THE USE OF ARTIFICIAL INTELLIGENCE IN THE RESILIENCE, SAFETY AND SECURITY OF THE NATIONAL POWER SYSTEM

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Abstract: Artificial Intelligence (AI) plays a key role in modernizing and protecting the National Power System (NPS). By integrating AI, *the resilience* of power grids is improved, allowing rapid detection of anomalies, failure prevention and automatic adaptation to crisis conditions or cyber attacks. In terms of *safety*, AI helps to continuously monitor operational parameters, optimizing the functioning of the critical infrastructure in order to prevent accidents or human errors. In the field of *security*, machine learning technologies and predictive analysis can identify cyber threats in real time, reducing the risk of attacks on critical power grids. Thus, AI becomes a strategic tool for strengthening a reliable, safe power system, able to respond rapidly to internal or external challenges.

Keywords: Artificial Intelligence (AI), Resilience, Safety, Security, National Power System

1. INTRODUCTION

The use of artificial intelligence (AI) in the National Power System contributes significantly to the increase of the resilience of the critical energy infrastructure. Through predictive analysis, machine learning and automated optimization technologies, AI enables fault anticipation, efficient consumption management, renewable source integration and rapid response to critical incidents. Smart systems can monitor the grids in real time, detecting anomalies or vulnerabilities before they cause major interruptions. In addition, AI helps to optimize maintenance operations and to better coordinate distributed energy resources, thereby enhancing national energy security and adaptability to risk factors such as climate change or cyber attacks. The integration of AI is essential for the modernization, security and sustainable development of the NPS.

Artificial Intelligence (AI) plays an increasingly important role in the safety and efficiency of the National Power System. The application of AI technologies in this sector helps to optimize processes, prevent faults, and monitor power grids in real time, which helps to increase their reliability and safety. Among the most important applications of AI in NPS safety are: *Monitoring and Proactive Diagnostics* (the AI algorithms can analyze data from sensors and monitoring equipment to detect anomalies and possible failures before they become critical. This way, corrective measures can be implemented in time, reducing risk and maintenance costs), *Forecast and Energy Management* (IA helps to forecast energy requirements and manage resources efficiently, including in conditions of fluctuations in renewable energy production. This helps to maintain the balance between energy supply and demand, avoiding NPS instabilities, *Optimization of Power Grids* (AI algorithms can help optimize energy transmission and distribution in power grids, managing the energy flow more efficiently, leading to reduced losses and improved overall performance of the NPS). The use of artificial intelligence in the NPS is essential to improve their safety, efficiency and stability. AI technologies enable better resource management and a rapid response to potential crises, contributing to the development of a more resilient and sustainable NPS. [1-2]

Artificial Intelligence (AI) is also playing an increasingly important role in improving the security of the NPS. The application of AI in this field helps to monitor, manage and protect the critical energy infrastructure, which is essential for the functioning of a modern economy. The main fields where AI contributes to energy security are: *Detection and prevention of cyber attacks* (AI can analyze in real time data from sensors and monitoring systems to identify potential cyber threats, such as DDoS (Distributed Denial of Service) attacks, malware or intrusions into control networks), *Optimization of energy transmission and distribution grids* (through machine learning algorithms, AI can anticipate energy requirements and dynamically adjust the energy distribution in order to prevent overcrowding or blackouts. This allows for more efficient resource management and a reduction of operational risks), *Forecast and management of the energy demand* (AI can model and predict consumer behaviors and variations in energy demand, contributing to plan efficient strategies for a safe energy supply), *The integration of renewable energy sources* (the use of AI helps to integrate renewable energy sources (e.g., solar and wind) more efficiently into transmission and distribution grids, given their intermittent nature. AI algorithms can adjust the grid dynamics to compensate for fluctuations in production and consumption), *Improvement of the physical infrastructure management* (AI can be used to monitor the state of the equipment and critical infrastructure (e.g., power lines, transformers, distribution, connection or transformer substations), forecasting failures and planning preventive maintenance. The use of Artificial Intelligence in NPS security is an important step towards ensuring a more robust, efficient and resilient system to various threats, both cyber and physical.

