ENERGY EFFICIENCY MANAGEMENT IN SMART DEVICES

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Abstract: This research paper provides an in-depth analysis of the theoretical foundations of energy consumption management, current technologies, and their practical significance. The study highlights the role of artificial intelligence technologies in the development of smart networks, particularly in ensuring efficient energy distribution and network stability. Furthermore, it explores the potential of employing AI algorithms in smart devices to enhance energy efficiency management.

Keywords: Intelligent networks, energy system, DSM, energy sources, PRISMA, distributed energy resources, mIoT, artificial intelligence

Аннотация: В данной исследовательской работе представлен углубленный анализ теоретических основ управления энергопотреблением, современных технологий и их практического значения. В исследовании подчеркивается роль технологий искусственного интеллекта в развитии интеллектуальных сетей, в частности, в обеспечении эффективного распределения энергии и стабильности сети. Кроме того, в нем исследуется потенциал использования алгоритмов искусственного интеллекта в интеллектуальных устройствах для повышения эффективности управления энергопотреблением.

Ключевые слова: Интеллектуальные сети, энергетическая система, DSM, источники энергии, PRISMA, распределенные энергетические ресурсы, Массачусетский технологический институт, искусственный интеллект

Annotatsiya. ushbu tadqiqot ishida energiya sarfini boshqarishning nazariy asoslari, mavjud texnologiyalar va ularning amaliy ahamiyati chuqur tahlil qilingan. Tadqiqot sun'iy intellekt texnologiyalarining aqlli tarmoqlarni rivojlantirishda, xususan, energiyani samarali taqsimlash va tarmoq barqarorligini ta'minlashdagi rolini ta'kidlaydi. Bundan tashqari, u energiya samaradorligini boshqarishni kuchaytirish uchun aqlli qurilmalarda AI algoritmlarini qo'llash imkoniyatlarini o'rganadi.

Kalit so'zlar: aqlli tarmoqlar, energiya tizimi, DSM, energiya manbalari,

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PRISMA, taqsimlangan energiya manbalari, mit, sun'iy intellekt

Introduction

The application of artificial intelligence (AI) algorithms for energy management in smart devices has become one of the most pressing issues today, given the need for efficient use of energy resources, reduction of excessive costs, and the promotion of environmental sustainability. The rapid growth in the number of devices in domains such as IoT technologies, smart homes, and Industry 4.0 has necessitated their optimal management. AI algorithms enable real-time data analysis, automated control of energy consumption, forecasting, and adaptive decision-making. This not only enhances energy efficiency but also ensures user convenience, economic savings, and environmental safety.

According to the Presidential Decree of the Republic of Uzbekistan No. PF–6079, signed on October 5, 2020, regarding the "Digital Uzbekistan – 2030" Strategy, it is stipulated that artificial intelligence, digital technologies, and smart systems should be introduced to increase efficiency across various sectors, including the energy system[1]. Additionally, Resolution No. PQ–3012 dated May 26, 2017, on "Measures for the Implementation of Energy-Saving Technologies and the Expansion of the Use of Alternative Energy Sources," outlines initiatives for improving energy efficiency and enhancing systems for energy monitoring and control[2].

Furthermore, Presidential Decree No. PQ–5177 of October 26, 2021, "On Measures for the Development of Artificial Intelligence Technologies," sets forth the tasks of advancing AI and integrating it into various sectors, including industry and energy systems[3].

Theoretical Foundations of Energy Consumption Management

Demand management, a recent advancement in smart grid technologies, has enabled communication between energy suppliers and consumers. Demand-side energy management (DSM) helps reduce energy procurement costs and associated penalties by continuously monitoring energy consumption and managing device operation schedules. Demand Response (DR), Distributed Energy Resources (DER), and Energy Efficiency (EE) represent the three main categories of DSM activities, and their development is accelerating as a result of technological progress in smart grid systems.

Over the past century, energy demand has grown significantly in parallel with the global population. This surge is closely linked to increased activity in business, industry, agriculture, and especially the widespread adoption of electric vehicles. The dramatic rise in global energy consumption has made it increasingly challenging to address issues such as identifying the characteristics of home appliances, integrating intermittent renewable energy sources, classifying loads,

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managing various constraints, implementing dynamic pricing, and segmenting consumers [4].

Demand-Side Management (DSM) refers to a set of measures aimed at modifying consumer energy usage patterns, with the primary goal of optimizing the performance of the energy system. In the context of smart grids, DSM becomes a critical component for enhancing the efficiency, stability, and economic viability of the entire energy infrastructure. This study examines the challenges, solutions, and development prospects of energy consumption management within smart grid environments[20].

