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Analysis of the National Power Grid from Romania in the context of identifying vulnerabilities and ensuring energy security

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Abstract. The National Power Grid is the most important national energy objective of strategic importance, having in its composition a multitude of critical infrastructures (power substations and overhead power lines of 400 kV and 220 kV) of national and european importance without which the economy and national well-being do not it could work. The proper functioning of all state mechanisms is ensured through the National Power Grid because all public systems are almost entirely dependent on electricity. Not operating the National Power Grid, or not operating at normal parameters, the economic security of our country is endangered, creating the state of economic insecurity, a negative factor with immediate effects on national security and well-being. This paper is of major importance in identifying the vulnerabilities of the National Power Grid and creating strategies for the protection and security of existing critical infrastructures and energy security, for the purpose of safety and security of the National Energy System.

Key words. National Power Grid, vulnerabilities, energy security

1. Introduction

Romania's level of energy security is given by the state's ability to hold and manage domestic energy resources correctly and rationally and to have access to external energy resources, and any longer disruption of energy supply has a negative effect on economic growth, political stability and the well-being of citizens. Energy security plays a very important role in economic security and for this reason it must be viewed in the most serious way, and not giving the importance of energy security can cause catastrophic damage with an effect of insecurity and instability. [1]

Romania's energy security also represents: the existence, accessibility and assurance finite sources of raw materials (oil, natural gas, coal, hydrocarbons, uranium, etc.) and renewable, sufficient and available; clear and stable international / European trade agreements on access to these finite sources of imported raw materials; price stability of these finished sources of raw materials; control of transport and distribution routes and alternatives of finite sources of raw materials; safety and security of transformation of these finite sources of raw materials into electricity; clear and stable trade agreements on the commercial exchange of electricity with neighboring or European Union countries; stability of the electricity price; control of electricity transmission and distribution routes; accessibility of each consumer (household / industrial) to electricity.

Energy security also means being insured from the point of view of: energy sources on electricity production; control of main overhead power lines for electricity transmission; control of main power distribution power lines; control of alternative energies for electricity production. Therefore, energy security must take into account the challenges posed by the process of globalization, any malfunction or vulnerability in a part of the EU or NATO (of an energy source) affecting consumers across the EU or NATO. In general, the concept of electricity is defined as „safe resource at a reasonable price", in other words it encompasses a much broader issue than the supply security triangle – sustainability – competitiveness. Therefore, the existence of sufficient and available resources (energy sources and alternative energy) is an imperative precondition for achieving energy security. Any longer power outages or untimely outages significantly damage the: stability of the national energy system, the non-quality of electricity traded in the system, the economic growth by disconnecting large industrial consumers, political stability, security of citizens, etc.

Therefore, electric power security mainly covers the following dimensions: ensuring primary energy sources or alternative energies; identification of alternative overhead power lines, with a high reliability role; securing existing overhead power lines.

2. Essential information on the National Power Grid

The activity of electricity transmission at national level is carried out through the National Power Grid, which is the most important national energy objective of strategic importance, having in its composition a multitude of critical infrastructures (power substations and overhead power lines of 400 kV and 220 kV) of national and european importance without which the economy and national well-being do not it could work. The proper functioning of all state mechanisms is ensured through the National Power Grid because all public systems are almost entirely dependent on electricity. Not operating the National Power Grid, or not operating at normal parameters, the economic security of our country is endangered, creating the state of economic insecurity, a negative factor with immediate effects on national security and well-being. The activity of electricity transmission, management and dispatching of the National Energy System, is carried out through the Transelectrica company, which is also the system operator.

Transelectrica functions: [2]

a) transmission and system operator of the National Energy System:
   - the infrastructure of the National Power Grid (operation, maintenance and development) on 81 power substations, 8932 km. of overhead power lines and 218 transformation units;
   - EMS / SCADA dispatching infrastructure that takes place within the Operational Unit – National Energy Dispatcher and the 5 Territorial Dispatchers;
   - capacity allocation on interconnection lines;
   - green certificates.

b) balancing market operator – OPE:
   - balancing market platform.

c) commercial operator of the electricity market – OPCOM:
   - trading platforms;
   - green certificate trading platform.

d) metering market operator – OMEPA:
   - metering system.

e) telecommunications and IT operator – TELETRANS:
   - fiber optics, digital telecom system.