Resilience is the ability of the NPS (power plants, power substations and overhead power lines) to *anticipate*, *resist*, *respond* and *recover* rapidly after major disturbances, whether natural disasters (storms, earthquakes), cyber attacks or technical failures, and the role of AI consists of the following essential activities:

- *Forecast and early detection*: AI can analyze data in real time (from sensors, smart meters, cameras) to anticipate problems or detect grid anomalies much earlier than traditional methods;
- *Optimization and automation*: AI algorithms can rapidly decide how to redirect the energy, reconnect or isolate sections of the affected grid in order to minimize blackouts;
- *Learning from incidents*: Machine learning helps to learn from past disturbances and adjust future response strategies;
- *Distributed source management*: in a modern grid, with many renewable energy sources (wind, solar), AI can balance supply and demand even under extreme stress conditions;
- *Cyber Defence*: AI can monitor grid activity to identify cyber attacks in real time and propose automated countermeasures.

Concrete examples of using AI in NPS resilience:

- *Smart Grids:* smart grids use AI to manage energy flows and respond automatically to fluctuations;
- *Predictive Maintenance:* predicting failures before they occur (e.g., in wind turbines or transformers).
- *Automatic restoration:* systems that automatically restore connections in a power grid after an interruption. [3-4]

2. STRUCTURE OF THE NATIONAL POWER SYSTEM

The structure of the NPS is the set of interconnected components that ensures the production, transmission, distribution and consumption of electricity. In Romania, the NPS includes several sectors, each playing a key role, from producing electricity to supplying it for the economy and the population. Here are the main components of the NPS structure:

2.1. Electricity production

Romania has a variety of power plants that help to cover the national consumption needs, but there are also challenges, especially regarding the energy transition to greener sources and the efficiency of the energy transmission grid. Romania's energy mix includes a high proportion of renewable, hydro and nuclear energy, complementing fossil-based production. In conclusion, Romania has a varied energy mix, with a significant role of renewable sources and a great potential in the field of wind and solar energy. The challenges of climate change and the transition to a greener power system, however, call for rapid adaptation and continued investment in new technologies and infrastructure.

<u>Nuclear Power Plants:</u>

- *Cernavoda Nuclear Power Plant*: it is the only nuclear power plant in Romania, with two functional reactors. The two CANDU (Canadian Deuterium Uranium) reactors have a capacity of about 700 MW each and produce about 20% of the country's total electricity. Romania plans to expand the plant by adding new reactors in the future.

<u>Hydro Power Plants:</u>

- *Iron Gates I and II Hydro Power Plant*: located on the Danube River, on the border with Serbia, it is the largest hydro power plant in Romania, with a total installed capacity exceeding 1000 MW at the two complexes (Iron Gates I and Iron Gates II);
- *Vidraru Power Plant*: located on the Arges River, has a capacity of about 220 MW and it is one of the oldest hydro power plants in the country;
- *Lotru-Ciunget Power Plant*: located on the Lotru river, in Valcea county, has a capacity of about 510 MW and it is one of the largest mountain hydro power plants in Romania;
- *Bicaz Hydro Power Plant*: located on the Bistrita river, in Neamt county, it is an important power plant in the Romanian hydro power system;
- *Fagaras Hydro Power Plant*: it has a significant capacity and it is one of the largest hydro power plants in the southern area of the country.

