

# Improving The Efficiency of Operating Modes of Smart Technology-Based Distribution Electric Networks

Huseynov N.R.<sup>a</sup>, Guliyev H.B.<sup>b</sup>, İbrahimov F.Sh.<sup>c</sup> and Yusifov S.P.


*Azerbaijan Technical University, Baku, Azerbaijan*


[nijat.huseyn.98@gmail.com](mailto:nijat.huseyn.98@gmail.com), [husevngulu@mail.ru](mailto:husevngulu@mail.ru), [amfanet@mail.ru](mailto:amfanet@mail.ru), [samiryusifovx@gmail.com](mailto:samiryusifovx@gmail.com)


**Keywords:** Smart Grid, distribution electric networks, efficiency improvement, operating modes, reliability, energy storage systems, green technologies, consumer participation, energy security, economic resilience.

**Abstract:** The presented study highlights practical issues of enhancing the efficiency of operating modes in distribution electric networks based on Smart technologies. It explores how new management principles and approaches, combined synergistically with modern high-speed electronics, data acquisition, and processing systems, contribute to improving the reliability of distribution networks. It is emphasized that these technologies transform consumers into active participants, enabling flexible and interactive control of energy consumption and distribution. Furthermore, the integration of energy storage systems through green technologies is substantiated as a key factor in enhancing system stability and reliability. The work analyzes existing algorithms and tools for improving the efficiency of distribution networks, evaluates the application potential of Smart Grid technologies, and proposes conceptual approaches for consumer-driven network management. The application of modern approaches is shown to be strategically important not only for increasing network reliability but also for ensuring energy security and economic resilience.

---

<sup>a</sup>  <https://orcid.org/0009-0001-2260-6738>

<sup>b</sup>  <https://orcid.org/0009-0006-7362-0619>

<sup>c</sup>  <https://orcid.org/0009-0003-4437-3511>

## 1 INTRODUCTION

Modern energy systems are actively adopting digitalization and intelligent technologies. The Smart Grid concept creates adaptive power networks that integrate distributed generation (solar, wind, storage), enable bidirectional power flows, and provide consumers with demand management capabilities.

The integration of renewable energy requires a transformation of distribution network management. Traditional centralized systems are increasingly inefficient under rising demand and reliability challenges. Smart Grid technologies enhance system flexibility and reliability, enabling real-time monitoring, optimal power flow distribution, loss reduction, and automated equipment control. They also engage consumers as active participants and strengthen stability through energy storage units.

A key enabler is the IEC 61850 standard, providing a unified platform for digital automation and data exchange in substations and networks via protocols such as GOOSE and MMS, ensuring interoperability and fast, reliable communication [1].

International experience shows significant progress in Smart Grid adoption. According to the U.S. Department of Energy, smart grids feature self-healing after outages, consumer participation, resilience to physical and cyber threats, quality power delivery, synchronized generation and storage, and support for new high-tech products and markets [2].

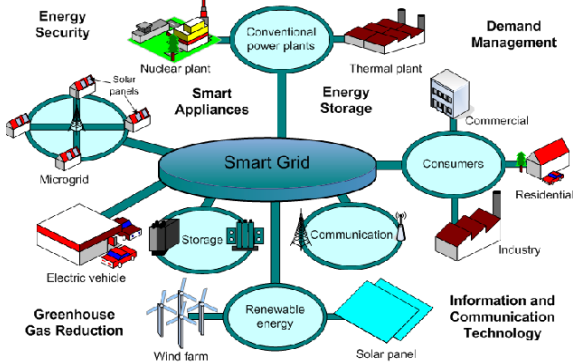


Figure 1: Infrastructure diagram of Smart Grid technology.

It should be noted that, in addition to the mentioned advantages, the application of Smart technologies is also associated with certain challenges, such as the high cost of grid modernization, the necessity of standardized data exchange protocols, cybersecurity and protection against cyberattacks, synchronization of distributed generation with the grid, and the persistence of “obsolete infrastructure” in some regions. Taking

these aspects into account, the study provides a systematic analysis of the theoretical and practical issues of applying Smart technologies to enhance the reliability and efficiency of distribution electric networks.

## 2 EVALUATION OF THE IMPACT OF SMART TECHNOLOGIES ON THE KEY TECHNICAL AND ECONOMIC INDICATORS OF DISTRIBUTION NETWORKS

For the purpose of evaluating the key technical and economic indicators of applying Smart Grid technologies in distribution networks, relevant quantitative parameters are used. These parameters are presented below. Smart Grid constantly ensures real-time balance within the generation–load–storage system:

$$\sum P_{Gen}(t) + P_{BEM}(t) + P_{Stor}(t) = \sum P_{Yuk}(t) + P_{hki}(t) \quad (1)$$

Here,  $P_{Gen}$  – conventional generation capacity;  $P_{BEM}$  – generation from renewable sources;  $P_{Top}$  – energy storage capacity;  $P_{Yuk}$  – total demand power;  $P_{hki}$  – network losses.

Smart Grid technologies reduce network losses in distribution electric networks through the optimization of power flows and the management of reactive power.

$$P_{hki} = \frac{P^2 + Q^2}{U^2} \cdot R \quad (2)$$

Here,  $P, Q$  = active and reactive power flowing through network elements;  $U$  = voltage of network lines;  $R$  – active resistance of network lines.