The National Power Grid has the following composition (critical infrastructures), according to Tables 1 and 2 and Figure 1.

Table 1. 400 kV şi 220 kV Power substations

POWER SUBSTATIONS	
400 kV	220 kV
400/220/110 kV București Sud;	220/110 kV Fundeni.
400/110 kV Domnești;	220/110 kV Gheorgheni;
400/220/110 kV Iernut;	220/110 kV Fântânele;
400/220/110 kV Sibiu Sud;	220/110 kV Ungheni;
400/110 kV Dârste;	220/110 kV Alba Iulia.
400/110 kV Brașov;	220/110 kV Munteni;
400/220/110 kV Gutinaș;	220/110 kV Iași (FAI);
400/220/110 kV Suceava;	220/110 kV Dumbrava;
400/110 kV Bacău Sud;	220/110 kV Stejaru.
400/110 kV Roman Nord;	220/110 kV Filești;
400 kV Isaccea;	220/110 kV Bărboși;
400 kV Stupina;	220/110 kV Focșani Vest;
400 kV Rahman;	220/110 kV Stâlpu.
400/220/110 kV Lacu Sărat;	220/110 kV Teleajen;
400 kV Cernavodă;	220/110 kV Mostiștea;
400/110 kV Medgidia Sud;	220/110 kV Turnu Măgurele;
400/110 kV Constanța Nord;	220/110 kV Ghizdaru;
400/110 kV Tariverde;	220/110 kV Târgoviște;
400/110 kV Tulcea Vest;	220/110 kV Pitești Sud;
400/110 kV Smârdan;	220/110 kV Arefu.
400/220/110 kV Brazi Vest;	220/110 kV Stupărei;
400/220/110 kV Bradu;	220/110 kV Târgu-Jiu Nord;
400/110 kV Gura Ialomiței;	220/110 kV Sărdănești;
400/110 kV Pelicanu;	220/110 kV Turnu Severin;
400 kV Ţânţăreni;	220/110 kV Cetate;
400 kV Porţile de Fier;	220/110 kV Calafat;

400/220/110 kV Urecheşti; 400/220 kV Slatina; 400/110 kV Drăgăneşti-Olt; 400/220/110 kV Arad; 400 kV Nădab; 400/220/110 kV Reşiţa; 400/220/110 kV Mintia; 400/220 kV Roșiori; 400 kV Gădălin; 400/110 kV Cluj Est; 400/110 kV Oradea Sud.	220/110 kV Grădişte; 220/110 kV Craiova Nord; 220/110 kV Râureni. 220/110 kV Calea Aradului; 220/110 kV Săcălaz; 220/110 kV Timişoara; 220/110 kV Iaz; 220/110 kV Peştiş; 220/110 kV Hăşdat; 220/110 kV Baru Mare; 220/110 kV Paroşeni. 220/110 kV Câmpia Turzii; 220/110 kV Cluj Florești; 220/110 kV Tihău; 220/110 kV Sălaj; 220/110 kV Baia Mare 3; 220/110 kV Vetiș.