<u>Thermal Power Plants (coal and natural gas):</u>

- *Oltenia Energy Complex*: it is the largest producer of coal-fired energy in Romania, operating several thermal power plants, including those from Rovinari, Turceni, Isalnita and Craiova. These use lignite and contribute significantly to Romania's electricity production;
- *Mintia Thermal Power Plant*: located in Hunedoara County, it was one of the most important coal plants, but it was closed recently due to financial and environmental problems, but now it is in the phase of total modernization and optimization;
- *Brazi Power Plant*: operated by OMV Petrom, it is one of the most modern natural gas power plants in the country, with an installed capacity of 860 MW. It is located near the city of Ploiesti and plays an essential role in the energy security of Romania;
- *Braila Thermo Power Plant*: also a coal plant, located on the Danube shore, it is another important point in the country's power system.
- *Constanta Power Plant*: using natural gas, this power plant plays an important

role in completing the energy mix of Romania;
- *Iernut Power Plant*: it is an important natural gas plant, located in Mures County, with a significant capacity.

Wind Power Plants:
- *Fantanele-Cogealac Wind Farm*: located in Dobrogea, it is the largest onshore wind farm in Europe, with an installed capacity of about 600 MW. The farm is operated by CEZ Romania and contributes significantly to the renewable energy produced in Romania;
- *Dobrogea Wind Farms*: Dobrogea is the region with the most and largest wind farms in Romania due to the excellent wind conditions. Other important wind farms in the area are those from Topolog and Mihai Viteazu.

Solar Power Plants:
- *Photovoltaic Farms in South of Romania*: although the installed capacity in solar power plants is lower than in other energy sources, Romania has developed several photovoltaic farms especially in the south of the country, in areas such as Giurgiu, Teleorman and Dolj. The total installed capacity of the solar power plants is several hundred MW.

Biomass Power Plants:
- *Biomass Power Plants from Suceava and Bistrita*: these power plants use forest and agricultural waste for the production of electricity and heat. Such power plants have lower capacities but play an important role in diversifying energy sources and reducing carbon emissions. [5]

2.2. Electricity transmission

The Power Transmission Grid in Romania plays a key role in the transmission of electricity from producers to distributors. It is managed and operated by *Transelectrica*, which is responsible for the safety and reliability of the NPS. The structure of the electricity transmission grid includes very high and high voltage lines, transformer substations and dispatching. Here is an overview of the main components and organizations of the transmission grid (fig. 1).

Overhead power lines – transmission OHL (high and very high voltage):
- *400 kV OHL* - the backbone of the transmission system, with lines that ensure the transfer of energy over very long distances;
- *220 kV OHL* - lines connecting different regions of the country with 110 kV distribution grids;
- Energy infrastructure: 8931.6 km of OHL, of which :
  - *154.6 km at the voltage of 750 kV;*
  - *4703.7 km at the voltage of 400 kV;*
  - *4035.2 km at the voltage of 220 kV;*
  - *38 km at the voltage of 110 kV (interconnection lines with neighboring systems).*

Connection and/or transformation substations:

Connection and/or transformation substations play a crucial role in regulating the voltage and distributing energy to distribution grids and, in some cases, directly to large industrial consumers.

The most important types of power substations include:
- *400 kV power substations*;
- *400/220 kV power substations;*
- *400/220/110 kV power substations;*
- *220/110 kV power substations;*
- *Power substations of international connection at the voltage of 400 kV* - used for the interconnection with the power grids of neighboring countries, such as Hungary, Bulgaria, Serbia, Ukraine and Moldova. These interconnections allow the import and export of electricity, contributing to the country's energy security.

- Energy infrastructure: 81 power substations, of which:
  - *1 power substation at the voltage of 750 kV;*
  - *38 power substations at the voltage of 400 kV;*
  - *42 power substations at the voltage of 220 kV.*

Dispatchers:

Transelectrica manages the power transmission grid through dispatchers, which monitor in real time the energy flows, voltage and frequency in the grid. The main dispatchers are:

- *The National Energy Dispatch (NED),* which coordinates and optimizes the functioning of the entire National Power System;
- *5 territorial Dispatchers* - these are divided on several areas to provide regionalized control over the flow of energy.

Romania is integrated into the European energy transmission grid, part of the *European Network of Transmission System Operators for Electricity (ENTSO-E)*.