Smart Grid technologies utilize computational methods for network management; for example, the Newton-Raphson method can be applied to determine active and reactive powers at network nodes:

$$\left. \begin{aligned} P_i &= \sum_{j=1}^n |U_i| \cdot |U_j| \cdot Y_{ij} \cdot \cos(\theta_{ij} - \delta_i + \delta_j) \\ Q_i &= \sum_{j=1}^n |U_i| \cdot |U_j| \cdot Y_{ij} \cdot \sin(\theta_{ij} - \delta_i + \delta_j) \end{aligned} \right\} \quad (3)$$

Here,  $P_i, Q_i$  – active and reactive powers at the nodes;  $|U_i|, |U_j|$  – voltage magnitudes at nodes  $i$  and

$j$ ;  $Y_{ij}$  – admittance between nodes  $i$  and  $j$  of the distribution network;  $\delta_i, \delta_j$  – voltage phase angles at nodes  $i$  and  $j$ .

Smart Grid technologies contribute to enhancing the reliability of power supply, which can be quantified using the  $S_{AIDI}$  and  $S_{AIFI}$  reliability indices. Here,  $S_{AIDI}$  – System Average Interruption Duration Index and  $S_{AIFI}$  – System Average Interruption Frequency Index. The reliability indices are defined as follows:

$$S_{AIDI} = \frac{\sum_{i=1}^n A_i \cdot N_i}{\sum_{i=1}^n N_i} \quad ; \quad S_{AIFI} = \frac{\sum_{i=1}^n \lambda_i \cdot N_i}{\sum_{i=1}^n N_i}$$

(4)

Here,  $A_i$  – duration of outages at consumers;  $\lambda_i$  – number of outages in the distribution network;  $N_i$  – number of interrupted consumers. The lower the  $S_{AIDI}$  and  $S_{AIFI}$  reliability indices, the more reliable the distribution network is considered. Smart technologies reduce these values through automation.

The next key indicator is demanding management (Demand Response). The Smart Grid regulates load based on price signals:

$$P_{\text{tik}} = P_o(t) - \alpha \cdot \Delta C(t) \quad (5)$$

Here  $P_o(t)$  – base load;  $\Delta C(t)$  – tariff change;  $\alpha$  – demand flexibility factor.

By using this indicator, it is possible to regulate consumption in Smart Grid networks when prices increase.

Thus, in this study, the expressions (1) – (5) are used to evaluate the key technical and economic indicators of distribution networks with Smart Grid technologies.

### 3 PRACTICAL ISSUES OF APPLYING SMART GRID TECHNOLOGIES TO IMPROVE THE EFFICIENCY OF DISTRIBUTION NETWORKS AND EQUIPMENT

Modern energy systems require significant modernization to address current challenges. Advanced management systems enhancing

automation and reliability are needed, transforming the grid from a passive to an active element. Network parameters change in real time depending on load, renewable generation, topology, and weather. High-speed electronics and intelligent systems providing real-time operational data are essential.

In renewable-based networks, energy storage devices are widely used, and consumers actively participate in distribution and consumption. Contemporary power systems face challenges such as limited transmission capacity, partial control, inadequate voltage and reactive power regulation, and inefficient power flows. Reliability is a critical global issue, as outages can cause substantial economic and human losses [3,4]. Experts predict that energy supply quality and reliability will become the primary industry challenge in the next 20 years [5–7].

Over the past decade, Smart Grid technologies have been adopted to enable centralized control, real-time monitoring, and reduced demands on automated protection systems. According to the European Technology Platform, a Smart Grid efficiently coordinates network elements, power plants, storage devices, and consumers through bidirectional communication [8,9].

Smart Grids address conventional network issues such as high transmission losses, reserve maintenance difficulties, and prolonged outages, leveraging modern monitoring, control, communication, and ICT technologies to optimize energy use and enhance system reliability and efficiency. Key features include self-diagnostics, self-healing, rapid outage detection, fault management, load forecasting, comprehensive metering, dynamic tariff regulation, and integration of advanced equipment and services [10].

A comparative overview of conventional and Smart Grid networks is presented in Table 1.

Table 1. Comparative Features of Conventional and Smart Grid Networks.

Comparison factors	Conventional network	Smart Grid network
<b>1. Consumer electricity networks</b>		
1.1. Automated energy consumption management system involving consumers in operational control	No	Yes
1.2. Intelligent electricity metering systems	Insufficient	Everywhere
1.3. Voltage regulation and reactive power compensation system	Insufficient	in the required amount

1.4. Local (renewable) generation sources	Practically nonexistent or insufficient	widely used
1.5. Communication interface with a unified control center	No	Yes
1.6. Energy-efficient intelligent technologies in power supply systems, including "Smart Home" – "Smart City"	No	Yes
<b>2. Distribution networks</b>		
2.1. Automatic control systems for ensuring the balance of active and reactive power in nodes	insignificantly	Everywhere
2.2. Monitoring of electric power quality	negligibly	Yes
2.3. Centralized automatic control systems of consumer load	No	Yes
2.4. Presence of controllable network elements that change network parameters	negligibly	Yes
2.5. Monitoring and control systems for power supply reliability	No	Yes

#### 4 ENHANCING THE OPERATIONAL EFFICIENCY OF DISTRIBUTION NETWORKS THROUGH CONSUMER PARTICIPATION

Technological and structural changes in the energy sector, especially the growth of renewable sources, require new management approaches for distribution networks. Traditional centralized control loses efficiency under variable generation and fluctuating loads, making Demand-Side Management (DSM) and Demand Response (DR) increasingly important.

Modern consumers, enabled by ICT, smart metering, and monitoring devices, can now track consumption, respond to dynamic tariffs, and even act as producers, forming the “consumer-active distribution network” model. Consumer participation optimizes load distribution, reduces peak demand, minimizes losses, and extends equipment life, providing technical and economic benefits. Peak reduction stabilizes voltages and prevents overloading, while dynamic tariffs lower overall

energy costs. Active consumer engagement also enhances network resilience, ensuring continuous supply during emergencies [11].

