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SUMMARY

Ph.D. THESIS

RESEARCH ON THE IDENTIFICATION OF CRITICAL INFRASTRUCTURE VULNERABILITIES FROM THE NATIONAL POWER GRID AT ULTRA HIGH AND VERY HIGH VOLTAGE WITH INTERNATIONAL CONNECTION

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CONTENTS

1. KEYWORDS

For a better understanding of the following exposition, it is necessary to enumerate several notions specific to the field addressed: *national power grid, vulnerabilities, risks, threats, hazards, industrial risks assessment, national/european critical infrastructures protection, power substations, overhead lines, security plan for operator, power security, industrial security, national security, welfare.*

2. THE THEME`S IMPORTANCE, NECESSITY AND OBJECTIVES

The theme`s importance

The more frequent occurrence of power terrorism – *black-out* (total exit of the National Power Grid) and the use of electrical energy as a possible power weapon or pressure instrument throughout the world, makes the theme to be of great importance and topicality, knowing that certain devices and equipments within power critical infrastructures (power stations, power substations, overhead lines) can be remotely controlled by cyber attacks. The non-supply of electricity to consumers automatically causes a national crisis to start, as all sectors of the national economy depend on electricity. Once the crisis is triggered, a state of social imbalance settles that brings extreme damages to the citizen's security and national security. In this context, the National Power Grid, through the Power Transmission Grid, becomes a trategic objective of national importance as it is a generator of national and european critical infrastructures.

Romania's power security depends on energy independence in the context of sustenaible development of the European Union, therefore energy stability factors must be created by: *ensuring the need for primary resources (natural gas, oil, coal, uranium, etc.) and electricity production and limiting dependence of the imported ones; diversification of the sources of primary resources from import; of electricity production and their transport routes; increasing the level of adequacy and safety of the national transports networks regarding the interruption of electricity and natural gases; the protection of the critical infrastructures regarding the physical integrity of the power objectives; securing the jobs and workers by avoiding and/or stopping accidents/technical incidents that can lead to disruption of the national power grid.*

But Romania's power security is endangered by different *vulnerabilities* (natural and anthropic hazards), *threats* (terrorism, political instability, armed conflicts and piracy) and *hazards* (lack of raw materials needed to produce electricity supply, electrical energy used as a weapon or pressure instrument, high costs of electricity, etc.) that can attempt to National Power Grid`s safety and security.

It is considered necessary that the National Power Grid must be rigorously subjected to a sectoral risk assessment – electricity transmission, in order to identify, combat and eliminate the vulnerabilities, hazards and threats that may create the National Power Grid`s non-safety and insecurity. It is recommended that the processes of identification, evaluation and control of the risks to be carried out more proactively than reactive.

The theme`s necessity

The necessity to identify the vulnerabilities of the ultra and very high voltage critical infrastructures within the National Power Grid, results from the followings considerations:

a) Knowing that the National Power Grid is a matter of national strategic importance, it must be constantly evaluated and monitored from the point of view of the sectoral risks – electricity transmission, in order to identify the vulnerabilities.
b) This necessity to assess the sectoral risks also comes from the european perspective because Romania is interconnected to the European Union's power grid, system which makes the interconnection of the different overhead lines from the nordic countries to the southern countries or from western countries to the eastern countries and even to the eastern end of Russin, Vladivostok.
c) By knowing the vulnerabilities, one can automatically identify the hazards and threats to which the National Power Grid is subjected and engaged and national/european measures or strategies for the protection and security of the national/european critical infrastructures can be created.
d) Certain developed risk scenarios have a high level of risk with devastating effects on national security.
e) In this context, Critical Infrastructures Protection Management, Risk Management and Occupational Health and Safety Management must form an integrated, coherent, transparent and convergent security system towards the SECURITY objective.
f) It is considered that power critical infrastructures is the common place where the military/intelligence and civilian sides meet and the duty of each specialist (military/intelligence/civilian) is to find common means

of securing these critical infrastructures through their own common and tangible means that gives security and well-being to Romania, the European Union and NATO.