Currently, the management of energy consumption faces the following key challenges:

1. Unusual and High Load Demand. One of the primary issues is the instability of energy consumption, which leads to peak load periods during certain hours. This results in increased costs for energy production and distribution.

2. Integration of New Energy Sources (NES). The intermittent nature of renewable energy sources such as solar panels and wind turbines creates difficulties in planning energy consumption and distribution. This situation demands flexibility not only from energy providers but also from consumers.

3. Technical Constraints. The existing infrastructure of electric grids—including transformers, transmission lines, and control equipment—is often not adequately adapted for the integration of new technologies such as smart meters and consumer energy management systems.

4. Lack of Coordination Among Market Participants. The energy market consists of various stakeholders including producers, suppliers, consumers, and regulatory bodies, who do not always engage in effective collaboration. This lack of coordination complicates the consistent implementation of DSM technologies[5].

Analysis of Scientific Research on Energy Consumption Management Technologies

Over the past century, the rapid growth of the global population has led to a significant increase in global energy demand. According to research by Martínez-Lao and colleagues, by 2030, global electricity consumption is projected to rise by more than 50%. This upward trend is primarily driven by expanded business activity, industrial processes, agricultural technologies, and the widespread use of electric vehicles.

The growth in global energy consumption has, in turn, posed major challenges in terms of controlling energy losses, ensuring system reliability, and maintaining energy efficiency and security. In response to these challenges, Fang et al. and Xu et al. proposed the concept of the "Smart Grid." Smart grids are characterized by

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features such as self-monitoring, self-healing, wide-scale control, adaptability, and distributed operation. These characteristics enhance the efficiency of the transmission process from energy production sources to end consumers[6].

The main research topics reviewed in the literature include:

- The global increase in energy consumption and its primary drivers: population growth, and the expansion of the industrial and transportation sectors.
- Electricity consumption forecasts for 2030: projections provided by international organizations and researchers.
- Challenges in energy systems: difficulties related to energy losses, system reliability, and security.
- Smart grid technologies: mechanisms for self-management and self-restoration, system adaptability, and optimization of energy transmission processes.
- The role of smart grids in energy management: improving efficiency and ensuring optimal use of resources.

These studies indicate that the future of energy systems lies in intelligent management and highly automated technologies. Further analysis is required regarding the large-scale implementation of digital technologies in the energy sector. The hardware and software components of smart grids provide utility companies with the ability to quickly detect and resolve issues that may arise between consumers and production enterprises, thereby ensuring the stability and quality of power supply.

Research in the field of electricity management demonstrates the application of both supply-side and demand-side control mechanisms aimed at reducing energy costs and altering the load profile. Supply-side management focuses on making the processes of energy generation, transmission, and distribution more efficient from a practical perspective. According to studies by Haffaf and others, the key benefits of DSM include the ability to provide efficient energy generation at minimal operational cost, meet existing energy demand without constructing new infrastructure, and reduce the environmental impact. However, the success of DSM is highly dependent on fuel price volatility, which significantly affects systems based on thermal generator management[7].

The research on Demand Side Management (DSM) focuses on reducing energy costs and associated penalties by continuously monitoring energy consumption and providing efficient management of device operation schedules. Dranka and Ferreira emphasize the key achievements of DSM, such as reducing peak loads, controlling consumption levels, analyzing user profiles, reducing carbon dioxide emissions, and providing consumers with the ability to choose their energy source. Gellings, along with Maharjan and colleagues, identify the main

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objective of DSM as regulating network load and minimizing environmental damage from the outset of the concept's development.

Energy Management Systems (EMS) implementation experiences from the UK (Warren), China (Ming and others), North America (Wang and others), and Turkey (Alasseri and others) are noteworthy. The results of these studies demonstrate that EMS are among the most effective tools for reducing energy costs while maintaining system stability. However, the literature also highlights several economic, technical, and organizational constraints to the full and effective implementation of EMS in less developed countries.

Research by Cappers and colleagues explores the potential benefits of DSM systems for electrical supply systems. Their findings show that DSM systems can enhance system efficiency, reduce losses, and slow equipment wear, thus providing secondary benefits.

There is a growing need for systems that can manage energy sources according to variable demand periods to quickly and effectively reduce costs. Jabir and colleagues illustrate the use of programmable logic controllers (PLC), supervisory control and data acquisition systems (SCADA), building management systems (BMS), energy management systems (EMS), and automation systems to achieve this goal.

