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Challenges in the Georgian energy sector and the role of AI programs in the development of Georgian power grid.

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Abstract

Georgia's power grid faces challenges related to its existing radial infrastructure, increasing consumption, and the integration of generation and transit capacities, along with new issues that have arisen in recent years due to energy market liberalization and climate change. The liberalization of the energy market has led to limits on reserve size and systematization, as well as the establishment of daily, hourly, 15-minute, and 5-minute electricity trading. This shift has moved operations beyond the comfort zone of dispatchers and has contributed to the automation and computerization of electricity trading and exchanges, thereby increasing the risk of cyber attacks and information insecurity.

To combat climate change, thermal and nuclear plants are being paired with wind and solar variable generation. The growing use of renewable energy sources requires the development of effective management strategies to satisfy the global demand for clean and affordable energy. One of the United Nations' Sustainable Development Goals is to ensure universal access to reliable, affordable, and sustainable energy. Achieving this goal necessitates innovative solutions and modern technologies to tackle constraints such as insufficient energy generation, faulty transmission and distribution infrastructure, accessibility challenges, and weather-related issues. Artificial intelligence presents a significant opportunity to meet the demands of modern society. Recent advancements in neural network research, machine learning, and cognitive computing have created new possibilities for energy management, monitoring, and optimization.

Artificial intelligence (AI) programs can help minimize losses and costs, promote clean renewable energy sources within global energy systems, and enhance the design, operation, and control of power systems. The article discusses the challenges and opportunities in the energy sector and highlights the role of artificial intelligence in the advancement of Georgia's energy system.

Key words: Artificial Intelligence programs, power grid, Georgian State Electrosystem, smart grid, Remedial Action Scheme.

Introduction

As a product of the Fourth Industrial Revolution, artificial intelligence is used in all aspects of our lives. AI tools play an increasingly important role in the activities of organizations. Artificial Intelligence is a growing, frequently discussed topic that already affects many sectors of the world, including education, healthcare, manufacturing, construction, industry, retail, finance, and more. The energy sector is no exception.

The energy field faces rising challenges related to increasing demand, shifts in supply and demand balance, and a lack of necessary analysis within the energy management system. In developed countries, the integration of artificial intelligence and related technologies has already begun, allowing interaction with smart systems and smart metering. These technologies can enhance energy management, improve efficiency, and promote the use of renewable energy sources. The implementation of artificial intelligence has also commenced in the energy systems of developing countries. Universal access to reliable, affordable, and sustainable energy is one of the UN Sustainable Development Goals. To achieve this objective, innovative solutions and modern technologies are essential to overcome challenges associated with inadequate energy generation, faulty transmission and distribution infrastructure, accessibility issues, and weather-related problems. Artificial Intelligence programs can help reduce losses and costs, promote clean renewable energy sources in global energy systems, and enhance the planning, operation, and control of power systems.

Omitaomu and Niu (Omitaomu O. A. and Niu H. 2021) discuss the use of artificial intelligence technologies in load forecasting, electrical network stability assessment, fault diagnosis, and smart grid security. The authors believe that AI technologies can strengthen and improve the smart network system and make it more reliable and durable.

Szepaniuk (Szczepaniuk H. and Szczepaniuk E. K, 2023) describes in his research that artificial intelligence algorithms can improve energy generation, distribution, storage, consumption, and trading processes in energy fields such as smart network management, cybersecurity, energy saving, minimizing energy loss, and fault diagnosis.

Georgia is actively modernizing its electric grid through a combination of state-led initiatives, federal support, and public-private partnerships. These efforts aim to enhance grid resilience, integrate renewable energy sources, and improve service reliability across the state. Currently, traditional power grid is used in Georgian State Electrosystem (GSE) and is planned to introduce a smart grid in the future. Also, the company considers to replace the existing remedial action scheme with an artificial intelligence-based, "Autonomous RAS" program.

The purpose of the research is to identify challenges in the energy market and highlight the role of artificial intelligence programs in the development of the Georgian energy system. Descriptive research was employed in the report to outline the current situation of the Georgian energy market. Interviews were conducted with seven GSE representatives. To obtain detailed information, secondary data and unstructured interviews were reviewed. Documentation and statistical data from the company were utilized. The information was gathered using the company's annual reports. The paper adheres to ethical standards. All study participants were informed of the study's goal, as well as the associated risks and benefits. All respondents participated voluntarily and consented to make their data and company documentation public.

Traditional and smart grid

The power grid is the backbone of modern energy systems, evolving from traditional infrastructures to advanced smart grids.

