C = 8670 Ik;
  - Buss bar 2, LL fault: A = 0 Ik; B = 7507 Ik; C = 7507 Ik;
  - Buss bar 2, LG fault: A = 7886 Ik; B = 0 Ik; C = 0 Ik;
  - Buss bar 2, LLG fault: A = 0 Ik; B = 8154 Ik; C = 8506 Ik.
- b) *Short circuit on 110 kV bar:*
- Buss bar II, 3P fault: A = 9511 Ik; B = 9511 Ik; C = 9511 Ik;
  - Buss bar II, LL fault: A = 0 Ik; B = 8249 Ik; C = 8249 Ik;
  - Buss bar II, LG fault: A = 11215 Ik; B = 0 Ik; C = 0 Ik;
  - Buss bar II, LLG fault: A = 0 Ik; B = 10652 Ik; C = 10728 Ik.
- c) *Short circuit all nodes:*
- Branch flow Buss bar II, 3P fault: A = 9511 Ik; B = 9511 Ik; C = 9511 Ik;
  - Branch flow Buss bar II, LL fault: A = 0 Ik; B = 8249 Ik; C = 8249 Ik;
  - Branch flow Buss bar II, LG fault: A = 11215 Ik; B = 0 Ik; C = 0 Ik;
  - Branch flow Buss bar II, LLG fault: A = 0 Ik; B = 10652 Ik; C = 10728 Ik.

Following the simulation of the permanent and short circuit regime of the 220/110/20 kV Sardanesti power substation, it can be seen that the power substation is within the normal functioning parameters, but it is proposed to modify the 220 kV power substation from a simple busbar system to a double busbar system, with three variants:

- *Scheme with double busbar system with 1 circuit breaker per circuit;*
- *Scheme with double busbar system with 1.5 circuit breakers per circuit;*
- *Scheme with double busbar system with 2 circuit breakers per circuit.*

The 3 schemes with double busbar system with 1, 1.5 and 2 circuit breakers, ensure a high reliability of the 220 kV power substation.

In the current version of a simple busbar system with 1 circuit breaker per circuit, the 220 kV power substation has low reliability.

**Chapter 3**, entitled DEVELOPMENT OF THE ENERGY SECURITY STRATEGY OF THE 220/110/20 kV SARDANESTI POWER SUBSTATION, is dedicated to the development of the Energy Security Strategy of the 220/110/20 kV Sardanesti power substation, composed of the three strategies related to the Identification of threats, hazards

and vulnerabilities (220 kV power substation, 110 kV power substation and 20 kV power substation), The energy security risk assessment (electricity supply risk assessment; Technical Failure risk assessment; Natural Disaster risk assessment; Terrorist Attack risk assessment; Fire risk assessment AT 220//110/20 kV – 200 MVA) and the Modeling of operating regimes (permanent regime and short circuit regime).

The three strategies generated (Strategy generated by identifying threats, hazards and vulnerabilities, Strategy generated by energy security risk assessment and Strategy generated by modeling of operating regimes) are the basis of the Energy Security Strategy of the 220/220/20 kV Sardanesti power substation and implicitly of the National Power System.

*Chapter 4*, entitled INDUSTRIAL SECURITY PLAN OF THE 220/110/20 kV SARDANESTI POWER SUBSTATION, is dedicated to the development of the industrial security plan that represents the totality of potential threats, hazards, risks and vulnerabilities with effect of instability and insecurity of the power substation.

*Chapter 5*, entitled CONCLUSIONS, ORIGINAL CONTRIBUTIONS, LIMITATIONS OF THE STUDY AND FUTURE RESEARCH DIRECTIONS, is dedicated to developing the Conclusions, Original Contributions, Limitations of the study and Future Research Directions.

## **General conclusions**

The topic addressed in this doctoral thesis "Critical analysis of the 220/110/20 kV Sardanesti power substation on the industrial security of the energy objectives in the Oltenia Carboniferous Basin", is very interesting, pragmatic and real, because the insecurity of the electricity supply of industrial consumers can lead to industrial insecurity, economic insecurity, societal insecurity and national insecurity, especially in the new context of world energy vulnerability.

This topic is of strategic importance, having direct implications on the quality of life of citizens, the functioning of institutions and the regional economic development. The critical analysis of the power substation not only identifies the vulnerabilities of the energy infrastructure, but also provides directions for a safer, more efficient and resilient system.

The paper addresses and analyzes the fundamental concepts related to the security of electricity supply, the risks associated with interruptions, the protection measures and future trends in the field of the National Power System.