Motivation mechanisms—dynamic tariffs, financial rewards, tax incentives, or support for technical devices—encourage participation [12–15]. Energy storage at the consumer level (home or EV batteries) allows energy to be stored and fed back to the grid, balancing intermittent renewable generation.

Intelligent grids rely on prosumers—entities that both consume and produce electricity—creating polycentric networks with multi-directional power flows [16]. Energy routers, using adaptive algorithms and power electronics, optimize power distribution, simplify connections for distributed generation, ensure high-quality electricity in Smart Grids, and reduce the risk of damage and data loss in critical infrastructure.

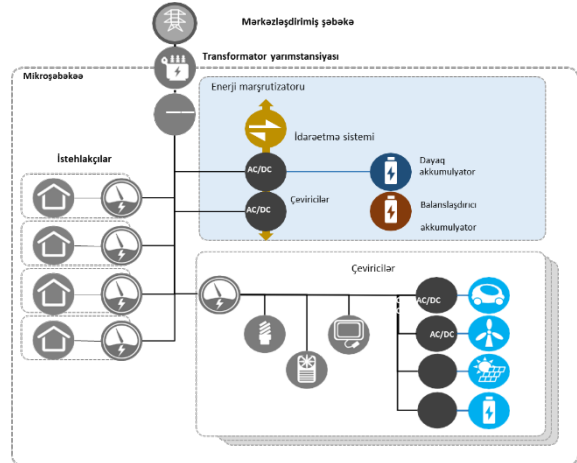


Figure 2: Block Diagram of the Network Structure with RES.

#### 5 MODELING RESULTS CONFIRMING THE RELIABILITY IMPROVEMENT OF SMART DISTRIBUTION NETWORKS

##### 5.1. Load Regime Analysis

To confirm the advantages of implementing smart technologies mentioned above, modeling studies were conducted for a real distribution network in both conventional and smart-transformed scenarios. The network schematic for both cases, developed in DiGSILENT PowerFactory, is shown in Figure 3.

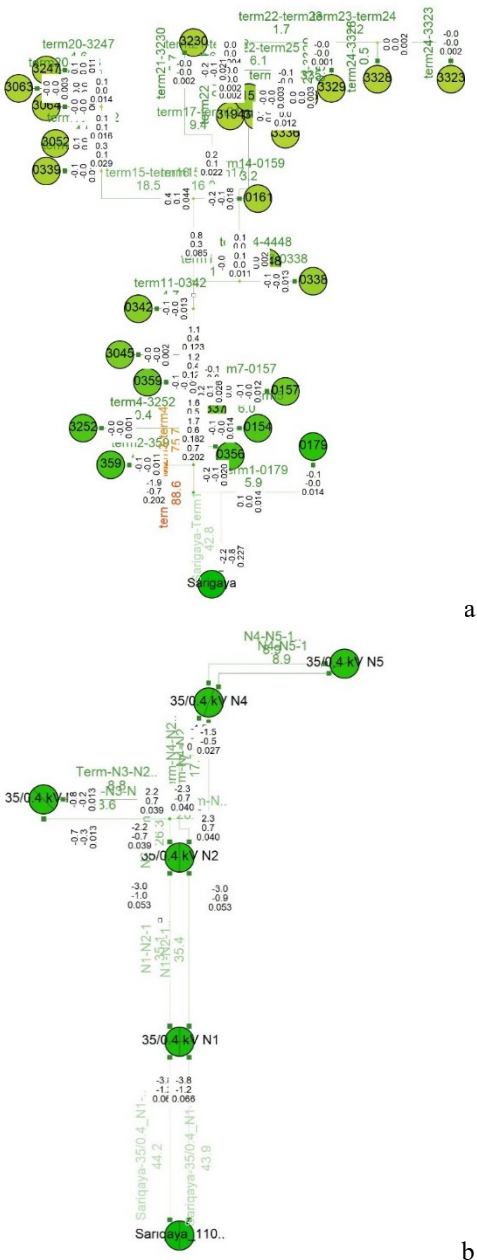


Figure 3: Schematics of the Existing and Planned High-Power Distribution Network  
 a – Existing distribution network schematic;  
 b – Distribution network schematic transformed based on smart technologies.

As shown in Figure 3, the existing 6/0.4 kV distribution network with 28 transformer substations of various capacities supplying a total demand of 12 MW (Figure 3a) was replaced by five dual-circuit 35/0.4 kV digital substations with the same total capacity (Figure 3b). This transformation led to

improvements in the reliability and quality factors of the network.

Voltage profile analyses for feeders under more than 50% overload conditions in both scenarios, conducted using DIGSILENT PowerFactory, are presented in Table 3 and Figure 4.