Table 2. 400 kV și 220 kV Overhed power lines

OVERHEAD POWER LINES	
400 kV	220 kV
București Sud – Domnești; București Sud – Gura Ialomiței; București Sud – Pelicanu; București Sud – Slatina; Domnești – Brazi Vest; Iernut – Gădălin; Iernut – Sibiu Sud; Sibiu Sud – Mintia; Sibiu Sud – Țânțăreni; Sibiu Sud – Brașov; Brașov – Bradu; Brașov – Dârste; Brașov – Gutinaș; Dârste – Brazi Vest; Gutinaș – Brașov; Gutinaș – Bacău Sud; Bacău Sud – Roman Nord; Roman Nord – Suceava; Rahman – Dobrudja (Bulgaria); Stupina – Varna (Bulgaria); Isaccea – Vulcănești (Moldova Republic); Isaccea – Ucraina Sud (Ucraina) – disabled; Smârdan - Gutinaș; Smârdan – Lacu Sărat; Smârdan - Isaccea; Lacu Sărat – Gura Ialomiței; Lacu Sărat – Isaccea; Isaccea – Tulcea Vest; Isaccea – Rahman; Isaccea – Stupina; Tulcea Vest – Tariverde; Tariverde – Constanța Nord; Constanța Nord – Cernavodă; Cernavodă – Medgidia Sud; Cernavodă – Pelicanu; Cernavodă – Gura Ialomiței; Lacu Sărat – CTE Brăila; Brazi Vest - Dârste; Brazi Vest – CTE Petrom Brazi; Brazi Vest - Domnești; Bradu - Brașov; Bradu - Țânțăreni; Gura Ialomiței – Lacu Sărac; Gura Ialomiței – Cernavodă; Gura Ialomiței – București Sud; Pelicanu – Cernavodă; Pelicanu – București Sud; Porțile de Fier – Djerdap (Serbia);	București Sud – Fundeni; București Sud – Ghizdaru; București Sud – Mostiștea; Fundeni – Brazi Vest. Gheorgheni – CHE Stejaru; Gheorgheni – Fântânele; Fântânele – Ungheni; Ungheni – Iernut; Iernut – Baia Mare 3; Iernut – Câmpia Turzii; Sibiu Sud – CHE Lotru; Alba Iulia – Mintia; Alba Iulia – CHE Șugag; Alba Iulia – CHE Gâlceag; Alba Iulia – Cluj Florești. Gutinaș – Dumbrava; Gutinaș – CTE Borzești; Gutinaș – Munteni; Gutinaș – Iași (FAI); Iași (FAI) – Munteni; Iași (FAI) – Suceava; Dumbrava – CHE Stejaru; CHE Stejaru – Gheorgheni. Focșani Vest – Gutinaș; Focșani Vest – Bărboși; Bărboși – Filești; Lacu Sărat – CTE Brăila; Teleajen – Brazi Vest; Teleajen – Stâlpu; Mostiștea – București Sud; Turnu Măgurele – Ghizdaru; Turnu Măgurele – Craiova Nord; Ghizdaru – București Sud; Târgoviște – Brazi Vest; Târgoviște – Bradu; Pitești Sud – Bradu; Arefu – CHE Vidraru; Arefu – Râureni; Bradu – Stupărei. Urecheşti – Târgu Jiu Nord; Urecheşti – Sărdănești; Sărdănești – Craiova Nord; Craiova Nord – Slatina; Craiova Nord – Turnu Măgurele; CTE Işalnița – Grădişte; Grădişte – Slatina; Porțile de Fier – Reșița; Porțile de Fier – Turnu Severin;

Țânțăreni – Kosloduy (Bulgaria); Urechești – Porțile de Fier; Urechești – Domnești; Urechești – Țânțăreni; Urechești – CTE Rovinari; Porțile de Fier - Slatina; Țânțăreni – Bradu; Țânțăreni – Slatina; Țânțăreni – CTE Turceni; Slatina – București Sud; Slatina – Drăgănești Olt; Nădab – Bekecsaba (Hungary); Arad – Sandorfalva (Hungary); Reșița – Pancevo (Serbia); Nădab – Arad; Arad – Mintia; Mintia – Sibiu Sud; Roșiori – Mukacevo (Ukraine); Roșiori – Oradea Sud; Roșiori – Gădălin; Gădălin – Cluj Est; Gădălin – Iernut.	Porțile de Fier – Cetate; Cetate – Calafat; Râureni – Arefu; Râureni – Stupărei; Stupărei – Bradu; Craiova Nord – CTE Isalnița; CHE Lotru – Sibiu Sud. Arad – Calea Aradului; Arad – Timișoara; Calea Aradului – Săcălaz; Săcălaz – Timișoara; Timișoara – Mintia; Timișoara – Reșița; Reșița – Iaz; Reșița – Porțile de Fier; Mintia – Pestiș; Mintia – Hășdat; Mintia – Alba Iulia; Hășdat – Pestiș; Hășdat – CHE Retezat; Hășdat – Baru Mare; Baru Mare – Parașeni; Parașeni – Târgu Jiu Nord. Roșiori – Vetiș; Roșiori – Baia Mare 3; Baia Mare 3 - Tihău; Baia Mare 3 - Iernut; Tihău - Sălaj; Tihău – Cluj Florești; Cluj Florești – CHE Mărișelu; Cluj Florești – Câmpia Turzii; Cluj Florești – Alba Iulia; Câmpia Turzii – Iernut.