The necessity for the "Critical analysis of the 220/110/20 kV Sardanesti power substation on the industrial security of the energy objectives in the Oltenia Carboniferous Basin", results from the following considerations:

- because the power substation is a national objective of strategic importance – national critical infrastructure, it must be analyzed, managed, monitored and assessed from the point of view of its stability, protection, security and resilience;
- the necessity for stability, protection, security and resilience of the power substation comes from the European obligation imposed by ENTSO-E (The European Network of Transmission System Operators for Electricity) and CNTEE Transelectrica SA (the national transmission and system operator);
- by identifying threats, hazards, risks and vulnerabilities to the power substation, different strategies regarding its safety and security can be generated;
- investments in infrastructure and specialized human resources become the central factor of the stability, safety and security of the power substation and implicitly of the National Power System;

- all the aspects listed above converge towards the dedication of scientific research towards industrial security and energy security and to become for economic decision-makers a pressing issue of ensuring national security and welfare and of sustainable development.

The electricity produced in the National Power System and transported through the Power Transmission Grid (the backbone of the NPS composed of several critical energy infrastructures) is an essential pillar of the functioning of society, the economy, defense, intelligence and public order institutions of the state

The electricity distributed by the 220/110/20 kV Sardanesti power substation plays a decisive role in the security of supply to industrial consumers in the Oltenia Mining Energy Basin and The National Railway Company “CFR” – SA.

At the voltage of 220 kV (electricity transmission voltage), the power substation represents an important connection node between the 400/220/110 kV Urechesti power substation and the 220/110 kV Craiova Nord power substation.

At the voltage of 110 kV, the power substation ensures the supply of electricity to the following industrial mining objectives in the Oltenia Carboniferous Basin and CFR: Jilt, Dragotesti, Pinoasa, Rosia – Pesteană, SRA Pesteană, Turceni T01, Turceni T03, Turceni 05 and CFR: Plopsoru – CFR 1 and Plopsoru CFR 2.

The identification of threats, hazards and vulnerabilities was carried out for the following objectives: 220 kV power substation; 110 kV power substation; 20 kV power substation.

The energy security risk assessment was carried out through the following: electricity supply risk assessment; Technical Failure risk assessment; Natural Disaster risk assessment; Terrorist Attack risk assessment; Fire risk assessment AT 220//110/20 kV – 200 MVA

The modeling of the operating mode was carried out for the following regimes: permanent regime; short circuit regime.

The three strategies generated (Strategy generated by identifying threats, hazards and vulnerabilities, Strategy generated by energy security risk assessment and Strategy generated by modeling of operating regimes) are the basis of the Energy Security Strategy of the 220/220/20 kV Sardanesti power substation and implicitly of the National Power System.

The Industrial Security Plan was also developed, covering all risks, vulnerabilities, hazards and potential threats to the energy objectives within the 220/110/20 kV Sardanesti power substation.

## **ORIGINAL CONTRIBUTIONS**

This scientific research paper (doctoral thesis) shows the basic elements and solutions to help decision makers on industrial and energy security issues, owners, managers and operators of national and European critical infrastructure within CNTEE Transelectrica SA, security liaison officers within power substations, specialists, experts and other entities interested in ensuring industrial, energy and national security.

I appreciate that the theoretical foundations and the methodology and applicative elements that I have synthesized, represent original contributions that denote the increase of the level of industrial and energy stability and security.

Personal contributions contain theoretical and practical aspects.

### **From the point of view of bibliographic research and analysis of the current stage of the addressed topic**

- a) The development and approach of a thorough analysis on national and European legislative frameworks on the protection and security of power substations, listed as national and European critical infrastructures within the National Power System, is based on a diversified and current bibliography;
- b) The bibliographic references show the constant concern regarding the most current research in the context of securing national and European critical infrastructures within the National Energy Sector where there is a significant concern regarding the updating of information and events.

### **From the point of view of establishing research objectives**

- a) Identification based on threats, hazards and vulnerabilities, based on the energy security risk assessment and based on the modeling of operating regimes, of elements of instability and insecurity within the 220/110/20 kV Sardanesti power substation, in the context of establishing research objectives;
- b) The exact establishment of the main lines of action and research - development - innovation, in order to achieve the objectives related to this research work and based on very carefully selected elements.