The traditional power grid is a centralized system in which electricity flows in a single direction. Transmission and distribution networks transport electricity from the power station to the end consumer. In the case of a traditional power grid, the power producing station may or may not be in the same geographical area as the consumption locations. As a result, traditional networks typically require the transfer of electricity over great distances.

The smart grid is a next-generation energy system that integrates existing energy infrastructure with information and communication technology. One of the benefits of a smart grid is the ability to transfer electricity and data in both directions via communication signals. It is distinguished by a combination of distributed and renewable energy sources. A smart grid built on artificial intelligence algorithms can respond correctly through distributed energy management, forecasting renewable energy generation, accurate network monitoring, and problem detection.

Table 1. Traditional and Smart Grid

Feature	Traditional Grid	Smart Grid
Generation	Centralized, fossil fuels	Centralized and decentralized, renewables
Power Flow	One-way	Two-way
Communication	Limited	Real-time, digitalized
Monitoring & Control	Minimal	Advanced, automated
Renewable Integration	Challenging	Facilitated
Consumer Interaction	Passive	Active, with feedback
Resilience	Lower	Higher

Remedial Action Scheme (RAS)

Remedial Action Scheme is an automated control system used in electric power systems to detect specific abnormal or emergency conditions and respond quickly to prevent power system instability, overloads, or blackouts. In Georgian State Electrosystem, a Remedial Action Scheme (RAS) has been introduced.

Due to the change in the topology[66] of the GSE grid, it is necessary to update and expand the RAS. To avoid disconnection of the electric power system, it is necessary to expand the grid along with the expansion of remedial action scheme. Expanding the grid leads to the creation of a very large number of possible scenarios in the RAS, the preliminary analysis of which and the determination of the dosed shutdown power, only with human resources, are associated with great difficulties. Therefore, it is advisable to develop artificial intelligence based Remedial Action Scheme ,,Autonomous RAS".

Use of Artificial Intelligence Programs in the Energy System:

• Prediction of defects - In an industry where equipment damage is anticipated, artificial intelligence programs equipped with appropriate sensors, can monitor equipment and detect failures, saving resources, time, money, and even lives.

• Recovery from disaster consequences - Following the hurricane that struck Florida in 2017, energy was restored in 10 days instead of 18, thanks to new technologies like AI, which could predict electrical availability without negatively affecting the system and ensuring supply where it was most needed.

• Preventing losses due to informal connections (theft) - AI can be employed to detect non-compliance based on usage patterns, payment history, and customer data. Additionally, alongside automated meters, monitoring capabilities can be enhanced. For instance, Brazil successfully leveraged this technology to address losses stemming from informal connections and billing errors. (Makala B, Tonci Bakovic T. 2020)

• Maintaining stability through image processing - The UK's national network utilizes drones to monitor transmission wires, detecting faults in extensive, challenging, and inaccessible areas. (Vaughan, Adam. 2018.)

[66] Change in the arrangement of elements in the electric power system

Challenges in the Power Grid of Georgia

The rise of prosumers, including factories, facilities, and residential homes equipped with their own wind or solar generation sources, has become increasingly attractive. They can sell surplus energy while drawing from the grid to cover any deficits, which creates additional instability in the system and complicates consumption predictions. Another challenge is the growing number of electric cars, which can dramatically increase peak consumption and make peak coverage more complicated if countermeasures are not implemented. Additionally, enterprises with highly variable consumption, particularly metallurgical plants, negatively impact the quality and stability of electricity.

Electric cars are replacing internal combustion engine vehicles worldwide. This transition leads, on one hand, to an increase in peak consumption and, on the other, to a potential distortion of electricity quality due to harmonics. Currently, around 1 million electric cars are registered in Georgia. The power consumption of fast chargers for each electric car is 50 kW, while standard chargers offer options of 3, 6, and 20 kW. During peak consumption hours, there may be a need for a swift but short-lived increase in imports. To mitigate this, a powerful hydro-accumulating station or a battery storage facility should be constructed within the power system.

Prosumers are increasingly seen as institutions, enterprises, and residents aim to establish autonomous electricity supply systems that connect to the distribution and transmission networks. If the reserve capacity proves insufficient, significant power shortages may ensue, creating a potential risk of emergencies. Conversely, distribution networks, typically designed to deliver power from the system to end users, could find themselves needing to supply power from users back to the transmission network. This situation may lead to higher voltages and increased losses. Therefore, it is essential to accurately track the number of decentralized users, reorganize the transmission and distribution system networks, build sufficient reserve sources in the system, ensure imports of this reserve, implement system automation, and ultimately define optimal storage battery parameters for prosumers.