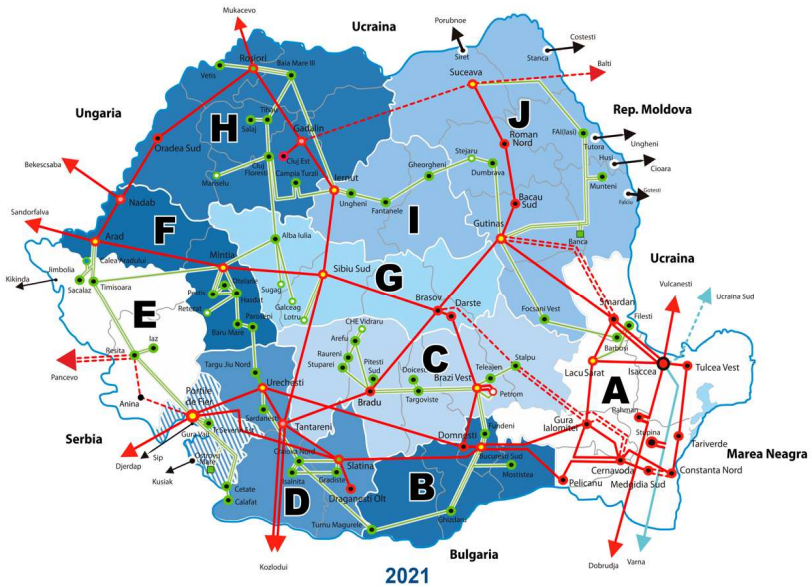

Fig. 1. Composition of the National Power Grid in 2021

3. Identification of vulnerabilities within National Power Grid

Following the critical analysis of the european critical connection infrastructures within the National Power Grid, the following vulnerabilities were identified: [3,4,5]

a) 750/400 kV Isaccea Power substation:
- 750 kV Isaccea – Pivdennoukrainska NPP (South Ukraine) OHL;
- 400 kV Isaccea – Vulcănești (Moldova Republic) OHL;
- 400 kV Isaccea – Rahman – Dodrudja (Bulgaria) OHL;

- 400 kV Isaccea – Stupina – Varna (Bulgaria) OHL – 750 kV gauge;
- 400 kV Isaccea – Lacu Sărat OHL (injection from Brăila Thermo Power Plant);
- 400 kV Isaccea – Smârdan OHL (double circuit)<
- 400 kV Isaccea – Tulcea Vest OHL.

b) 400 kV Ţânţăreni Power substation:
- 400 kV Ţânţăreni – Kosloduy (Bulgaria) OHL – double circuit, connection to ENTSO-E;
- 400 kV Ţânţăreni – Turceni OHL (injection from Turceni Thermo Power Plant) – doublr circuit;
- 400 kV Ţânţăreni – Slatina OHL;
- 400 kV Ţânţăreni – Sibiu OHL;
- 400 kV Ţânţăreni – Urecheşti OHL (injection from Rovinari Thermo Power Plant and Porţile de Fier 1 Hydro Power Plant);
- 400 kV Ţânţăreni – Bradu OHL.

c) 400/220 kV Porţile de Fier 1 Power substation:
- 400 kV Porţile de Fier 1 – Djerdap 1 OHL (Serbia);
- 400 kV Porţile de Fier 1 – Urecheşti OHL (injection from Rovinari Thermo Power Plant);
- 400 kV Porţile de Fier 1 – Slatina OHL;
- 220 kV Porţile de Fier 1 – Reşiţa (double circuit) OHL – vulnerabily, 220 kV → 400 kV, closing ring of 400 kV from west zone);
- 220 kV Porţile de Fier 1 – Cetate OHL;
- 220 kV Porţile de Fier 1 – Calafat OHL;
- 220 kV Porţile de Fier 1 – Turnu Severin OHL.