Additionally, the electrical equipment market is undergoing significant changes. The primary goal is to minimize peak demand by maximizing the use of available resources. Phuangpornpitak and Tia emphasize the importance of dynamic pricing mechanisms in energy tariffs and how tariffs and social factors are crucial in encouraging consumers to shift energy consumption to off-peak periods.

In their article "Household Load Profile and Personalized Optimization in DSM," Sharda and colleagues stress the strong correlation between household appliance load profiles and consumers' stochastic behaviors and environmental conditions. They argue that developing a universal DSM optimization method for all types of consumers is challenging, as energy consumption patterns and environmental factors are variable and difficult to predict. Moreover, creating a unified forecasting system for various users presents additional challenges since each user and device has unique characteristics[11].

Sharda and colleagues further emphasize that consumer load profiles play a pivotal role in developing personalized optimization algorithms that account for user preferences for comfort. As different household appliances have distinct energy requirements and operating styles, DSM optimization must group devices based on user preferences or behaviors.

The variability of renewable energy sources and electricity price fluctuations complicate optimal energy demand planning. To address this, it is essential to study

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locations individually and assess the advantages of renewable energy sources in natural resource production. Several methods have been proposed in the literature to improve the scheduling of distributed energy resources. Erdinc and colleagues recommend using mixed-integer linear programming (MILP) in their article "Optimization in Smart Grids with Renewable Energy Resources." Liu and Hsu have developed a two-stage robust optimization approach that improves energy distribution in response to changing conditions. Furthermore, Luo and colleagues propose heuristic optimization methods aimed at improving computational complexity and adaptability to variability.

The potential of using electric vehicles as battery storage systems through Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G) technologies has also been explored (Erdinc et al.). Several studies have highlighted the importance of enhancing the integration of renewable energy sources (such as solar, wind, distributed micro-generators, and batteries) into Demand Side Management (DSM) strategies, as well as the efficient management of smart devices based on scheduling. Qureshi and colleagues, as well as Wang and Wu, have analyzed these approaches in their works on "Smart Energy Management in DSM Context" [10].

Rahman and Miah, along with Zhang and Peng, studied how electricity prices affect consumers' energy consumption decisions. The literature emphasizes that by analyzing and shaping load profiles through DSM, not only can energy prices and carbon emissions be reduced, but system stability, safety, and reliability can also be improved.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a set of methodological guidelines widely used in scientific literature for systematic reviews and meta-analyses. Cortese and colleagues emphasize that the main goal of the PRISMA standard is to assist researchers in publishing systematic reviews and meta-analyses. Unlike the previous QUOROM standard, PRISMA ensures high-quality reviews, allows for replication, and provides readers the ability to evaluate the strengths and weaknesses of the reviews.

Sarkis-Onofre and others have elaborated on how the PRISMA standard helps in conducting systematic literature analyses. According to them, PRISMA enables the identification, selection, and synthesis of all relevant articles to answer specific scientific questions. In this way, articles are selected based on predetermined inclusion and exclusion criteria, which enhances the consistency and impartiality of the analysis.

Analysis of Smart Grids and Their Current Trends

Smart grids are typically part of the "smart" phenomenon, which involves automating decisions made by people through wireless connectivity and intelligent, controllable distributed devices. A prominent example of this trend is the Internet

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of Things (IoT), where smart phones, thermostats, refrigerators, and even cars share data in real-time and make independent decisions. Smart grid technology operates in a similar manner, but within the energy sector.

This research guide explains how smart electrical grids function, why they are important, and how they are helping to revolutionize the energy landscape.

To understand what a smart grid is, it is necessary to briefly discuss the design of traditional electrical grids. In traditional energy grids:

A supplier company generates electricity at a centralized location using fossil fuel sources such as oil, natural gas, and coal, or sustainable energy technologies like solar, nuclear, or hydroelectric power.

The generated electricity is then distributed in one direction through relay stations and transmission lines to local communities, with electric meters installed at individual locations to measure consumption and generate utility bills for each customer.

This centralized system worked effectively for over a century, as the number of devices used in each home or business was relatively low. Moreover, utility companies only needed to manage and distribute the electricity they produced.

However, in the past decade, homeowners and businesses have started to add their own energy production and storage solutions, such as rooftop solar panels or on-site batteries. Additionally, the introduction of energy-consuming devices and assets such as laptops, smart phones, electric vehicles (EVs), and others has caused a surge in demand for reliable electricity. As a result, supplier operators are facing increasing challenges in managing the rapidly evolving electrical grid. Most of the distributed energy resources are beyond their direct control, making it difficult to manage production or incorporate surpluses and shortages into the larger electrical grid.