Metallurgical plants present a considerable challenge for energy systems due to their rapid and large fluctuations in active and reactive capacity consumption, which can cause significant changes in frequency and voltage within small systems like Georgia. They are also sources of harmonic distortion. Challenges mainly arise during periods of water scarcity and hydrogenation shortages. Therefore, if the potential for daily minute and hourly balancing of wind energy is recognized, wind generation could positively impact the adequacy of Georgia's energy system.

Energy consumption continues to increase annually (see Diagram 1), particularly during winter, (see Diagram 2) and the country relies on imports, which primarily come from Russia. (see Diagram 3) Therefore, increasing generation capacity is vital.

Diagram 1. Generation, Consumption and Export 2023 - 2034

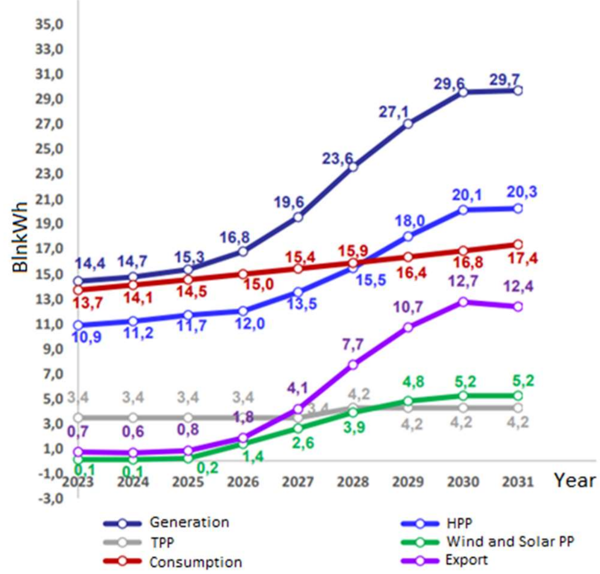


Diagram 2

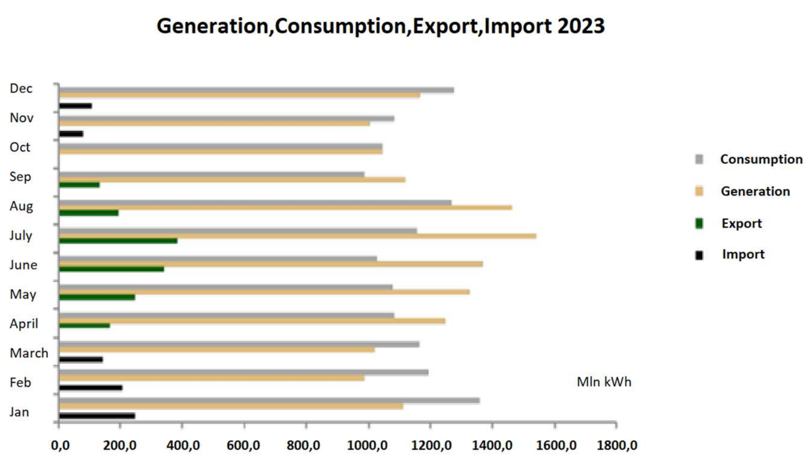
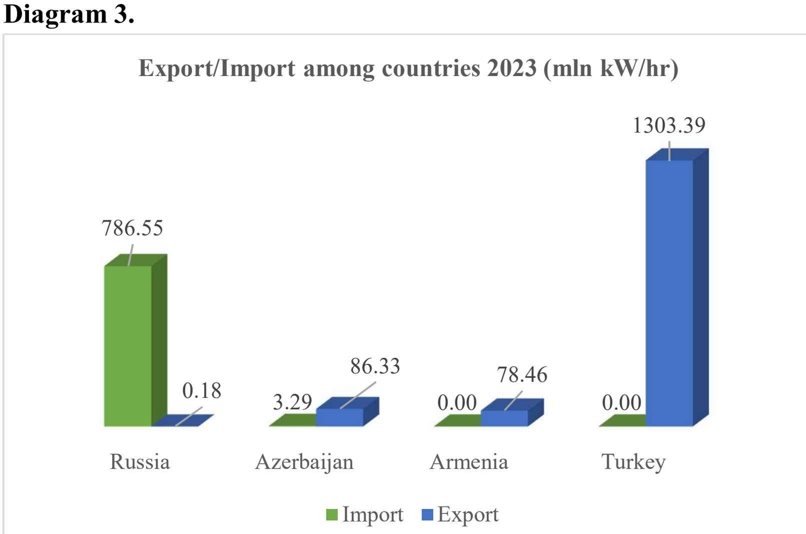


Diagram 3.