d) 400/220 kV Reşiţa Power Substation:
- 400 kV Reşiţa – Pancevo (Serbia) OHL – double circuit;
- 220 kV Reşiţa – Porţile de Fier 1 (double circuit) OHL (injection from Porţile de Fier 1) – vulnerabily, 220 kV → 400 kV, closing ring of 400 kV from west zone);
- 220 kV Reşiţa – Timişoara (double circuit) OHL – vulnerability 220 kV → 400 kV, closing ring of 400 kV from west zone;
- 220 kV Reşiţa – Iaz (double circuit) OHL.

e) 400/220 kV Arad Power substation:
- 400 kV Arad – Sandorfalva (Hungary) OHL – connection to ENTSO-E;
- 400 kV Arad – Mintia OHL;
- 400 kV Arad – Nădab OHL;
- 220 kV Arad – Timişoara (double circuit) OHL – vulnerability 220 kV → 400 kV, closing ring of 400 kV from west zone.

f) 400 kV Nădab Power Substation:
- 400 kV Nădab – Bekescsaba (Hungary) OHL – connection to ENTSO-E;
- 400 kV Nădab – Arad OHL;
- 400 kV Nădab – Oradea OHL – vulnerability 220 kV → 400 kV, closing ring of 400 kV from west zone, according to fig. 2.

g) 400/220 kV Roşiori Power Substation:
- 400 kV Roşiori – Mukacevo (Ucraina) OHL – connection to ENTSO-E;
- 400 kV Roşiori – Oradea OHL;
- 400 kV Roşiori – Gădălin OHL (injection from Iernut Thermo Power Plant)<
- 220 kV Roşiori – Vetiş OHL;
- 220 kV Roşiori – Baia Mare (double circuit) OHL.

h) 400 kV Gădălin – Suceava OHL (under construction) - vulnerability 220 kV → 400 kV, closing ring of 400 kV from north zone.

i) 400 kV Suceava – Bălţi OHL (Moldova Republic) (under construction) – lack of interconnection to 400 kV from north-east zone.

The european interconnections of the National Power Grid bring the following benefits, according to table 3: [6,7,8,9]
- increasing reliability;
- increasing security;

- emergency aid without the need to install and maintain a significant power in a warm reserve;
- trade in electricity between Romania, the European Union and neighboring countries.

Table 3. 400 kV Power critical infrastructures of european connection from Romania
(power substations and overhead lines)

POWER SUBSTATIONS	OVERHEAD POWER LINES
400 kV Isaccea* → Moldova Republic	400 kV Isaccea – Vulcănești (Moldova Republic)
400 kV Isaccea* → South Ukraine	400 kV Isaccea – Ucraina Sud** (Ukraine)
400 kV Stupina → Bulgaria	400 kV Stupina – Varna*** (Bulgaria)
400 kV Rahman → Bulgaria	400 kV Rahman – Dobrudja (Bulgaria)
400 kV Ţânţăreni → Bulgaria	400 kV Ţânţăreni – Kosloduy (Bulgaria)
400 kV Porţile de Fier → Serbia	400 kV Porţile de Fier – Djerdap (Serbia)
400/220/110 kV Arad → Hunagry	400 kV Arad – Sandorfalva (Hunagry)
400 kV Nădab → Hungary	400 kV Nădab – Bekecsaba (Hungary)
400/220/110 kV Reşiţa → Serbia	400 kV Reşiţa – Pancevo (Serbia)
400/220 kV Roşiori → Ukraine	400 kV Roşiori – Mukacevo (Ukraine)
** Isaccea power substation working to 400 kV but the gauge is 750 kV (old function);* *** Isaccea – South Ukraine OHL has a gauge 750 kV (disable OHL);* **** Stupina – Varna (Bulgaria) OHL working to 400 kV but the gauge is 750 kV (old function).*	