Globally, there is a major push for rapid decarbonization to mitigate the negative impacts of climate change. For example, solar energy is a pollution-free renewable energy generation technology once installed. Thus, alongside savings in utility bills, owners of photovoltaic (PV) systems can reduce their carbon footprint by utilizing solar energy. For grid-connected installations, solar energy helps green the entire electrical grid, as less fossil fuel is required to meet the overall energy needs of the utility market [8].

A smart grid system relies on four key enabling technology areas to ensure reliable and cost-effective electricity supply for everyone in the network:

- Distributed energy management systems
- Autonomous microgrid technology
- Network stability and continuity
- Artificial intelligence-powered electrical grids

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Globally, although remote devices have full access to sensor data, people are not equipped to manage the increasing complexity of modern networks. This is particularly true for many distributed energy resources, which depend on energy sources that are constantly fluctuating[12].

However, machines excel in real-time data analysis and decision-making. Artificial intelligence (AI) can analyze energy production, consumption, weather, and climate data, resulting in highly accurate forecasting of energy supply and demand—seconds, days, and even weeks ahead. These forecasts are then fed back into algorithms, enabling machines to learn, improve, and make even more precise predictions in the future.

AI also helps electrical grids recover quickly from natural disasters or cyberattacks. By detecting faults, AI enables self-healing in electrical grids, which does not require technician intervention. When on-site repairs are necessary, the distributed nature of smart grid technology allows technicians to quickly identify and locate problems.

Application of Distributed Energy Resource Management Systems in Smart Grids

Distributed Energy Resources (DER), including assets such as solar, wind, storage systems, and even electric vehicles (EV), transmit electricity to and draw electricity from large utility grids. Devices like solar photovoltaic (PV) installations, often located on rooftops, are typically privately owned and are outside the direct control of grid operators. However, there is an increasing demand to provide utilities and asset managers with better tools for coordinating electricity production, storage, and distribution across the network.

A Distributed Energy Resource Management System (DERMS) is a combination of hardware and software that enables real-time management and communication of devices, such as batteries, solar panels, and other distributed energy assets, typically outside the direct control of network operators. This integrated control system relies on sensors and receivers to facilitate coordination across the grid:

Sensors: They transmit real-time data from distributed energy devices to the network, alerting operators to changes in energy storage and production. For example, a network provider might immediately receive information that a customer's PV installation is generating 25% less power due to cloudy weather.

Receivers: Distributed energy assets receive commands from the network and adjust their energy production and storage accordingly. For example, the network can remotely control a customer's solar battery to release energy to compensate for a sharp drop in wind energy production elsewhere[13].

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Distributed energy management systems work in collaboration with other smart grid concepts, including microgrids and resilience, to optimize resource allocation and ensure more stable electricity supply for everyone on the network:

Microgrids: These are systems that collect and integrate distributed energy resources and operate as independent, yet connected, power stations. Such systems can be seen in universities and industrial parks, where they rely on a mix of solar, storage, and EV-charging assets.

Resilience: This refers to backup systems that ensure a failure in one part of the network does not negatively impact the entire grid's operation. This concept is similar to data centers or blockchain technology—both reduce the frequency and severity of system disruptions through extended and redundant reserves.

Application of Artificial Intelligence in Smart Devices

Smart devices have become an integral part of our daily lives. They serve to automate everyday activities, save time and energy, and ease human labor. For example, smart home systems allow remote control of lighting, heating, and security systems. Additionally, smart devices assist users in responding quickly and efficiently to environmental changes.

The necessity of smart devices primarily stems from the need for quick and accurate decision-making. For instance, in the industrial sector, production processes are monitored and automated through smart devices, improving production efficiency. In agriculture, smart devices enable monitoring of soil conditions and automatic management of fertilization for crop production. These technologies help save human resources and improve quality.

The importance of smart devices is also evident in the fields of security and healthcare. In healthcare, devices that continuously monitor heart rate, blood sugar levels, or sleep quality help individuals monitor their health. Similarly, the use of security cameras and motion detectors enhances the protection of homes and workplaces.

In general, smart devices are of great significance for the advancement of society and the quality of life. They simplify daily tasks, increase efficiency, and create new opportunities in various fields. In the future, smart devices are expected to develop further and find broader applications across different sectors. Therefore, it is crucial to understand their technological capabilities and use them effectively.