g) The acces to electricity that is created by these power critical infrastructures is a common right of every citizen and it is our responsability to find together technical/military/intelligence solutions in time of peace, but also in time of crisis or war.

h) The vulnerability of power security must be tackled and eliminated through major investment in power infrastructures (power stations, power substations and overhead lines) and specialized personnel in critical infrastructures security and the security of the National Power Grid.

i) The issue of the security of the appliances and equipments within the power critical/normal security should not only approached from the perspective of the essential security requirements that designers and manufacturers of power appliances and equipments must take into account but by the human-infrastructure interaction too, that is, by ensuring the occupational health and safety of the workers who use them at the respective workplace (power stations, power substations and overhead lines).

j) The risks, hazards and threaths generated by the use by workers of power appliances and equipments within critical infrastructures constitute a particular area of the risks, hazards and threath to which they can be exposed and, as a result, they cannot be dissociated and treated separately, they must benefit from a systemic and integratated approach, which takes into account the complex set of conditions and interdependencies specific to modern work systems.

k) All these aspects support the importance and the opportunity of the scientific research devoted to the evaluation of the sectoral risks – electricity tramsmission, the development of the assessment methods dedicated to minimizing the occupational risks that can be used by all the actors involved.

Objectives

General objectives

The main objective of the doctoral research is to define a methodological approach, as well as the specific application tools that will allow the identification, designation, analysis, assessment, protection and securing of the critical power infrastructures and the structuring of the global and specific security requirements when operating the critical power infrastructures. The targeted result consists in the elaboration and integration of tools applicable by security officers, experts or specialists on security issues and the operative personnel from power stations/substations, who work and operate with the critical infrastructures, in order to prevent and minimize the risks, to combat and eliminate vulnerabilities and combating and eliminating hazards and threats.

Specific objectives

1) Conducting a study on the evolution, principles of risk prevention and minimization, vulnerabilities, hazards and threats combating and eliminating and the legislative framework regarding the protection and securing of critical infrastructures and workers.
2) Synthesizing the typology and security features of critical power infrastructures
3) Structural analysis of the risks assessment process for critical power infrastructures.
4) Multifactorial analysis of the statistics of technical incidents, technical damages and work accidents when operating critical infrastructures.
5) The elaboration of a *Methodology for identifying, designating, analyzing, evaluating, protecting and securing critical power infrastructures and assessing risks, identifying vulnerabilities, hazards and threats generated by them*, applicable and simplistic, which requires documentary study in the specialized literature and knowledge of national/european law and standards for security and risks. The methodology comprises 3 component parts:
    - *Unassessed critical infrastructures within the National Power Grid (power station, power substations and overhead lines), with the following processes* :
        - *identification;*
        - *designation;*
        - *analysis.*
    - *The risks or risk factors for unassessed critical infrastructures*:
        - *evaluation;*
        - *vulnerabilites identification;*
        - *hazards identification;*
        - *threats identification.*

- *Assessed critical infrastructures within the National Power Grid (power stations, power substations, overhead lines), with following processes*:
  - *protection measures;*
  - *security measures.*

3. THE STRUCTURE OF THE DOCTORAL THESIS

The doctoral thesis is structured on 8 chapters and comprises a total of 215 pages, 172 pages devoted to the actual scientific approach and 43 pages corresponding to the 9 annexes, 64 figures, 92 tables and 107 bibliographic references. The structure by chapters of the paper follows a process approach, whereby each chapter presents aspects that were subsequently introduced in the conception and elaboration of the methodology. Within the paper are presented synthetically and systematically my own research, which represents the result of the coordination of the efforts of documentation, data collection and processing, as well as conception.

The ***first part*** of the doctoral thesis is devoted to the current state of the legislative, conceptual and methodological framework addressing the critical infrastructures within the National Power Grid.

The ***second part*** of the doctoral thesis is devoted to the contributions regarding the identification of the vulnerabilities of the critical infrastructures within the National Power Grid of ultra high and very high voltage with international connection.