Table 3. Comparative Voltage Profile Analysis of Feeders in the Distribution Network

Name	Network PDP	U <sub>nom</sub> , kV	U, p.u.	U, kV	Name	Network Determined	U <sub>nom</sub> , kV	U, kV	U, p.u.
35/0.4 kV N4	Sariqaya	35,0	0,977	34,2	3323	Sariqaya	6,0	5,3	0,876
35/0.4 kV N4	Sariqaya	35,0	0,977	34,2	3328	Sariqaya	6,0	5,3	0,877
35/0.4 kV N3	Sariqaya	35,0	0,978	34,2	3329	Sariqaya	6,0	5,3	0,878
35/0.4 kV N3	Sariqaya	35,0	0,978	34,2	3335	Sariqaya	6,0	5,3	0,880
35/0.4 kV N2	Sariqaya	35,0	0,982	34,4	3336	Sariqaya	6,0	5,3	0,880
35/0.4 kV N2	Sariqaya	35,0	0,982	34,4	4448	Sariqaya	6,0	5,5	0,915

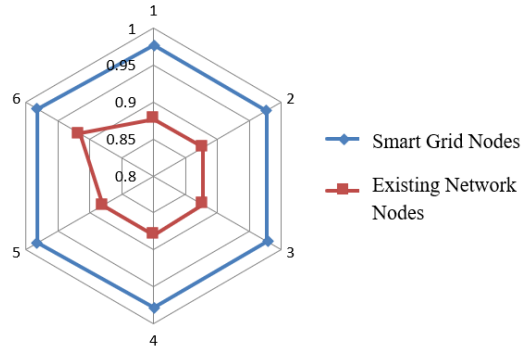


Figure 4. Voltage Profiles at Distribution Network Nodes for Both Scenarios.

According to IEC 60364 and the Electricity Usage Rules approved by the Cabinet of Ministers of the Republic of Azerbaijan, permissible voltage drops in the network are 3% for lighting and 5% for power lines [17–22]. Analysis shows that under more than 50% overload, the voltage drop at the end of feeder TM3323 in the existing network reaches 12.4%, whereas in the proposed future 35/0.4 kV digital substation scheme, the voltage drop at the 0.4 kV bus of the final transformer is only 2.4%. As seen from Table 3 and Figure 4, voltage profiles at network

nodes are significantly worse in the conventional network. Implementation of smart technologies maintains voltage levels within permissible limits. In the 6/0.4 kV scenario, voltages at the 6 kV nodes of the distribution network were  $0,882 \cdot U_{nom}$ ,  $0,878 \cdot U_{nom}$ ,  $0,880 \cdot U_{nom}$  and  $0,915 \cdot U_{nom}$ , while at the 35 kV buses, the voltages were  $0,997 \cdot U_{nom}$ ,  $0,978 \cdot U_{nom}$  vs  $0,982 \cdot U_{nom}$  respectively. In other words, the voltage profile has significantly improved.

## 5.2. Investigation of Network Voltage Stability

For the voltage stability analysis of the distribution network, two nodes were selected, and their characteristics were determined under stress conditions for both scenarios. The stress was applied over a load interval of [1..3]. The  $U - P$  characteristics of the existing and transformed networks are shown in Figures 5 and 6.

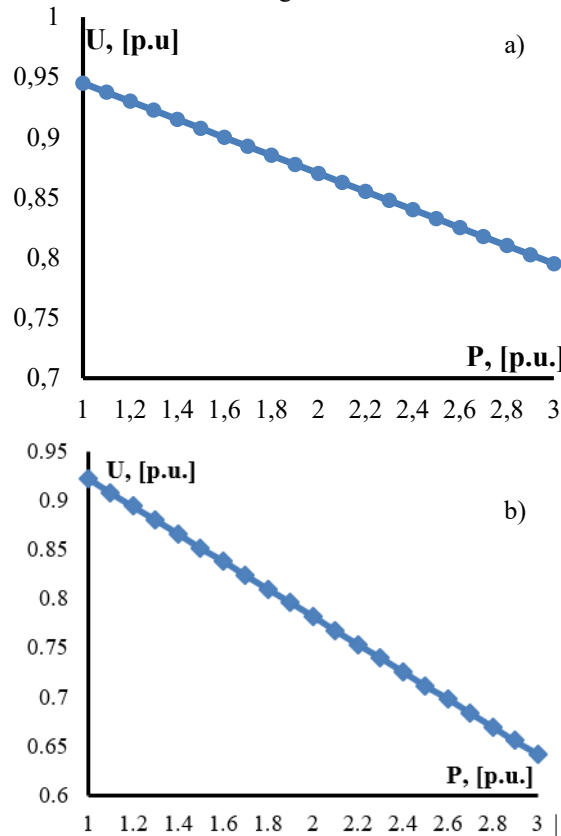


Figure 5:  $U - P$  Characteristics of the Nodes in the Existing.

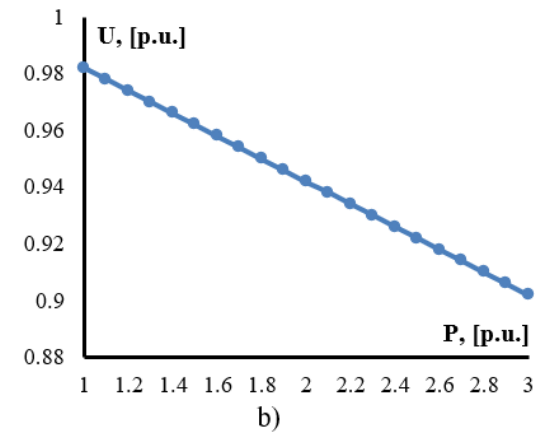
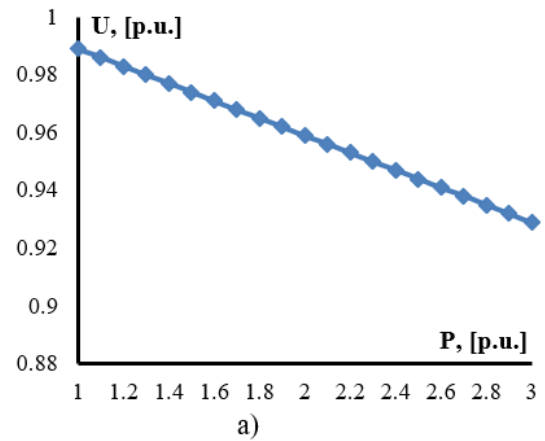


Figure 6:  $U - P$  Characteristics of the nodes of the transformed network.