In the era of modern digital transformation, the concept of smart devices has deeply penetrated almost all areas of our lives. These devices play a key role in simplifying daily activities, using resources efficiently, and enhancing security. Fundamentally, smart devices are systems that integrate digital technologies, sensor systems, artificial intelligence, and cloud computing capabilities[14].

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There are several key characteristics that differentiate smart devices from traditional electronic devices:

Sensing and Data Collection: Information about the external environment is collected through sensors installed to detect physical and chemical parameters such as temperature, humidity, light, motion, and pressure.

Intelligent Analysis and Decision-Making: The collected data is analyzed through artificial intelligence algorithms (such as machine learning and deep learning) to develop an optimal course of action.

Connectivity and Communication: Devices communicate with each other and central control systems via the Internet (IoT - Internet of Things), exchanging data for integrated functionality.

Automated Control: Devices operate autonomously based on predefined rules, often eliminating the need for human intervention in many cases.

Self-Adaptation and Updates: Smart devices optimize their operation in real-time and frequently enhance their functionality through remote updates (over-the-air updates).

Smart devices are composed of the following key components:

Sensors and Actuators: Tools for obtaining data from the environment and influencing it.

Data Processing Module: Internal processors or cloud-based processing via network connections.

Communication Module: Data exchange through technologies like Wi-Fi, Bluetooth, ZigBee, and 5G.

Power Source: Energy obtained from batteries, solar panels, or electrical grids.

Interface: Mobile applications, web platforms, or voice control systems facilitating interaction with the user.

Smart devices are an integral part of the IoT ecosystem. In the IoT concept, millions of smart devices connect with each other, exchanging information through global or local networks and forming complex systems in collaboration. For example, all vehicles, streets, and energy supply systems in a city can function as a unified smart city infrastructure.

The concept of smart devices is a crucial part of modern technological progress, bringing revolutionary changes to lifestyles, industrial processes, urban infrastructure, and the ecological environment. These devices significantly contribute to improving the quality of life, conserving resources, and addressing global challenges. However, their successful development requires continuous improvements in security, privacy, and efficiency[15].

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Artificial intelligence (AI) and smart devices are closely related technologies. The true "smart" nature of these systems is directly linked to their enhancement with AI capabilities. With AI, devices not only collect data but also analyze it, learn from it, and make independent decisions. This enhances their adaptability to user needs and ensures autonomous operation.

The main functions of artificial intelligence in smart devices include:

a) Data Analysis and Interpretation: Smart devices collect large amounts of data through various sensors. AI algorithms analyze this data, identify patterns and trends, and, based on this analysis, provide recommendations or trigger automated actions. For instance, a smart watch continuously analyzes heart rate and sleep quality, offering health-related recommendations.

b) Learning and Adaptation (Machine Learning): With AI, smart devices learn user behaviors over time and optimize their service strategies. For example, a smart home system automatically turns off the lights in the evening and activates the heating system in the morning because it has "learned" the user's habits.

c) Automatic Decision-Making and Early Detection of Issues: With AI, smart devices can anticipate threats or malfunctions and respond in a timely manner. For example, a smart security system can detect suspicious movements and either alert the user or automatically lock the doors.

This academic translation highlights the core components of smart devices, their role within the IoT ecosystem, and how artificial intelligence enhances their functionality and autonomy.

Smart Elements in Intelligent Networks and Their Energy Efficiency

An intelligent network is a digital communication system capable of self-management, optimization, and learning, driven by artificial intelligence (AI), machine learning, big data, and advanced algorithms. Unlike traditional networks, intelligent networks have the ability to analyze traffic in real-time, detect faults, and automatically resolve issues. These network technologies not only ensure data transmission but also manage it efficiently, self-adapt, and provide services tailored to user needs.

One of the main advantages of intelligent networks is their ability to quickly adapt to changing conditions. The network can automatically reallocate its resources and maintain service quality despite changes in traffic. For example, in mobile communication networks, intelligent management systems can maintain internet speed even when the number of users increases drastically. This, in turn, leads to improved service continuity and user experience.

The importance of intelligent networks is growing across numerous sectors, including industry, healthcare, transportation, and urban infrastructure. For instance, in smart city projects, intelligent networks manage traffic flow, provide

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rapid responses to emergencies, and optimize energy consumption. In the industrial sector, networks play a crucial role in ensuring the continuity of manufacturing processes and the stable operation of automated systems[16].

Overall, intelligent networks are becoming the cornerstone of future digital infrastructure. They not only enhance the quality of data exchange but also guarantee the security, efficiency, and sustainability of digital services. With the development of artificial intelligence and automation technologies, the capabilities of intelligent networks are expected to expand further, becoming a key factor in innovative development and global digital transformation.