International interconnections enable energy exchanges, optimization of energy resources and contribute to system stability in the event of major variations in consumption or production.

The power transmission grid in Romania is a very complex strategic infrastructure of national interest, well interconnected with the rest of Europe, which allows both an efficient internal energy transfer, as well as a cross-border flow (fig. 1).

This structure ensures not only the national energy security, but also the active participation of Romania in the European energy market. [6]

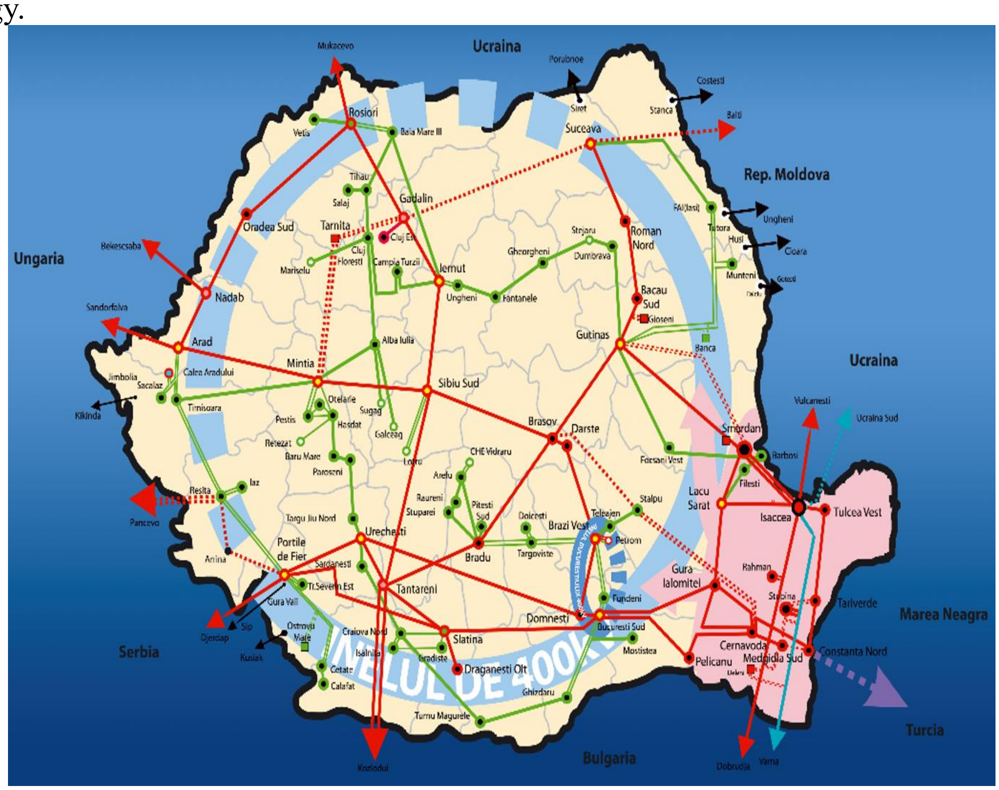

Fig. 1. The Power Transmission Grid in Romania

2.3. Electricity distribution

The Power Distribution Grid in Romania is an essential part of the national energy infrastructure, responsible for the distribution of electricity to consumers. This grid includes overhead power lines and distribution power substations at the voltage of 110 kV, providing energy to both urban and rural areas.

The Power Distribution Grid Structure:

The power distribution grid in Romania is organized on several voltage levels:

- *High voltage (110 kV)* - is intended for long-distance energy transfer and connects power plants or transmission grids with power distribution grids;
- *Medium voltage (20 kV)* - distributes electricity from high voltage substations of 110 kV to transformer substations of 20/0.4 kV or industrial consumers powered at medium voltage;
- *Low voltage (0,4 kV)* - is the level of voltage at which energy is delivered to domestic or industrial consumers.