Chapter 1, entitled ***„The legislative and structural framework for critical power infrastructures”*** is dedicated to the synthetic presentation of the relevant aspects aimed at analyzing the legislative and structural framework in the field of national and european critical infrastructures and the industrial sectors where they are found, as well as generalities regarding the operation of the National Power Grid as a system for generating critical infrastructures. The results of the analyse carried out within this chapter are based on highlighting the role and importance of the critical infrastructures within the National Power Grid (power stations, power substations and overhead lines) in the context of national security.

Chapter 2, entitled ***„The role and importance of critical infrastructures in the context of national security”*** is devoted to the analysis and study of the conceptual framework of national and european critical infrastructures regarding threats, protection, safety and security, as well as power security regarding vulnerabilities, threats and hazards to her adress. The chapter also discusses the fact that electrical energy can be used as a power weapon or pressure instrument. The results of the analysis and study carried out in this chapter are based on highlighting the need to assess the risks associated with the critical infrastructures and to integrate the sectoral risk assessment related to the National Power Grid in the context of identifying vulnerabilities, threats and hazards to it. The results of the analysis carried out within the methodology of risk assessment associated with critical infrastructures and the integration of sectoral risk assessment are based on the necessity of the theme of this doctoral thesis.

Chapter 3, entitled ***„The methodology of risk assessment associated with critical infrastructures and the integration of sectoral risk assessment”*** is dedicated to the conceptual and legislative analysis, as well as to the overall presentation of the methodology for assessing the risks associated with critical infrastructures and integrating the risk assessment sectoral risk. This method will evaluate the sectoral risks related to the critical infrastructures of the power sector, electricity transmission subsector and present the steps that must be followed in the process of identifying and evaluating the different possible risk scenarios that may endanger the National Power Grid. Once the method is known and applied correctly by the users, it is possible to proceed to the actual assessment of the risks associated with the critical power infrastructures, but not before modeling (constructing) the maps related to the Power Transmission Grid.

Chapter 4, entitled ***„Modeling with GIS of the Power Transmission Grid – Strategic objective of national importance”*** is dedicated to the general presentation of the GIS (Geographical Information System) spatial modeling and analysis program, as well as to the modeling (cartographic representation in the Stereographic Projection 1970) maps of 220 kV and 400 kV within Power Transmission Grid from Romania. Once the 220 kV and 400 kV maps are modeled (built), constructive – regional delimitation and the identification of the critical infrastructures of national and international strategic interest within the Power Transmission Grid can be started.

Chapter 5, entitled ***„The constructive – regional delimitation and the identification of the critical infrastructures of national and international strategic interest from the Power Transmission Grid”*** is dedicated to the constructive – regional delimitation of the infrastructures for the development region in Romania, as well as identifying critical infrastructures of national strategic interest with international

connection, critical infrastructures that can become of national strategic interest and with possible international connection, and critical infrastructures that can become of international strategic interest and with possible national connection, for the purpose of safety and security of the National Power Grid and of the neighboring power systems. The results of the delimitation and identification of the critical infrastructures carried out in this chapter are based on the need to evaluate the risks associated with critical infrastructures and to integrate the sectoral risk assessments related to the National Power Grid in the context of identifying vulnerabilities, threats and hazards to it.

Chapter 6, entitled ***„Assessment of risks associated with critical infrastructures amd integration of sectoral risks analyzes – Power Transmission Grid"*** is dedicated to the assessment of risks associated with critical power infrastructures according to the 4 risk scenarios (technical incident, technical damage, natural calamity and terrorist attack), a risk identification and analysis (sectoral, natural, technological, biological and occupational health and safety), vulnerabilities, hazards and threats, as well as the conception and elaboration of the *"Methodology for identifying, designating, analyzing, evaluating, protecting and securing the critical power infrastructures and assessing the risks, identifying the vulnerabilities, hazards and threats generated by them"*. The results obtained from the asssessment of the risks associated with the critical power infrastructures and the identification of vulnerabilities, hazards and threats within this chapter are the basis for highlighting the need to improve the safety and security of the National Power Grid by implementing technical and managerial solutions, as well as the design and elaboration a new methodology for identifying, designating, analyzing, evaluating, protecting and securing critical power infrastructures. This chapter is the base of the present doctoral thesis.

