



Shahar iste'molchilarining elektr ta'minoti ishonchliligi: hozirgi muammolar, strategik yechimlar va istiqbolli yo'nalishlar

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Dolzarbli: energiya tizimining ishonchliligini baholashda sifat ko'rsatkichlaridan miqdoriy, samaradorlikka asoslangan tartibga solishga o'tish global energetika sohasida dolzarb masalaga aylandi. SAIFI/SAIDI kabi standartlashtirilgan ko'rsatkichlarning mavjudligi energiya tizimlarida ishonchlilikni oshirishga bevosita rag'batlantiruvchi mexanizm sifatida xizmat qiladi. Bu yondashuv, ayniqsa, elektr energiyasiga bo'lgan talab ortib borayotgan sharoitda, iste'molchilar uchun uzluksiz va barqaror ta'minotni ta'minlashda muhim ahamiyat kasb etadi.

Maqsad: energiya tizimlarining ishonchliligini baholash va uni oshirishga qaratilgan standartlashtirilgan ko'rsatkichlarning (SAIFI, SAIDI va boshqalar) ahamiyatini aniqlash, ularning me'yoriy-huquqiy bazaga integratsiyalashuv jarayonini tahlil qilish hamda ushbu ko'rsatkichlarning elektr ta'minoti kompaniyalari faoliyatiga strategik ta'sirini asoslash.

Usullari: xalqaro va milliy me'yoriy hujjatlarining (IEEE, mintaqaviy regulyatorlar) tahlili; SAIFI, SAIDI va boshqa ko'rsatkichlarning qo'llanilish amaliyoti bo'yicha statistik ma'lumotlarni o'rganish; Elektr ta'minoti kompaniyalarining investitsiya siyosatiga ushbu ko'rsatkichlarning ta'sirini baholash; Operatsion natijalar va strategik rejalashtirishdagi o'zgarishlarni tahlil qilish.

Natijalar: SAIFI/SAIDI kabi standart ko'rsatkichlar energetika sohasida sifat baholashdan samaradorlikka asoslangan boshqaruvga o'tishni jadallashtirmoqda; Ushbu ko'rsatkichlar orqali elektr ta'minoti kompaniyalari ishonchlilikni oshirishga yo'naltirilgan kapital qo'yilmalarga rag'batlantiriladi; Standartlashtirilgan ko'rsatkichlarning keng qo'llanilishi ishonchlilikni oddiy operatsion ko'rsatkichdan strategik biznes imperativiga aylantirib, investitsiya qarorlariga, operatsion amaliyotga va moliyaviy barqarorlikka bevosita ta'sir ko'rsatadi. o'tish davrida va O'zbekiston EETda shamol va quyosh qurilmalari bilan bozor munosabatlarini joriy etish davrida, shamol va quyosh qurilmalarining beqaror ishlashini samarali muvozanatlash uchun talabni operativ boshqarish usullaridan foydalanish zarur. Tahlil asosida talabni boshqarish usullaridan foydalanish bo'yicha tegishli takliflar kiritiladi.

Kalit so'zlar: ishonchlilik, aqlli tarmoqlar, standartlashtirilgan ko'rsatkichlar, investitsiyalar, modern-izatsiya, elektr tarmoqlari kompaniyalari, kiberxavfsizlik, texnik nosozliklar, elektr tar-moqlari ob'ektlariga texnik xizmat ko'rsatish.

Надежность электроснабжения городских потребителей: текущие вызовы, стратегические решения и перспективы будущего

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Актуальность: современные энергосистемы находятся под растущим давлением из-за увеличения нагрузки, интеграции возобновляемых источников энергии и стареющей инфраструктуры. В этих условиях надёжность электроснабжения становится ключевым фактором устойчивого развития. Переход от качественной оценки к количественному, основанному на производительности регулированию (например, использование показателей SAIFI/SAIDI) отражает глобальную тенденцию в энергетическом секторе. Этот подход позволяет не только объективно оценивать эффективность систем электроснабжения, но и стимулирует предприятия к постоянному улучшению качества услуг.

Цель: провести анализ роли и значения стандартизированных показателей (SAIFI, SAIDI и др.) в оценке надёжности электроснабжения и показать, каким образом их интеграция в регуляторные рамки влияет на инвестиционную политику, операционные решения и стратегическое развитие энергокомпаний.

Методы: анализ международных и национальных нормативных документов (IEEE, региональные регуляторы);

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сравнительный анализ применения показателей SAIFI/SAIDI в различных энергосистемах; изучение статистических данных о надёжности электроснабжения и достижении целевых показателей; оценка влияния внедрения количественных показателей на инвестиционные решения и операционную практику энергокомпаний.