Distribution operators:

The grid is managed by several electricity distribution operators:

- *Power Grids* (regions Banat, Dobrogea and Southern Muntenia);
- *Energy Distribution Oltenia* (counties Dolj, Arges, Olt, Gorj, Valcea, Mehedinti and Teleorman);
- *Delgaz Grid* (counties Suceava, Botosani, Neamt, Iasi, Bacau and Vaslui).
- *Electricity Distribution Romania* (regions Northern Transylvania, Southern Transylvania and Northern Muntenia). [7]

2.4. Electricity consumption

End consumers – this sector includes all electricity users in the country, both households (for household consumption) and various industrial and commercial sectors. Electricity consumption is regulated, and tariffs vary depending on the type of consumer (domicile, firm, industry).

2.5. Electricity market

Electricity market – this is the place where the electricity produced and consumed is traded, regulated by the National Energy Regulatory Authority. There are several energy markets in Romania, including the daily market, the balancing market and the capacity market.

2.6. Regulation and control

Regulation and control authorities:

- *The National Energy Regulatory Authority*: is the governmental authority responsible for the regulation and supervision of activities in the field of electricity. The National Energy Regulatory Authority sets licensing rules, tariffs and performance standards;
- *The General Secretariat of the Government;*
- *Ministry of Energy.*

2.7. Security and sustainability

Important activities regarding security and sustainability:

- *Energy storage*: although it is not a direct component of the National Power System, energy storage (through large batteries, accumulation hydro power or other technologies) plays a key role in balancing energy demand and supply;
- *Energy efficiency*: energy efficiency policies are promoted to reduce energy consumption and maximize the use of renewable sources;
- *Energy transition*: in the context of climate change, Romania (like many other countries) is trying to diversify energy sources, reduce dependence on fossil fuels and invest in renewable energy sources.

2.8. Impact on the environment

The National Power System must also take into account environmental protection measures, regarding EU and international rules on reducing CO_2 emissions and air pollution.

3. THE FUNCTIONING OF SCADA ON THE NATIONAL POWER SYSTEM

SCADA (**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition) is an essential technology in the operation and monitoring of the NPS. This enables remote supervision and control of geographically distributed electrical equipment and installations, such as power plants, transformer substations and transmission lines. SCADA contributes significantly to the stability and efficiency of the grid as well as to the prevention and management of crisis situations in the NPS. [8-14]

3.1. The role of SCADA in the NPS

The SCADA system plays a crucial role in the management and operation of the NPS. SCADA allows real-time monitoring, control and data collection for essential equipment and processes in the electricity grid, facilitating a more efficient, safe and reliable operation of the system. Here are some key roles that SCADA performs in the NPS:

- *Coordination of The National Power System:* SCADA ensures coordination between power plants, transformer substations and distribution grids. In Romania, the transmission operator, Transelectrica, uses SCADA to manage the flow of energy between different regions and to ensure a balanced distribution;
- *The interconnectivity of the systems:* SCADA is essential for integrating renewable power systems, such as wind and solar farms, which are more volatile, into the national grid in order to maintain a stable balance between production and consumption;
- *Ensuring grid stability:* SCADA helps to maintain the stability of the frequency and voltage in the grid, essential for the safe functioning of equipment and for the prevention of the occurrence of large blackouts;
- *Real-time monitoring of grid parameters:* SCADA collects and displays real-time data about critical parameters such as voltage, current, frequency, and active/reactive power at critical points in the grid. This continuous monitoring allows operators to observe fluctuations and anticipate problems such as voltage variations or overloads, providing information essential to maintaining the stability of the NPS;
- *Remote control of equipment:* Operators in command centers can remotely control the essential equipment of the grid (for example, switches, transformers and voltage regulators). This control capacity is vital for rapid reactions in emergency situations or for implementing grid configuration changes without the need for physical intervention on site;
- *Process automation and optimization of energy flows:* SCADA enables the automation of critical processes, such as balancing production and consumption, optimal energy distribution and compensation of load variations. Through pre-established algorithms and rules, the system can adjust energy flows according to demand, helping to reduce losses and optimize operating costs;
- *Detection and management of faults:* SCADA can rapidly identify areas with failures and locate affected equipment. By analyzing historical and real-time data, SCADA can point to locations with problems and suggest corrective measures. Early detection allows to avoid major damage and reduce downtime, which leads to greater continuity of the power supply service;
- *Data collection for performance analysis and predictive maintenance:* SCADA stores a large amount of historical data, useful for analyzing the performance of equipment and of the grid as a whole. These data are used for predictive maintenance, identifying equipment that requires maintenance before it fails, thus reducing costs and increasing the reliability;
- *Ensuring cybersecurity and system integrity:* SCADA is integrated with cybersecurity systems in order to protect the power grid from software threats. SCADA systems in the NPS are protected by rigorous security measures, given the enormous impact