Chapter 7, entitled ***„Proposed technical and managerial solutions regarding the safety and security of the National Power Grid for the purpose of increasing the power security"*** is dedicated to the suggestions of technical and managerial solutions following the assessment of the risks associated with the critical power infrastructures. The technical and managerial solutions proposed by the author following the assessment of the risks associated with the critical power infrastructures and the identification of vulnerabilities, hazards and threats within this chapter, are the basis of the safety and security of the National Power Grid.

Chapter 8, entitled ***„Conclusions, Original Contributions, Study Limits and Future Development Direction"*** is dedicated to the conclusions, original contributions and study limits and future development directions of the author of this doctoral thesis. The detailed presentation of the conclusions, original contributions and the study limitation and future directions of development, described, highlights the need and applicability of the present doctoral thesis in the power industrial field or other industrial fields. Within this chapter are presented the main aspects of the study and analysis of concepts, phenomena, method, applications and the obtained results. The presentation of the personal contributions in the field of the topic studied in the doctoral thesis is structured on the 2 components, theoretical contributions, respectively applicative contributions, a special attention being paid to the way in which they can be implemented and exploited. The main research directions in which effort to prevent, reduce, combat, astop and eliminate risks, vulnerabilities, hazards and threats for the protection and security on infrastructures and the occupational health and safety of workers operating critical infrastructures have also been identified.

The degree of novelty of the paper consists in the gradual, procedural approach, based on the latest knowledge, theories, principles and assumptions in the field of protection and security of critical infrastructures and risk management, in a form that allows to understand the concepts, phenomena, analysis of different types of risks associated with the critical infrastructures analyzed and assessed. The method proposed in chapter 6 can be appreciated as a novelty at national level.

The degree of complexity. Considering the nature of the critical infrastructures approached, the importance of the legislative and regulatory context, the information explosion, as well as the evolution of scientific research in the field of security, for the conceptualization of the system and the theoretical foundation of the models used, for the elaboration of the methodology of risk assessment, knowledge from several fields (electrical and industrial engineering, national security, energy security, industrial security, occupational safety and health, etc.) was required, which gives the doctoral thesis an interdisciplinary and multidisciplinary character.

4. CONTRIBUTIONS

Original contributions

The present doctoral thesis describes original tools and solutions for supporting:

- state authorities on national security, economic security, power security issues;
- owners/operators for national or european critical infrastructures;
- security officers;
- security experts and specialists;
- workers (operating personnel from power station, power substations, maintenance personnel and dispatching personnel).

and other stakeholders in fulfilling the obligations set out in european and national legislation regarding:

- the prevention and reduction of the sectoral risks;
- the prevention and reduction of the natural risks;
- the prevention and reduction of the technological risks;
- the prevention and reduction of the biological risks;
- the prevention and reduction of the occupational health and safety risks;
- the prevention, combating and elimination of the vulnerabilities;
- the prevention, combating and elimination of the hazards;
- the prevention, combating and elimination of the threats.

I consider that the theoretical foundations and methodological and applicative tools that we have developed during the doctoral period, summarized in what follows, represent original contributions in the field of research aimed at increasing the level of security of the national and european critical infrastructures and of course, the human factor. The personal contributions in the mentioned field include both theoretical and practical aspects.

From the point of view of bibliographic researches and the analysis of the current state of the subject approached:

- carrying out an analysis on the national and european legislative framework regarding the protection and security of the national and european critical infrastructures, based on an extensive, diversified and very current bibliography;
- the objective of the author of this doctoral thesis is to develop a simplistic and applicable methodology for identifying, designating, analyzing, evaluating, protecting and securing the critical power infrastructures and risk assessment, identifying vulnerabilities, hazards and threats generated by them;
- the bibliographic references reflect a constant concern for the most recent and relevant research in the field of protection and security of the national and european critical infrastructures and with a focus on the specific field of power security, proving a special interest for keeping the information current.