So far, each chapter has been dedicated to various components of intelligent network architectures, including:

A general overview of what intelligent networks are, how they operate, and why they represent the future of energy supply.

The use of Distributed Energy Resource Management Systems (DERMS) for data exchange with edge devices, which include non-continuous renewable energy sources such as batteries, solar, and wind energy.

The application of microgrids as local power stations that can operate independently and are increasingly detached from the main energy system.

The importance of network stability, which includes all tools and normative requirements developed to prevent outages caused by natural or human factors in the electrical grid.

The examination of how AI and machine learning technologies are being used to optimize energy production and distribution more quickly, cheaply, and accurately. This is especially beneficial when network management decisions could be more effective than those left to human cognition.

In essence, intelligent automation is the key component that makes a network "smart."

Microgrids, DERMS programs, and network stability are fundamental to intelligent networks, providing affordable and reliable energy supply to everyone. However, each of these components generates a large volume of data, which makes it difficult for network operators and asset managers to efficiently balance energy supply, pricing, and demand when network conditions change in real-time.

To understand the potential of AI in network management, it is important to define several key terms:

Artificial Intelligence (AI): A field of computer science focused on developing algorithms designed to accurately replicate human cognition. While AI tools are still often applied to narrow domains such as chess, traffic lights, or energy systems, they are highly effective at processing vast amounts of data in real-time.

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Machine Learning: A type of AI where algorithms analyze datasets and build stronger concepts from this data to make precise predictions about the future. These predictions are based on identifying patterns within the data, which allows for insights into things that may be difficult for humans to detect.

When implemented correctly, AI enables energy traders to predict energy prices minutes or even hours in advance, giving them a significant edge in large markets. Conversely, these insights are also critical for national security, as the U.S. Department of Energy is already using AI's forecasting capabilities to help protect energy reserves and infrastructure.

AI can also help improve the maintenance and operational (O&M) services of assets such as large solar panel or wind energy stations. For instance, alongside thermal drone technology, AI can alert field workers about which solar panel requires repair. Preventive maintenance, powered by AI, can save thousands of dollars on photovoltaic farms compared to traditional trial-and-error methods.

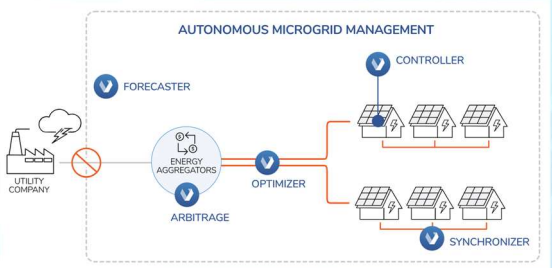


Figure 1. General Architecture for Organizing Energy Systems in Intelligent Networks

Specifically, in the Veritone Energy technology, artificial intelligence has proven its efficiency in addressing this task, as four interconnected pillars work together, providing utilities operators and asset managers with unprecedented control over networks and distributed energy resources:

Forecasting – A system that analyzes big data in real time, including meteorological satellites, data from peripheral devices, electricity generation levels, battery capacity, and energy prices. It provides accurate forecasts to determine the future direction of prices and supply.

Optimizer and Controller – Sends instructions to peripheral devices to ensure the stability of the entire network.

All of this data is fed back into artificial intelligence, which further refines future forecasts and instructions. Indeed, it is best to view the "smart grid" technology not as an endpoint but as an ongoing process. With the help of Veritone Energy's artificial intelligence, DERMS technology, autonomous microgrids, and sensor devices are becoming increasingly widespread.

Energy Efficiency Management in Smart Devices Based on Artificial Intelligence Technologies

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Power management in AI-based IoT systems requires the application of advanced approaches for efficient and optimized energy consumption. These systems leverage the powerful capabilities of artificial intelligence to optimize resources, extend battery life, and reduce energy consumption. For example, by analyzing the data collected from IoT devices, sensors, and network nodes, power management and distribution processes can be optimized in real time. AI algorithms enhance the performance of IoT systems by analyzing data streams, selecting the necessary energy sources, and developing strategies to reduce energy consumption. This approach is particularly important in IoT environments where devices have limited battery resources.

In IoT systems, sensors play a critical role as key components, performing several functions, including communication, data processing, detection, and power supply. The ZigBee transceiver, operating at 2.4 GHz, enables communication with minimal resources and is designed to enhance network efficiency through an architecture developed with Verilog Hardware Description Language (HDL). This architecture helps reduce power consumption, improve network performance, and decrease computational latency.