Steps to Overcome Challenges in Power Grid of Georgia

One of the solutions to the challenges faced by the power grid is constructing large reservoir hydropower plants, alongside restoring and upgrading existing power plants. These plants provide capacity reserves for future growth while also enhancing system stability. Their ability to meet peak usage, which is essential for operating electric car chargers and integrating solar and wind farms, is particularly impressive.

The development of energy storage facilities, such as hydro-accumulating stations and storage batteries, will help balance consumption schedules and boost peak capacity. Solar-powered plants can be linked to national consumption, alleviating daytime peaks. However, as clouds move across solar plants, their generation fluctuates significantly, requiring the integration of fast-acting power reserves into the power system to manage the variability of solar energy. To tackle this issue, accumulator batteries with optimal specifications can be utilized alongside solar plants to ensure stable solar generation.

Wind power plants, unlike solar plants, typically show little correlation with overall power system usage; moreover, wind generation can suddenly increase during peak consumption or decrease during low consumption. Therefore, it is essential to have mechanisms in place to balance the energy system, addressing both excessive consumption (high peaks, loss of generation) and excess generation. Implementing accumulator batteries may serve as a method for integrating highly variable users into the network.

Integration with the European domestic energy market is crucial. Adapting ENTSO-E network rules,[67] the Georgian State Electro System aims to connect with the European energy market, allowing our energy system to exchange electricity with Europe. This will create additional opportunities for incorporating renewable energy sources into the network and managing peak consumption.

To convert the challenges of integrating solar and wind energy sources into opportunities for Georgia's energy system, GSE has explored the integration potential of renewable energy sources into the network with assistance from the European consulting company DigSILENT. This study will assess the maximum capacity of solar and wind power plants that can be incorporated while ensuring reliable and sustainable network operations. Additionally, with support from the European Investment Bank (EIB), research is underway on energy storage solutions, including hydro-accumulating stations and storage batteries.

The smart grid plays a crucial role in integrating distributed and renewable energies. As the processes of electricity generation, transmission, and storage become more intensive and unpredictable, it is vital for distribution system operators to manage the loads of connected users, while transmission system operators oversee their consumption and that of distribution operators. To facilitate this, all entities involved in generation, transmission,

[67] https://www.entsoe.eu/network_codes/ last seen 06/09/2025

distribution, consumption, and storage must be integrated into a smart network that manages consumption and generation at various levels to ensure energy system reliability.

According to the diagram 1, 17.5-18% of power generation will come from renewables. When power systems feature 15%-30% of renewable energy sources, forecasting the capacity obtained from renewable resources in line with current demand becomes increasingly important. (Rhatrif A.E; et. al, 2024) Therefore, the need for smart technologies is significant.

Artificial Intelligence techniques and their applications in electric power.

Load Prediction - Artificial intelligence neural networks are used to forecast electricity demand, which is essential for providing reliable and efficient power supplies to network operators. Neural networks can accurately predict future energy consumption by considering a wide range of characteristics such as the weather, time of day, and prior demand.

Renewable Energy Prediction: Artificial neural networks can also anticipate the effects of renewable energy sources such as solar and wind energy, which can be highly unpredictable and challenging to forecast. By accurately predicting renewable energy generation, neural networks can assist network operators in more efficiently and effectively integrating these resources into their network.

Energy Optimization - Neural networks can optimize energy systems by determining the best schedule for power plants, distributing energy resources, and establishing energy management systems. They can analyze trends based on historical data.

Detection and Diagnosis of Faults - Neural networks can detect and diagnose faults in energy systems, such as determining the cause of power outages or pinpointing equipment malfunctions. By swiftly recognizing and diagnosing defects neural networks can assist reduce power outages by shortening response time and enhancing system reliability.

Energy Trading and Prices - Neural networks can model and project energy prices, enabling traders to make more informed purchasing and selling decisions. They can assess a wide range of factors affecting energy prices, such as supply and demand and weather.

Conclusion

Georgia's energy sector is at a crossroads, facing a complex interplay of infrastructure constraints, rising demand, and the evolving dynamics of liberalized energy markets. The integration of renewable energy sources, along with the need to combat climate change, underscores the significance of adaptive and intelligent energy management systems. Artificial intelligence emerges as a transformative tool in this context, offering innovative solutions to enhance operational efficiency, ensure energy security, and promote sustainable growth. Georgia can tackle its current challenges and position its energy system for a resilient, reliable, and sustainable future by embracing AI-driven technologies that align with global development goals.

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