From the point of view of establishing the research objectives:

- identifying, based on the assessments and analyzes performed, the difficulties and problems in the field of protection and security of the national and european critical infrastructures relevant to the specific aspects related to the risks generated by them and accordingly establishing the research objective of theis doctoral thesis.
- the identification of the specific objectives and the clear establishment of the action and research directions for achieving the intermediate objectives circumscribed to the thematic of the doctoral thesis based on carefully selected criteria;
- Identifying the possibility of developing a methodology for identifying, designating, analyzing, evaluating, protecting and securing critical power infrastructures and analyzing the risks, vulnerabilities, hazards and threats generated by them, which comes in security officers, experts and specialists on security issues help.

Theoretical contributions:

- The structure of the european pyramidal legislative system regarding critical infrastructures;
- The structure of the national system operation regarding critical infrastructures;
- The structure of the Operator Security Plan – OSP;
- The scheme of the interdependencies of the sectors of the national economy;
- The scheme of the purposes and requirements of National Power Grid;
- The organizational chart of the National Power Grid operation in Romania;
- National Power Grid status scheme;
- The logic diagram of National Power Grid states and the transition mode from one state to another;
- The typology of the defects in the operation of National Power Grid;
- Infrastructure classification scheme;
- The organization chart of the dynamics of the hazards and threats to the critical infrastructure;
- Organizational chart of the threats to critical infrastructures – stages (Risk Assessment – Risk Identification – Vulnerability Identification – Threats and Hazards Indentification);
- The scheme of the structure and the modalities of ensuring the power security;
- The scheme of power security policies;
- The organizational chart of threats, vulnerabilities and hazards to power security;
- The principle diagram of the electrical energy use as a power weapon or pressure instrument;
- The logical scheme of using the pressure means in the favor of the promotion and the gain;
- The logical scheme of power chain operation (producer – consumer) with or without the state intervention;
- The logical scheme (algorithm): Electrical energy – possible power weapon or pressure intrument;
- The scheme of the european legislative pyramid system regarding the evaluation of sectoral risks;
- The scheme of the romanian legislative pyramid system regarding the evaluation of sectoral risks;
- The scheme of risks scenarios types;
- The organizational chart of the detailed description of the sectoral risk assessment stages:
    - *Stage 1 – Risk scenarios construction;*
    - *Stage 2 – Risk scenarios prioritizing and selection;*
    - *Stage 3 – The assessment of the probability and impact;*
    - *Stage 4 – The modality of risk calculation and uncertainly analysis*
    - *Stage 5 – The intervention capacity analysis.*

Practical and applicative contributions:

- The map of the cartographic representation in the Stereographic Projection 1970 of the 400 kV power substations and overhead lines from Romania;
- The map of the cartographic representation in the Stereographic Projection 1970 of the 220 kV power substations and overhead lines from Romania;
- The map of the cartographic representation in the Stereographic Projection 1970 of the 400 kV and 220 kV power substations and overhead lines from Romania;
- The map of the cartographic representation in the Stereographic Projection 1970 of the 400 kV and 220 kV power substations and overhead lines from Romania, by highlighting the transformation elements (autotransformers);
- The map of the cartographic representation in the Stereographic Projection 1970 of power substations and overhead lines from Romania, with international connection;
- The map of the cartographic representation in the Stereographic Projection 1970 of the critical infrastructure from Romania related to the 8 development regions;
- The map of the constructive delimitation (modeling) of all the critical infrastructures related to the 8 regions of regional development in Romania;