Результаты: показано, что внедрение стандартизированных показателей SAIFI/SAIDI способствует переходу от реактивного управления к проактивной стратегии повышения надёжности; установлено, что постоянная интеграция этих показателей в регуляторную базу превращает надёжность из операционной задачи в стратегический бизнес-приоритет; подтверждено, что использование количественных показателей напрямую влияет на привлечение инвестиций, улучшение операционных процессов и повышение конкурентоспособности энергокомпаний.

Ключевые слова: надёжность, умные сети, стандартизированные показатели, инвестиции, модернизация, электросетевые компании, кибербезопасность, технические сбои, обслуживание электросетевого хозяйства.

Reliability of Urban Power Supply: Current Challenges, Strategic Solutions, and Future Prospects

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Relevance: ensuring reliable power supply has become a critical requirement in modern energy systems due to increasing demand, the integration of renewable energy sources, and aging infrastructure. The transition from qualitative to quantitative, performance-based regulation—exemplified by standardized metrics such as SAIFI and SAIDI—represents a significant paradigm shift in the power sector. This approach promotes objective assessment of power system performance and creates strong incentives for utilities to improve service reliability, thereby reducing societal and economic risks associated with outages.

Aim: to analyze the role and significance of standardized reliability metrics (SAIFI, SAIDI, etc.) in evaluating power system performance and to assess their impact on regulatory frameworks, utility investment strategies, and operational practices.

Methods: review of international and national regulatory frameworks (IEEE, regional regulatory bodies); comparative analysis of the implementation of SAIFI/SAIDI metrics across various power systems; evaluation of statistical data on reliability performance and compliance with established targets; assessment of the influence of quantitative performance metrics on investment decisions, operational improvements, and strategic positioning of utilities.

Results: demonstrated that standardized metrics such as SAIFI/SAIDI drive a shift from reactive to proactive reliability management; established that integration of these metrics into regulatory frameworks transforms reliability into a strategic business imperative; confirmed that quantitative performance-based regulation influences investment allocation, enhances operational practices, and improves the competitive positioning of utilities in the energy market.

Keywords: reliability, smart grids, standardized indicators, investments, modernization, electric grid companies, cybersecurity, technical failures, maintenance of electric grid facilities.

Introduction

Reliability of power supply is the foundation of modern society, ensuring the operation of critical infrastructure, industries, and the daily life of citizens. However, contemporary power systems face a number of increasing and complex challenges. These include an aging infrastructure inherited from previous decades, a rise in the frequency and intensity of extreme weather events, and the inherent variability associated with the growing integration of renewable energy sources (RES). In addition, there is an unprecedented growth in electricity demand from emerging energy-intensive sectors, particularly electric vehicle charging and data centers, which are rapidly altering load profiles. Traditional approaches focused on failure prevention are no longer sufficient. The current situation necessitates a fundamental reassessment of strategies, with an emphasis on comprehensive resilience. This concept not only implies minimizing the frequency and duration of outages but also encompasses the ability of the system to rapidly recover and maintain the operation of critical services following major disruptions. The economic impacts of power outages are significantly higher than commonly perceived, as indirect costs often exceed direct losses. This underscores that investments in enhancing resilience can yield substantial economic and social benefits.

1. Методы и материалы (Methods and materials)

Quantitative assessment of power system reliability is based on a set of standardized indicators widely employed by international organizations such as the Institute of Electrical and Electronics Engineers (IEEE), as well as various national and regional regulatory authorities. These metrics provide



a quantitative foundation for evaluating different aspects of power supply performance and service quality.

- **SAIFI (System Average Interruption Frequency Index)** This index measures the average number of interruptions experienced by a typical customer within the system during a given reporting period, typically on an annual basis. It is calculated by dividing the total number of customer interruptions (the sum of all outage events experienced by customers) by the total number of customers served by the system. For example, regulatory benchmarks in certain jurisdictions, such as Kazakhstan, set the SAIFI target at 3.7 interruptions per year.

- **SAIDI (System Average Interruption Duration Index): SAIDI (System Average Interruption Duration Index):** SAIDI quantifies the total cumulative duration of outages for the average customer in the system over a specified period of time. The calculation involves summing the total duration of outages for all customers (the duration of each outage multiplied by the number of affected customers) and dividing this by the total number of customers served. Some regulatory documents specify a normative value of 3.7 hours per year.

- **CAIDI (Customer Average Interruption Duration Index):** This indicator represents the average time required to restore service following an outage, specifically for those customers who were actually affected by the interruption.

- **MAIFI (Momentary Average Interruption Frequency Index):** MAIFI measures the average frequency of momentary interruptions—typically defined as outages lasting five minutes or less—experienced by each served customer. It is important to note that not all regulatory authorities have established specific benchmark values or standards for MAIFI, although utilities may be required to report this metric where their infrastructure allows for its measurement.