### **From the point of view of theoretical research**

#### Theoretical contributions:

- a) Identification and role and importance of the benefits of the European interconnection of the Power Transmission Grid (PTG);
- b) Exemplification of ENTSO-E recommendations on major aspects of the functioning of a national power system within the European power system;
- c) Definition and composition of dimensions on industrial security;
- d) Identification of the elements of instability to industrial security;
- e) Composition and definition of the concept of Integrated Industrial Security System;
- f) The role, purpose, definitions, legislation and composition of critical infrastructure protection;
- g) Importance of industrial sectors related to national and European critical infrastructures;
- h) Structure and organization chart of the Security Plan at the critical infrastructure operator;
- i) The role, purpose, definition and composition of critical infrastructure resilience;
- j) Structure, single-wire diagram and composition of the primary circuits of the 220/110/20 kV Sardanesti power substation;
- k) Description, phasing and schematization of the methodology for energy security risk assessment;
- l) Theoretical prerequisites regarding risks, including the mathematical model on 3 and 5 risk levels;
- m) Presentation and mathematical model regarding the modeling of operating regimes (permanent and short circuit regime).

## **From the point of view of practical and applied contributions**

### Practical and applied contributions:

- a) Field layout scheme of critical energy infrastructures within the National Power System (NPS);
- b) The scheme, working method and composition of the NPS;
- c) The role, purpose, necessity and identification of international interconnections of the NPS for safety and security purposes;
- d) NPS operation scheme at ENTSO-E;
- e) Identification of the main risk factors (fault causes) in the event of a blackout;
- f) Identification and exemplification of key elements in the assessment of national resilience;
- g) Identification and exemplification of assessment methods for national resilience;
- h) Identification and exemplification of the stages of preventing, preparing and managing electricity crises;
- i) Scheme of interdependencies between national public systems and the Power Transmission Grid;
- j) Scheme of functions of national transmission and system operator CNTEE Transelectrica SA;
- k) PTG composition (power substations, power lines and power plants);
- l) Critical analysis of the 220/110/20 kV Sardanesti power substation by identifying threats, hazards and vulnerabilities for the following energy objectives:
  - 220 kV power substation;
  - 110 kV power substation;
  - 20 kV power substation.
- m) Critical analysis of the 220/110/20 kV Sardanesti power substation by assessing the following energy security risks:
  - Electricity supply risk assessment;
  - Technical Failure risk assessment;
  - Natural Disaster risk assessment;
  - Terrorist Attack risk assessment;
  - Fire risk assessment AT 220//110/20 kV – 200 MVA.
- n) Modeling the operation of the 220/110/20 kV Sardanesti power substation through the following regimes:
  - Modeling of the permanent regime;
  - Modeling of the short circuit regime.
- o) Development of the strategy generated by identifying threats, hazards and vulnerabilities;
- p) Development of the strategy generated by energy security risk assessment;
- q) Development of the strategy generated by modeling operating regimes;
- r) Development of the energy security strategy;
- s) Development of the Industrial Security Plan.

## **From the point of view of the dissemination of results**

During the doctoral internship and the preliminary documentation carried out, I published as first and co-author a number of **12** scientific articles and **2** books published by national publishing houses and **4** book chapters published by international publishing houses, as follows (details in Appendix 1):

- **1** article published in a journal (MDPI) indexed by Web of Science (Q2);

- 11 scientific papers published in BDI indexed journals;
- 2 books published by national publishers;
- 4 book chapters published by international publishers.

## **LIMITATIONS OF THE STUDY**

The essential limits of the research presented in this research paper for the critical analysis of the 220/110/20 kV Sardanesti power substation by identifying threats, hazards and vulnerabilities, assessing the following energy security risks and modeling operating regimes, can be summarized as follows:

- the approached scientific research topic has the mission to identify the elements of instability and insecurity to the power substation rated as critical infrastructure, through critical analysis, in order to prevent and eliminate potential threats and to be applicable by the security liaison officer, experts and specialists on industrial, energy and national security issues;
- an analysis and approach of this kind is imperative to start from the decision makers, managers, operators and managers of national and European critical infrastructure, in order to ensure a healthy climate of industrial, energy and national security.

## **FUTURE RESEARCH DIRECTIONS**

Thus, to deepen and emphasize technical and security knowledge in this multidisciplinary, interdisciplinary and transdisciplinary research specialization, addressed within the framework of this scientific research work and the personal contributions made, the following essential research directions can be proposed towards which efforts should be directed and mobilized in the context of continuing and perfecting scientific research:

- the continuity and deepening of research will have to include important directions regarding the culture of protection and security of national and European critical infrastructures (power substations) for each manager/owner/operator of national and European critical infrastructure (power substation), deficient at European and national level;
- the need to verify how the security liaison officer and specialists organize and manage the protection and security of national and European critical infrastructures (power substations), for the purpose of prevention and resilience to blackout conditions.