- The map of critical infrastructures of national interest with international connection;
- The map of critical infrastructures that can become of national interest and with possible international connection;
- The map of critical infrastructures that can become of international strategic interest and with possible national connection;
- The conception and elaboration of the Methodology for identifying, designating, analyzing, evaluating, protecting and securing critical power infrastructures and analyzing the risks, vulnerabilities, hazards and threats generated by them;
- The sectoral risks analysis – electricity transmission;
- The identification of the risk scenarios – Techical Incident – 110 kV – 750 kV power substation:
    - *Sequential and causal development of phenomena and events in the event of a Technical Incident - 110 kV – 750 kV power substation;*
    - *Risk scenario 1 (sequential and causal development) – Technical Incident → Lightning → Explosion → Fire → Interruption in the electricity supply to consumers;*
- The identification of risk scenarios – Technical Damage – 110 kV – 750 kV power substation:
    - *Sequential and causal development of phenomena and events in the event of a Technical Damage;*
    - *Risk scenario 2 (sequential and causal development) – Technical Damage – Succesion of Techical Incidents – Total exit from National Power Grid function;*
    - *Risk scenario 3 (sequential and causal development) – Natural Calamity – Total exit from National Power Grid function;*
    - *Risk scenario 4 (sequential and causal development) – Terrorist Attack – Total exit from National Power Grid function;*
- The risk scenarios assessment on National Power Grid:
    - *Risk scenario 1 (sequential and causal development) – Technical Incident → Lightning → Explosion → Fire → Interruption in the electricity supply to consumers;*
    - *Risk scenario 2 (sequential and causal development) – Technical Damage – Succesion of Techical Incidents – Total exit from National Power Grid function;*
    - *Risk scenario 3 (sequential and causal development) – Natural Calamity – Total exit from National Power Grid function;*
    - *Risk scenario 4 (sequential and causal development) – Terrorist Attack – Total exit from National Power Grid function.*
- The natural risks analysis (causes, effects, impact):
    - *Storm – Tornado;*
    - *Flood;*
    - *Drought – Heat – Fire;*
    - *Frost – Snow – Chica – Snow Avalanches;*
    - *Landslides;*
    - *Earthquakes.*
- The technological risks analysis (causes, effects, impact):
    - *Technical Incident;*
    - *Technical Damage.*
- The biological risks analysis (causes, effects, impact):
    - *Epidemic;*
    - *Epizootic/Zoonosis.*
- The occupational health and safety risks analysis (causes, effects, impact):
    - *Failure to implement national Occupational Health and Safety norms at organizational management level;*
    - *Failure to comply with the electrical safety norms at the lucrative level (workers – operating personnel).*

- The vulnerabilities identification and analysis (causes, effects, impact):
  - *Internal vulnerabilities with internal impact within National Power Grid;*
  - *Internal vulnerabilities with external impact within National Power Grid;*
  - *External vulnerabilities within the neighboring power grid with internal impact on National Power Grid.*
- The hazards identification and analysis (causes, effects, impact):
  - *Hazards inside National Power Grid;*
  - *Hazards outside National Power Grid.*
- The threats identifications and analysis (causes, effects, impact):
  - *Terrorist Threat – Terrorist Attack;*
  - *Cyber Threat – Cyber Attack.*
- Technical solutions regarding the safety of the National Power Grid:
  - *Technical solutions for combating and eliminating internal vulnerabilities with internal impact within the National Power Grid;*
  - *Technical solutions for combating and eliminating internal vulnerabilities with external impact on the European Power Grid;*
  - *Technical solutions for combating and eliminating external vulnerabilities with internal impact on the National Power Grid;*
  - *Technical solutions regarding the construction of new power critical infrastructures at the 400 kV of national connection;*
  - *Technical solutions regarding the construction of new power critical infrastructures of international connection.*
- Managerial solutions regarding the security of the National Power Grid:
  - *Organizational and administrative solutions for the prevention and reduction of sectoral risks;*
  - *Organizational and administrative solutions for the prevention and reduction of natural risks;*
  - *Organizational and administrative solutions for the prevention and reduction of techological risks;*
  - *Organizational and administrative solutions for the prevention and reduction of biological risks;*
  - *Organizational and administrative solutions for the prevention and reduction of occupational health and safety risks;*
  - *Organizational and administrative solutions to prevent, combat and eliminate hazards;*
  - *Organizational and administrative solutions to prevent, combat and eliminate threats;*
  - *Recommendations regarding the national strategy for the protection of critical infrastructures in the short, medium and long term as a result of the proposed solutions to eliminate the internal or external vulnerabilities of National Power Grid;*
  - *Recommendations regarding the national strategy for the protection of critical infrastructures in the short, medium and long term as a result of the proposed technical solutions for operational safety.*