- **ASAI (Average Service Availability Index):** ASAI is the ratio of the total number of customer-hours during which service was available over a given period to the total number of customer-hours demanded. Sometimes referred to as the service reliability index, it provides an overall measure of system availability.

The existence of specific regulatory benchmarks, such as the SAIFI/SAIDI value of 3.7 found in some regulatory frameworks, underscores a significant shift from qualitative assessments toward quantitative, performance-based regulation in the energy sector. This quantitative approach directly incentivizes utilities to invest in enhancing reliability, as persistently low performance can result in regulatory penalties or significant negative public perception. The fact that many electric utilities still struggle to meet SAIFI targets highlights that achieving these benchmarks remains a continuous and complex challenge, even with ongoing capital investments. The widespread adoption of these standardized indices and their deep integration into regulatory frameworks have fundamentally transformed reliability from a purely operational concern into a strategic business imperative. This transformation directly influences utility investment decisions, shapes operational practices, and impacts financial outcomes, making reliability a core element of strategic planning and competitive positioning for utilities.

The reliability of power supply is influenced by a variety of factors, which can be grouped into several key categories:

- **Technical Failures and Aging Infrastructure:** Approximately 12% of outages are directly attributable to outdated and inadequate energy infrastructure. This includes overloaded sections of the grid, unstable operation of voltage control systems, and overall equipment degradation.

- **Natural Disasters and Extreme Weather Events:** The overwhelming majority of outages—86.6%—are caused by extreme weather conditions or natural disasters. These include thunderstorms, high winds, icing, floods, and other adverse climatic events. The increasing frequency and severity of such phenomena due to climate change makes them an escalating and primary concern.

- **Human Factors and External Impacts:** Unprofessional actions by operational personnel, accidents, and deliberate attacks on infrastructure (e.g., cyberattacks) also make a significant contribution to unreliability. Notably, the number of attacks on electrical infrastructure increased by 71% in 2022 compared to 2021.

- **Cybersecurity Threats:** The growing digitalization of grid infrastructure increases the risk of cyberattacks that can cause outages. Multi-layered security systems, the use of AI for anomaly detection, and regular security audits are key counter-measures.

- **Rising Demand from Charging Stations and AI Data Centers:** The rapid development of electric vehicle charging stations and artificial intelligence-driven data centers is driving an unprecedented surge in electricity demand. Projections indicate that these facilities could increase global electricity consumption by approximately 100 GW by 2030—equivalent to the consumption of 75 million U.S. households. Without adequate measures, this imbalance could lead to a substantial increase in outages, potentially by a factor of 100 by 2030.



2. Results and discussion

Traditional Approaches:

- Preventive and Predictive Maintenance: Preventive maintenance involves scheduled activities to prevent equipment failures, whereas predictive maintenance leverages real-time data and analytics to anticipate potential failures, enabling condition-based servicing rather than fixed schedules.
- System Redundancy and Reserve Capacity: Deploying backup systems or components ensures uninterrupted operation in the event of a failure. Decentralized energy resources inherently provide higher reliability, as the failure of one among many small sources is easier to compensate for than the loss of a single large power plant.
- Modernization and Hardening of Infrastructure: Upgrading aging networks addresses deterioration issues and facilitates the integration of modern technologies. Physical reinforcement of infrastructure protects the grid from severe damage, particularly during natural disasters, through strengthened lines, supports, and substations. Underground cable installation is also an effective method of shielding against environmental and mechanical impacts.

Advanced Technologies and Innovations:

- Smart Grids: Smart grids collect real-time data, enable two-way communication, and automate processes, thereby improving efficiency, reliability, and financial performance. They can detect faults and possess self-healing mechanisms.
- Self-Healing Network Systems (FLISR, AFS): These systems automatically detect outages, isolate damaged sections, and reroute electricity to restore service to unaffected areas in under a minute. Their implementation significantly reduces downtime (SAIDI) and enhances customer satisfaction.
- Online Monitoring and Intelligent Sensors: A vast network of sensors throughout the grid provides real-time data on voltage, current, and temperature, essential for predictive maintenance and situational awareness.
- Artificial Intelligence (AI) and Machine Learning (ML): AI and ML algorithms analyze vast datasets to predict potential failures, simulate contingencies, and optimize investment decisions.
- Digital Twins: Virtual models of physical systems, created from real-time data, support maintenance planning, system design, and operational control.
- 5G Connectivity: 5G technology delivers ultra-reliable, low-latency communications, critical for real-time grid monitoring, the deployment of digital twins, and high-sensitivity control mechanisms.

The effectiveness of these technologies is interdependent. For instance, AI-driven predictive maintenance relies on sensor data, while digital twins use this data for accurate modeling. The implementation of 5G provides the high-speed, low-latency backbone required for these data-intensive applications to function in real time.

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