As seen from Figure 5, a and b, during the loading of the existing network nodes, the voltage values at the nodes in the  $U \rightarrow P$  format were as follows.

$$[U \rightarrow P]_a \Rightarrow \begin{pmatrix} [0,95 \rightarrow 1,0] \\ [0,9 \rightarrow 1,6] \\ [0,87 \rightarrow 2,0] \\ [0,8 \rightarrow 3,0] \end{pmatrix}_a \quad \text{and}$$

$$[U \rightarrow P]_b \Rightarrow \begin{pmatrix} [0,93 \rightarrow 1,0] \\ [0,9 \rightarrow 1,15] \\ [0,78 \rightarrow 2,0] \\ [0,64 \rightarrow 3,0] \end{pmatrix}_b$$

For the considered scheme, the voltage collapse corresponding to the loading value  $P = 3,0$  occurred at 0.8 and 0.64, respectively.

As seen from Figure 6, a and b, during the loading of the transformed network nodes, the voltage values at the nodes in the  $U \rightarrow P$  format were as follows.

$$[U \rightarrow P]_a \Rightarrow \begin{pmatrix} [0, 98 \rightarrow 1, 0] \\ [0, 96 \rightarrow 1, 6] \\ [0, 94 \rightarrow 2, 0] \\ [0, 9 \rightarrow 3, 0] \end{pmatrix}_a \quad \text{and}$$

$$[U \rightarrow P]_b \Rightarrow \begin{pmatrix} [0, 99 \rightarrow 1, 0] \\ [0, 97 \rightarrow 1, 6] \\ [0, 96 \rightarrow 2, 0] \\ [0, 93 \rightarrow 3, 0] \end{pmatrix}_b$$

As can be seen in the transformed state of the distribution network, even at the most critical loading point  $P = 3, 0$ , the stability of the nodes with respect to voltage is not violated, and the network continues to operate normally. Compared to the existing network, the voltage stability margin of the transformed network has improved by 12.5% for the schemes in Figure 5,a and Figure 6,a, and by 45.3% for the schemes in Figure 5,b and Figure 6,b, relative to the critical loading point  $P = 3, 0$ . The studies have confirmed that similar results are valid for other nodes as well.

## 6 SIMULATION MODELING OF DISTRIBUTION NETWORK OPERATING MODES

### 6.1. Simulation Models of Distribution Networks

For the purpose of analyzing the operational efficiency of existing and transformed distribution electrical networks, simulation modeling for both variants was carried out in Simulink at voltage levels of 6/0.4 kV and 35/0.4 kV. The simulation schemes of the variants are shown in Figure 7 and Figure 8. As seen from Figures 7 and 8, both in the existing and transformed networks, a wind power plant with a capacity of 12 MW and a solar power plant with a capacity of 10 MW are considered.

As seen from the Simulink model of the existing 6/0.4 kV distribution network (Figure 7), the renewable sources and the system are connected to consumers later through a 6/0.4 kV distribution transformer from the 35 kV network. The 35/0.4 kV

distribution network equipped with SmartGrid technologies, on the other hand, is connected to the system via 35 kV lines and supplies electricity to consumers directly through a 35/0.4 kV distribution transformer without the 6/0.4 kV transformer (Figure 8).

As shown in Figure 8, a 2nd generation FACTS device, namely a STATCOM unit, is used to compensate for the reactive power demand of the network.

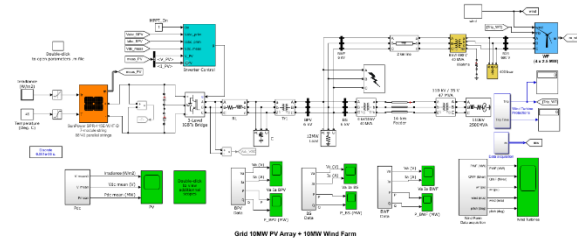


Figure 7: Simulink model of the 6/0.4 kV distribution electrical network.

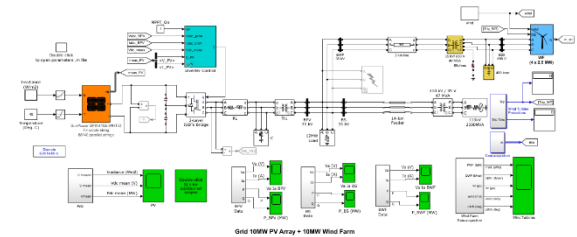


Figure 8: Simulink model of the 35/0.4 kV distribution network with SmartGrid technologies.

### 6.2. Simulation Modeling of Steady-State Operating Modes of Distribution Networks

#### 6.2.1 Simulation Results of the Operating Modes of the 6/0.4 kV Distribution Network

Computational experiments were carried out on the Simulink models of both the existing and SmartGrid-equipped distribution networks using the MATLAB software suite. The experiments were performed for both steady-state and fault (short-circuit) operating modes.

Figures 9 and 10 illustrate the results of the computational experiments for the steady-state mode in the existing 6/0.4 kV distribution network with the inclusion of solar and wind power plants. As seen from Figure 9, depending on the variation of solar

radiation, the active power delivered from the solar plant bus to the consumer and the system ranges from 1.5 to 6 MW, while the reactive power delivery remains around zero. The active power decreases from 7 MW to 1.5 MW as the radiation drops over the time interval of 0.4–1.15 seconds.