To promote energy saving and optimization, various artificial intelligence approaches are being explored, such as the Operator Decision Environment model, k-nearest neighbors system, Fuzzy Q-Learning, and other methods. These systems serve to improve energy efficiency and encompass the four main levels of control algorithms: data storage, data access, AI application interfaces, and decision-making[17].

In mIoT (mobile IoT) systems, small, cost-effective, and highly scalable sensors are used, enabling efficient and reliable medical services. The integration of IoT devices fosters the development of smart homes and intelligent transportation systems. IoT devices require high reliability, flexibility, and low latency, which significantly enhances the performance of these systems.

The proposed energy optimization algorithm (IRBEOA) focuses on the efficient management of energy consumption and the proper allocation of resources in IoT networks. IRBEOA aims to improve energy consumption in the physical, MAC, and software layers. It reduces energy consumption by optimizing networks and utilizing wireless channels, and is also used to create reliable and efficient data transmission systems.

Integrated mIoT and AI platforms are driving innovations in various sectors, including healthcare, business, autonomous systems, and organizations. M2M (Machine-to-Machine) communication is a crucial part of IoT, ensuring rapid data transmission between technologies and systems. However, alongside these processes, challenges arise, such as power loss, heterogeneity between systems,

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and rapid battery depletion. Additionally, IoT devices face synchronization issues between heterogeneous AI systems and large-scale data during data transmission. Ensuring fast communication between devices and seamless integration with surrounding systems creates a significant load. Furthermore, managing short battery life and increased energy consumption requirements is critical to maintaining the effective operation of IoT and AI systems.

AI technologies excel in data detection, collection, and analysis processes in mIoT systems, thereby improving decision-making efficiency. Many industrial and business sectors are working to enhance their operations by analyzing data collected through IoT. At the same time, AI and mIoT technologies are updating traditional approaches and helping to create smart cities and healthcare systems. In smart cities, the integration of programming and wireless connectivity systems ensures the successful implementation of IoT transformations. Instead of using conventional LTE networks, evolving technologies, such as classification machines or NB-IoT, ensure effective performance. Dynamic and distributed designs are considered key factors in creating efficient and user-friendly platforms.

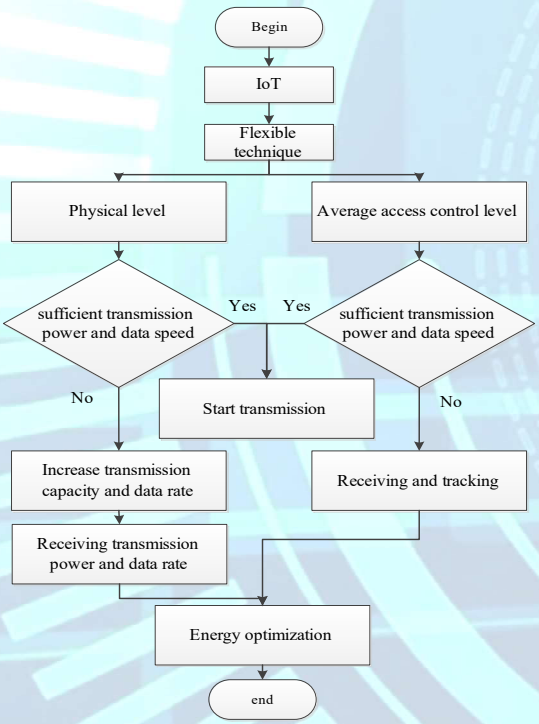


Figure 2. Random Power Optimization Algorithm

An experimental procedure was developed using convex optimization techniques in MATLAB, where the parameters of the physics and MAC layers were implemented. The application of the hybrid AI and mIoT systems of the IRBEOA and Baseline algorithms was evaluated. In performance assessments, parameters such as power consumption, packet delivery ratio, data rate, and sensor network lifetime were considered. Service cycle scheduling, maintenance, data classification, and transmission level adjustments for mIoT sensors were carried

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out at the MAC and PHY layers. During data transmission between layers, connections between platforms were tightly interlinked to ensure seamless communication across all layers.

To create such a system, it is necessary to design the AI and mIoT network based on physics power optimization and MAC techniques. According to Figure 2, which demonstrates the relationship between data transmission speed and power consumption, there are improvements between inter-layer communication and reduced power consumption. At a data speed of 0.8, power consumption remains the same under both conditions, but in the absence of inter-layer communication, this indicator increases. With an increased number of sensor nodes, power is distributed appropriately across the transversal layers. However, the addition of many sensor nodes complicates the system, requiring additional opportunities and resources for data transmission and exchange [18].