that a cyber attack could have on the power distribution grid;

- *Integration of renewable energy sources:* SCADA enables the efficient integration of renewable energy sources (such as solar and wind power plants) into the NPS. The system can monitor and adjust the flow of energy generated from intermittent sources, ensuring that production from renewable sources is optimally used and well integrated into the grid;
- *Managing emergency situations and rapid reactions:* In the case of major events (for example, storms, earthquakes or technological incidents), SCADA plays a key role in coordinating rapid reactions. The system allows rapid identification of the affected areas and implementation of grid containment or reconfiguration measures to reduce impact and restore power supply as rapidly as possible.

The SCADA system is the backbone of efficient operation and management of the National Power System. By monitoring, controlling and automating processes in the NPS, SCADA helps to ensure a safe, reliable and efficient energy flow. It also contributes to the development and integration of modern technologies and to maintaining operational safety in the context of increasingly complex and interconnected energy grids.

3.2. The functioning of the SCADA system in the NPS

SCADA is essential in monitoring and controlling the critical infrastructure in the NPS, which includes power plants, transformer substations, transmission lines, and electricity distribution grids. Its functioning within the NPS requires an integrated grid of components that allow both the supervision, and efficient control of energy flows, ensuring the stability and security of the power grid. The functioning of a SCADA system in the NPS involves several essential components and processes:

- *RTUs (Remote Terminal Units) and PLCs (Programmable Logic Controllers),* which are located at control points and transformer substations. These devices collect data from local equipment and transmit it to command centers.
- *The communication network* is crucial for the real-time transmission of data to command centers. In the NPS, this may include dedicated fiber-optic networks, radio communications or satellite links, all secure and redundant in order to ensure continuity of transmissions.
- *The command and control centers*, which are usually regional centers and a national center. This is where the data collected from all over the grid is centralized, allowing operators to monitor the functioning of the grid in real time.
- *SCADA software* takes data from the field, processes it and presents it to operators in the form of diagrams and graphs. It also allows the emission of commands for the control of remote equipment, including adjustments of energy flows or shutdown of equipment for protection.

In conclusion, the SCADA system plays a vital role in the functioning of the National Power System, ensuring the efficient monitoring and control of the power grids, improving the safety and reliability of power supply, reducing damage risks and maximizing system efficiency.

3.3. The advantages of SCADA for the National Power System

SCADA systems play a key role in managing and monitoring power grids, including within a country's NPS. In the context of the NPS, SCADA brings multiple advantages, which contribute to increasing the efficiency, reliability and safety of the entire power system. Here are some of the key advantages of SCADA for the NPS:

- *Real-time monitoring:* SCADA allows continuous monitoring of important parameters of power grids (voltage, current, frequency, active and reactive power) in real time. This helps to rapidly detect any anomalies or failures in the grid, facilitating rapid interventions to fix the problems and prevent system collapse;