A similar behavior is observed in Figure 10 in terms of voltage and current variations. With the connection of the solar panel, the voltage regime stabilizes approximately within 0.8 seconds, and the

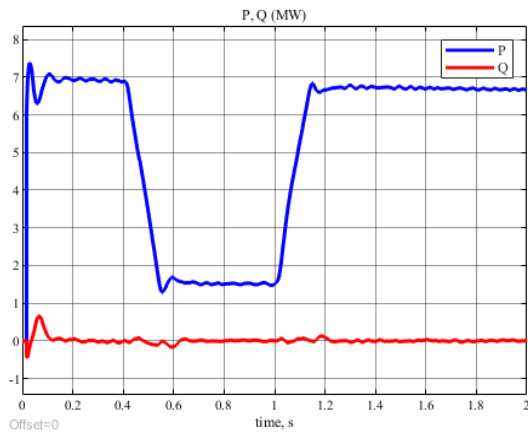


Figure 9: Variation curves of active and reactive power in the steady-state regime of a solar power plant in a 6/0.4 kV distribution network

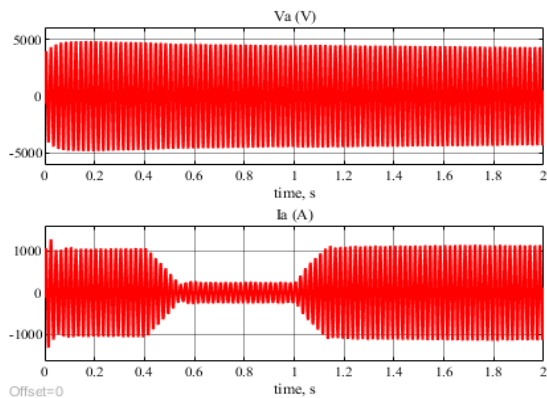


Figure 10: Variation curves of voltage and current in the steady-state regime of a solar power plant in a 6/0.4 kV distribution network

current recovery occurs similarly to the changes in active power.

Based on analogous reasoning and analyses, we can present the results of the computational experiment for the steady-state mode at the wind power plant buses. As seen in Figure 11, the mode stabilizes approximately after 2 seconds, with the active power output of the wind plant reaching 11

MW. The reactive power, however, is of opposite sign, meaning that reactive power flows from the system into the network. This is necessary to cover the reactive power demand of both the wind unit and the network.

The curves of current and voltage variations

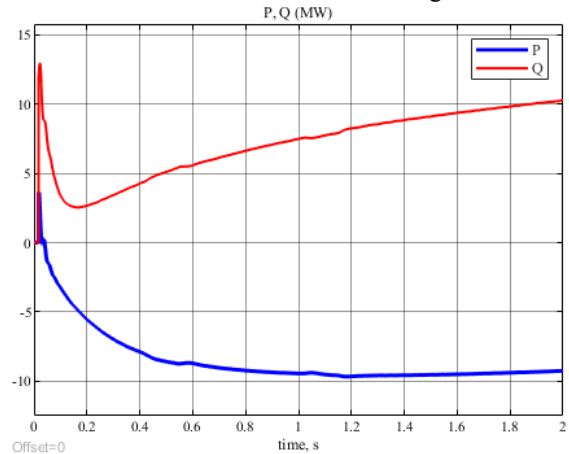


Figure 11: Variation curves of active and reactive power in the steady-state regime of a wind power plant in a 6/0.4 kV distribution network

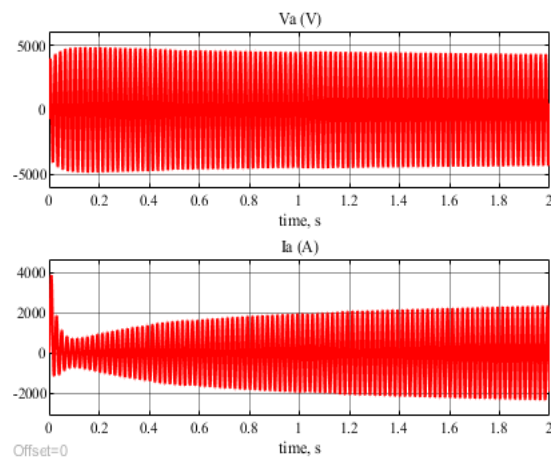


Figure 12; Variation curves of voltage and current in the steady-state regime of a wind power plant in a 6/0.4 kV distribution network

are shown in Figure 12, and as can be seen, the mode stabilization occurs within approximately 2 seconds.

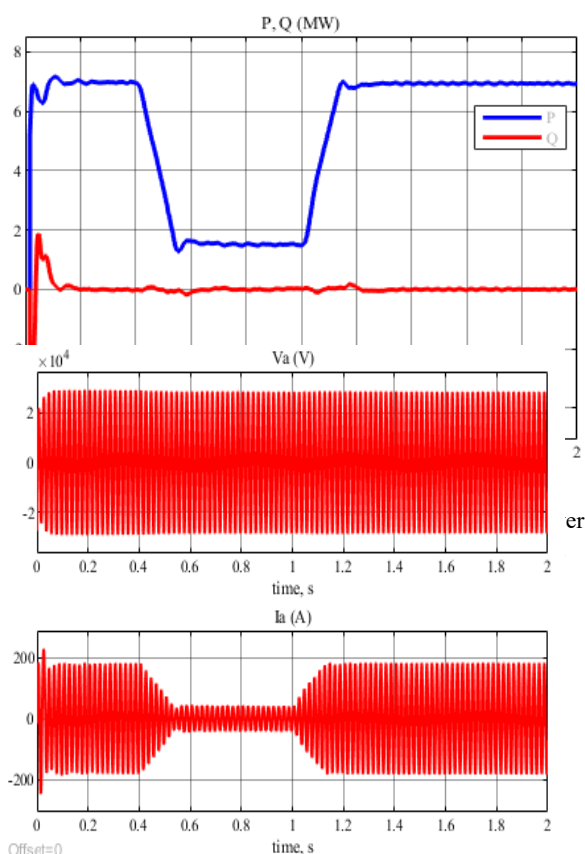
### 6.2.2. Simulation Results of the Operating Modes of the 6/0.4 kV Distribution Network