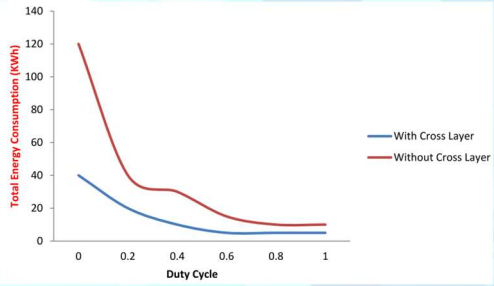


Figure 3. Service Cycle and Total Power Loss in IoT

Furthermore, new architectures are required to address issues such as service cycle resource limitations, high power consumption, and limited battery life in mIoT systems. Research proposes hybrid AI and mIoT systems to tackle these challenges. As the number of sensor nodes increases, the system becomes more complex, necessitating the implementation of more opportunities and technologies for information exchange. In order to improve power consumption and battery life, experimental tests were conducted using the convex optimization technique of MATLAB, which helps address data and energy collection issues for smart medical cities.

This study discusses the latest developments in the fields of AI and IoT. The existing methods for data and energy distribution need to be transformed into innovative and energy-efficient systems with the help of AI. There is a need to address key challenges such as the small size of IoT devices, limited resources, high power consumption, and the shortening of battery life. To overcome these challenges, the study proposes a revolutionary hybrid AI and mIoT architecture. Additionally, the smart structure of the mIoT system becomes more complex with the increase in the number of sensor nodes, which demands the improvement of data transmission and exchange processes. To enhance power consumption and battery capacity for mIoT applications, an experimental setup was developed using

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the convex optimization technique in MATLAB. Furthermore, the issues of data collection and energy generation within the framework of smart medical cities are also considered.

Conclusion

This study analyzes the potential of advanced AI algorithms for optimizing energy management and effectively managing resources. The results indicate that the integration of IoT devices and artificial intelligence can significantly enhance energy consumption management.

The study emphasizes that artificial intelligence methods such as machine learning and deep learning can be used in energy management systems to forecast and optimize energy consumption. Adapting these technologies for real-time operation can help substantially reduce energy consumption. Additionally, the integration of artificial intelligence technologies in managing smart grids can improve the stability and efficiency of networks.

Furthermore, the study highlights the need to integrate IoT devices into energy resource management systems and to improve real-time energy management based on new algorithms. These approaches create essential opportunities for minimizing energy consumption and reducing the negative environmental impact[19].

As a result, the study underscores the critical role of integrating IoT and AI technologies in improving the efficiency of energy management systems and resource conservation. The proposals and recommendations presented during the study will help expand the practical implementation of these technologies and develop new approaches to energy management.

Based on the results obtained, the following proposals and recommendations have been developed:

1. Improving Energy Management through IoT Systems:

The study illustrates the potential of optimizing energy consumption through the integration of IoT devices and artificial intelligence. To expand these technologies and ensure their more efficient operation, it is essential to integrate IoT devices into smart energy management systems. Advanced AI algorithms should be implemented for analyzing and optimizing energy consumption in real-time.

2. Broad Application of Artificial Intelligence to Enhance Energy Efficiency:

The study emphasizes that artificial intelligence technologies can help energy management systems function effectively. The use of advanced AI methods such as machine learning and deep learning can provide effective results in forecasting and optimizing energy consumption. Therefore, it is crucial to expand the application of these methods, particularly for energy consumption management.

3. Developing Innovative Solutions for Stable Management of Smart Grids:

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The study shows that artificial intelligence technologies play a vital role in managing and optimizing energy resources in smart grids. It is necessary to develop innovative solutions aimed at increasing the role and efficiency of artificial intelligence in creating smart grid management systems. This will enable the automation of decision-making processes and enhance the network's efficiency.

4. Expanding Energy Management and Resource Conservation:

The study emphasizes the need to optimize energy consumption and conserve resources using the technologies presented. By integrating IoT devices into energy management systems and controlling them, energy consumption can be reduced. This ensures resource-efficient use and sustainable energy management.

5. Practical Implementation:

The theoretical results and approaches examined in the study need to be applied in practice. It is essential to develop and test highly efficient AI-based energy management systems, as well as expand energy management systems in real-world conditions in the industrial and residential sectors. Implementing and evaluating the effectiveness of such systems will lead to further improvement in energy management processes.

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