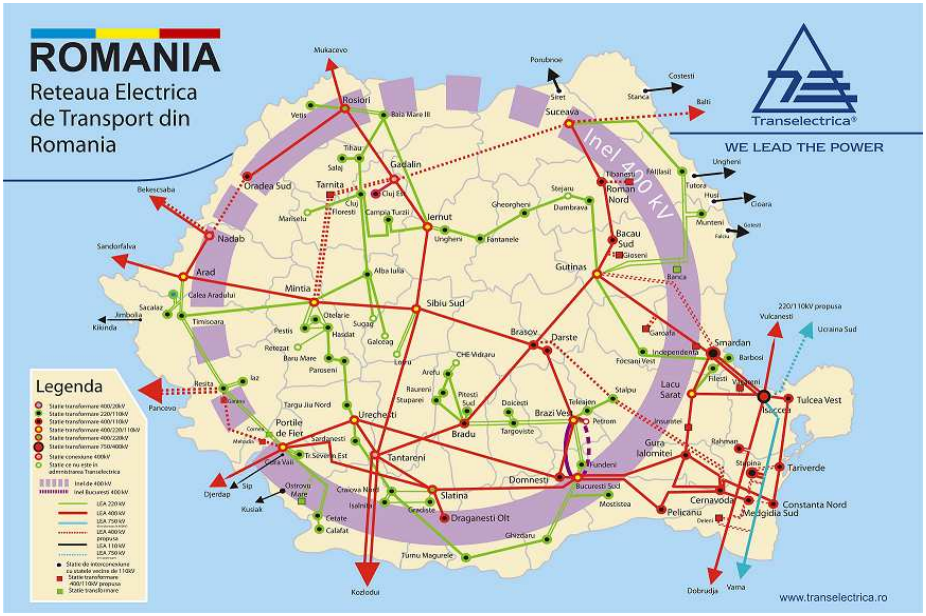

Fig. 2. Ring of 400 kV within National Power Grid

4. Conclusions

In the context of increasing the importance of energy security for national security, the security of power installations must be a major and constant objective of interest to the transmission system operator Transelectrica company.
Developments in recent decades have shown an increase in vulnerabilities caused by:

- failure, destruction and / or interruption of technological infrastructures (transport, energy, informatics, etc.) caused by acts of terrorism;
- natural disasters (earthquakes, floods, hurricanes, etc.);
- negligence (lack of staff competence, periodic non-training, omissions, etc.);
- technical work accidents;
- technical incidents;
- criminal activities.

In order to ensure the safe and stable operation of the National Energy System, Transelectrica company will consider increasing the level of security of the objectives, taking into account both the patrimonial value of the objectives and their functional importance.

Transelectrica company must have a strategy for ensuring an adequate level of security of objectives, with minimum costs (is not a mandatory condition) and will have to include a set of own activities, carried out at company level. From this perspective, strategic priorities should include:

a) Vulnerability assessment and risk management: this activity identifies critical objectives for the activity as well as their degree of vulnerability;
b) Continuous improvement of threat response capacity: is the extent to which staff are prepared to deal with as wide a range of threats as possible, both physical and computer;
c) Crisis management: by which it is ensured that the system, as a whole, is ready to react to physical and computer threats;
d) Preparation of process continuity plans: which address issues related to reducing the likelihood of long-term malfunctions and increasing the promtitude of return operations, through a unitary coordinated multicriteria prioritization, starting from ensuring the functionality of the national / European critical infrastructures, completing with those vital to the company and reaching the optimal operating solution in the new conditions;
e) Communication development: ensuring the coherence of response-related activities, crisis management and recovery plans and an important aspect is the ways of connecting with the authorities;
f) Increasing the level of physical security: which aims to reduce internal and external threats to the system;
g) Increasing IT security: which ensures the reduction of the level of risk on command and control systems, data acquisitions and teleprotection;
h) Staff protection measures: which must lead to a reduction in threats within the system and must take into account criteria for the employment and regular verification of staff involved in critical activities;
i) Information protection: in order to reduce the likelihood that certain critical, classified or unclassified information will be available to potential aggressors.

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