After studying the steady-state regimes of the existing 6/0.4 kV distribution network, the results of the simulation reports for the transformed 35/0.4 kV distribution network with SmartGrid technology are analyzed. The computational experiments were

carried out based on the distribution network simulation model shown in Figure 8. In Figure 13, the variation curves of active and reactive power in the steady-state regime are depicted, while Figure 14 illustrates the variation curves of voltage and current in the steady-state regime.

As seen from Figure 13, the active power transmitted from the busbars of the solar power plant to the system settles after approximately 0.1 s, then decreases to 1.6 MW at 0.4 s and remains at this level for a duration of 0.55–1 s. Within 0.15 s, it rises again to the level of 1.6 MW, where it stabilizes. The value of the reactive power, after a transient process lasting 0.12 s, stabilizes at zero. The reactive power required by the grid is supplied through the STATCOM device.

Analogous reasoning can also be made for the voltage and current values at the busbars of the solar plant (Figure 14). Thus, the voltage and current values settle in a shorter time — the voltage in approximately 0.05 s and the current in 0.03 s. This indicates that the operating mode stabilizes more quickly compared to the existing 6/0.4 kV network scheme (0.8 s versus 0.05 s).



Şəkil 14: Variation curves of voltage and current in the steady-state regime of a solar power plant in a 35/0.4 kV distribution network with SmartGrid technology.

Figures 15 and 16 respectively illustrate the power output, voltage, and current variation patterns of a wind power plant in a 35/0.4 kV distribution network. The analysis of the obtained dependencies once again confirms the advantages of a Smart Grid-based distribution network.

## 7 CONCLUSION

1. Modernization and efficiency improvement of distribution electrical networks is possible not only

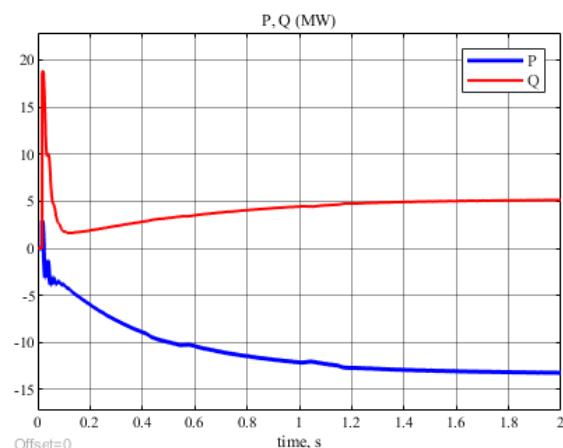


Figure 15: Variation curves of active and reactive power in the steady-state regime of a wind power plant in a 35/0.4 kV distribution network with SmartGrid technology.

through the renewal of technical equipment but also

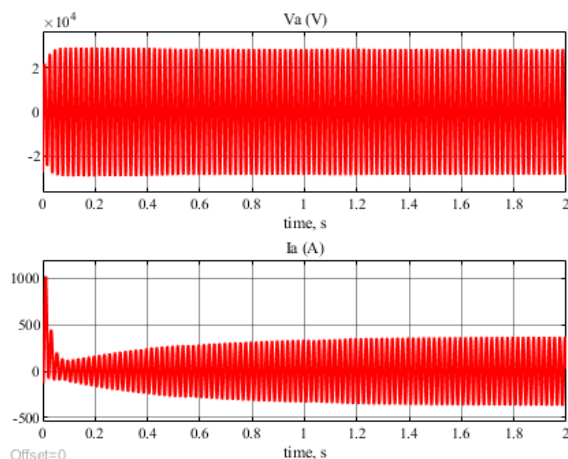


Figure 16.: Variation curves of voltage and current in the steady-state regime of a wind power plant in a 35/0.4 kV distribution network with SmartGrid technology.

by changing management principles. Traditional centralized systems are insufficiently effective in the face of increasing energy demand, the instability and uncertainty of renewable energy generation, and reliability issues. Therefore, the implementation of Smart Grid technologies should be considered a key solution for ensuring energy security, improving reliability, and strengthening economic resilience.

2. Actively involving consumers in the energy management process—transforming them from passive users to active participants through DSM (Demand Side Management) and DR (Demand Response) approaches—plays a crucial role in reducing peak loads, optimizing energy flows, improving power quality indicators, and minimizing losses. This process should be supported by dynamic tariffs, incentive mechanisms, and energy storage technologies.

3. Since the voltage stability indices of existing distribution networks differ significantly from IEEE standards, the introduction and integration of SmartGrid technologies emerge as an important task. The study of voltage stability in existing and SmartGrid-enabled distribution networks confirmed that the voltage stability reserve is significantly increased.

4. To evaluate the efficiency of SmartGrid-enabled distribution networks, computational experiments based on Simuling modeling were conducted for steady-state regimes of both existing and transformed networks integrated with wind and solar power plants. The results confirmed the relevance of creating SmartGrid networks and gradually transforming existing networks through modernization.