- *Centralized control:* SCADA provides a centralized control system that allows operators to adjust the parameters of power grids (power plants, transformer substations, transmission lines) remotely. This reduces dependence on manual intervention and increases the rapidity and precision of control actions;
- *Diagnosis and forecast:* SCADA systems can provide detailed analysis of the data collected from the field, allowing the forecasting of the behavior of the system, in the short and long term. Thus, possible weaknesses or risks in the grid can be identified and preventive measures, reducing the risk of major damage, can be taken;
- *Increasing the reliability of the system:* SCADA helps to detect failures early, thus providing the opportunity to intervene rapidly and prevent serious damage to equipment. Also, by automating processes and optimizing the energy flow, the risk of energy loss and power supply interruptions is minimized;
- *Optimization of energy distribution:* The SCADA system allows operators to optimize the distribution of energy in the grid by adjusting the flow of energy between different production sources and consumers. This helps to balance loads and maintain the stability of frequency and voltage in the grid, essential for an efficient power system;
- *Integration of renewable energy sources:* Another significant advantage of SCADA is the easier integration of renewable energy sources (such as solar and wind energy) into the grid. SCADA enables the monitoring and management of the flow of energy from variable sources, adjusting production and consumption in real time in order to maintain the grid stability;
- *Data accessibility and transparency:* The data collected by SCADA are accessible to operators and Regulators, providing greater transparency on the performance of the power system. This can improve decision-making and ensure better investment planning and infrastructure maintenance;
- *Reduction of operational costs:* Automating processes through SCADA reduces the need for manual interventions and field monitoring activities, leading to significant cost savings. In addition, by preventing major damage and interruptions, the costs associated with the repair of faults and energy losses, are reduced;
- *Rapid response to emergency situations:* SCADA allows the implementation of automatic or semi-automatic emergency procedures, which are activated in case of major damage or unpredictable events. Thus, interventions can be carried out rapidly, minimizing the impact on consumers and protecting grid equipment and infrastructure;
- *Support for regulations analysis and reporting:* SCADA helps grid operators to collect accurate data, necessary for complying with energy regulations and for reporting performance to regulators. This helps to improve compliance and transparency in the energy industry;
- *Increasing energy efficiency:* Resource usage optimization through accurate monitoring of consumption and production;
- *Safety and security:* Allows rapid detection of damage and anomalies, reducing the risk of extensive blackouts or damage to equipment;
- *Integration with other IT and protection systems:* SCADA allows integration with other technologies (e.g., IoT and data analysis) so as to ensure better coordination of grid maintenance and modernization operations.

In conclusion, the implementation and use of SCADA systems within the National Power System bring significant benefits in terms of monitoring, control, efficiency and safety of power grid operation, and, thus contributing to a more stable, reliable and sustainable system.

4. CONCLUSIONS

The integration of Artificial Intelligence (AI) and SCADA (Supervisory Control and Data Acquisition) programmes, brings numerous advantages in increasing the resilience, safety and security of the NPS.

First of all, AI enables advanced real-time data analysis, anticipating major faults or incidents, thereby optimizing the rapid response to emergencies and reducing the risk of major interruptions. Machine learning algorithms can detect subtle anomalies in the functioning of power grids, improving prevention and predictive maintenance.

On the other hand, SCADA systems provide centralized monitoring and control, ensuring complete visibility on the critical energy infrastructure, from production to distribution. These contribute to making rapid and well-grounded decisions in case of damage or cyber attack. AI integration with SCADA adds an extra layer of operational intelligence, allowing incident response automation and limiting their impact on consumers.

The combined use of AI and SCADA also enhances cybersecurity by identifying and blocking potential cyber attacks before they affect critical systems. Through smart simulations and continuous risk assessments, the NPS is becoming more robust in the face of natural disasters, demand fluctuations or other emerging threats.

In conclusion, Artificial Intelligence and SCADA are complementary technologies that greatly improve the efficiency, reliability and safety of the NPS, supporting the transition to a safer, more flexible and sustainable power system.

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