## REFERENCES

- Voropaj, N. I., Efimov, D. N., Kolosok, I. N., Kurbackij, V. G., 2012. *Koncepciya intellektual'noj elektroenergeticheskoy sistemy s aktivno-adaptivnoj set'yu* (Red. 5.0, s. 45–67). Moskva: FSK EES.
- Kobec, B. B., Volkova, I. O., 2010. *Innovacionnoe razvitie elektroenergetiki na baze koncepcii Smart Grid*. 208 s.
- Savina, N. V., 2014. *Innovacionnoe razvitie elektroenergetiki na osnove tekhnologij Smart Grid: uchebnoe posobie* (s. 45–60). Blagoveshchensk: Amurskij gos. un-t.
- Khaleel, M., Yusupov, Z., Alfal, B., Güneşer, M. T., Nassar, Y., El-Khozondar, H., 2024. Impact of Smart Grid Technologies on Sustainable Urban Development. *International Journal of Electrical Engineering and Sustainability*, 2(2), 62–82.
- Hohlov, A., Mel'nikov, YU., Veselov, F., 2018. *Raspredeleonnaya energetika v Rossii: potencial razvitiya* (s. 5–80). Energeticheskij centr «Skolkovo».
- Teksler, A.L., 2018. *Cifrovaya energetika: ot avtomatizacii processov k cifrovoj transformacii otrasli*. *Energeticheskaya politika*, 5, 5–30.
- Guliyev H.B., Huseynov N.R., 2024. Improving the efficiency of distributive networks with the application of green technologies. *Reliability: Theory & Applications*, Special Issue No.6(81), Part-3, Vol.19, USA, San Diego, pp.1445-1456.
- Rahmanov. N.R., Guliyev. H.B., Ibrahimov. F.Sh., Mammadov. Z.A.. 2024. Optimal Sizing of Hybrid AC/DC Distributed Generation Systems with On-Site Renewables for Off-Grid Power Supply to Remote Areas, *Energy Systems Research*, Vol. 7, No. 4, pp.76-83
- Hossain, M. A., Islam, M. R., Amin, M. R., Rahman, M. A., 2025. Smart Grids and Sustainability: The Impact of Digital Technologies. *Energies*, 18(9), 2149.
- Rakhmanov, N.R., Kurbatsky, V.G., Guliyev, H.B., Tomin, N.V., Rakhmanov, R.N., 2018. Analysis and modeling of harmonic distortions in consumer's distribution networks, containing a powerful non-linear load. Rudenko International Conference “Methodological problems in reliability study of large energy systems” (RSES 2018). Irkutsk, Russia, July 2-7, 2018, E3S Web of Conferences 58, 03015, pp. 1-5
- International Electrotechnical Commission (IEC). (2003–2020). IEC 61850: Communication Networks and Systems in Substations. Geneva: IEC.
- Reza, S. M. S., Hossain, M. A., Rahman, M. A., 2021. IEC 61850 communication-based dual-stage load frequency control for microgrids. *International Journal of Electrical Power & Energy Systems*, 129, 107563
- Yan, X., Liu, Z., Li, Y., 2024. How do dynamic electricity tariffs and different grid charge designs affect consumer participation in demand response programs? *Renewable and Sustainable Energy Reviews*, 169, 113228.
- Rahmanov, N.R., Guliyev, H.B., Ibrahimov, F.Sh., Mammadov, Z.A., 2024. Hybrid AC/DC with Renewable Sources for Power Supply of Remote Locations, *Energetik*, No. 11, Moscow, pp. 27-33.
- Guliyev, H.B., Huseynov, N., 2024. Improving The Efficiency Of Distributive Networks With The Application Of Green Technologies. *Reliability Theory and Applications*, 19(Special issue 6), pp. 1445–1456
- Ilyushin, P.V., Shepvalova, O.V., Filippov, S.P., Nekrasov, A.A., 2022. The effect of complex load on the reliable operation of solar photovoltaic and wind power stations integrated into energy systems and into off-grid energy areas. *Energy Reports*. Vol. 8. pp. 1515-1529.
- Wang, J., Zhang, Y., Li, K., 2023. Time-based pricing and electricity demand response: A review of consumer perspectives and policy implications. *Renewable and Sustainable Energy Reviews*, 157, 112019.
- Zhang, J., Liu, Z., 2023. Decentralized and coordinated scheduling model of interconnected multi-microgrid

- based on virtual energy storage. *Applied Energy*, 307, 118228.
- Rahmanov, N.R., Kurbatskiy, V.G., Guliyev, H.B., Tomin, N.B., Mammadov, Z., 2017. Probabilistic assessment of power system mode with a varying degree of wind sources integration. *E3S Web of Conferences*, Volume 25 (2017), *Methodological Problems in Reliability Study of Large Energy Systems (RSES 2017)*, Bishkek, Kyrgyzstan, September 11-15, pp.1-5
- Hashimov, A.M., Rahmanov, N.M., Tabatabaei, N.M., Guliyev, H.B., Ibrahimov, F.Sh., 2020. Probabilistic evaluation of voltage stability limit of power system under the conditions of accidental emergency outages of lines and generators. *IJTPE Journal International Journal on Technical and physical problems of engineering (IJTPE)*, Issue 43, Vol. 12, No. 2, pp.40-45.
- Parvania, M., Dallinger, D., Auer, H., 2021. Prosumer-based electricity markets: Modeling, challenges, and opportunities. *Applied Energy*, 283, 116310.
- Kundur, P., 2017. *Power System Stability and Control*. — McGraw-Hill.
- Benson, S., Zhukov, S., 2020. *Smart Grid: intellektual'nye energosistemy*.