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Research on Intelligent Control and Optimization Strategies for Household Electricity Usage

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Abstract. Recent research has shown that the household electricity consumption in each country often occupies the largest amount of electricity consumption in the country. This problem has been exacerbated by the increasing prevalence of electric vehicles, leading to a continuous rise in power consumption. Addressing this issue is crucial for achieving substantial energy savings. The research focuses on analyzing electricity consumption patterns in both office and residential areas. The primary method employed involves utilizing mobile devices to collect and examine relevant data. The findings reveal that household electricity consumption is indeed substantial, regardless of the number of family members or the age composition within a household. Based on these findings, the study proposes effective strategies to reduce residential electricity consumption. These strategies are designed to be practical and applicable, offering potential solutions to this pressing issue. The research concludes that with proper implementation, significant reductions in household electricity consumption can be achieved, contributing to overall energy conservation efforts.

Keywords: AI, Save electricity, Smart meters, System design, Low-carbon

1. Introduction

Electricity is a major source of carbon emissions, with residential electricity emissions growing at over 10% annually, surpassing the growth rate of industrial emissions [1]. As living standards rise, household electricity consumption increases, exacerbating power shortages. Population growth and dwindling non-renewable energy sources further strain the environment. The advent of new energy vehicles has also significantly boosted electricity demand. Amid global pursuit of low-carbon development, China has pledged to achieve carbon peaking by 2030 and carbon neutrality by 2060, with total electricity consumption projected to reach 10.3 trillion KWH in 2025, growing 5-6% year-on-year. The secondary industry accounts for the largest proportion of the total social electricity consumption and contributes the most to the growth of electricity consumption. With the economic recovery and the promotion of consumption policies, industrial electricity consumption gradually rebounded. The well-being of the people is the foundation of a nation, and the people cannot live without electricity, which accounts for a large part of the electricity consumed by each country itself. Therefore, it is necessary to carry out intelligent control and design optimization strategy for household electricity consumption. Improving the efficiency of electricity consumption and

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reducing the consumption of electricity will be conducive to the energy conservation and emission reduction of the whole society.

This study explores how to better save household electricity through a multi-participation approach, involving not just systems and AI, but also other aspects. This study makes contributions to energy conservation and emission reduction.

2. Theoretical framework

With the rapid development of smart grid technology, line optimization and dispatching has become the key to improve the operation efficiency and reliability of power grid.Building a more scientific smart grid will be the key to solving the problem [2]. There are a variety of technologies behind the implementation of intelligent control and optimization strategies for electricity consumption An intelligent control system should be established.

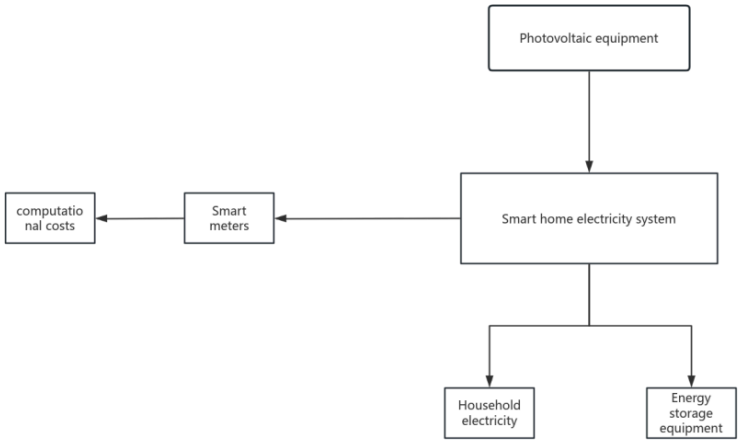

Figure 1. Home intelligent power flow system [3]

As can be seen from Figure 1, the new intelligent control strategy for household electricity consumption involves a mixed calculation of power generation and electricity consumption, with electricity costs calculated through feedback to smart meters. In the smart home electricity system, photovoltaic power generation equipment is essential, but other options are also available. This strategy is akin to building a new small microgrid device. However, due to its novelty, people still need to connect to the national grid to maintain basic energy supplies. In rural areas or sparsely populated regions, more efficient power generation can be built and surplus electricity can be sold.

First of all, the measurement system, the AMI system, is completely adequate. It is composed of four levels: smart meter, local area communication network (HAN/NAN), wide area communication network (WAN) and metering data management platform (MDMS). As a terminal device, smart meter integrates an embedded operating system and anti-interference circuit, responsible for electricity data collection and two-way communication. This system is highly advanced and intelligent, featuring functions, such as automatic meter reading and online payment. It reduces labor costs to a certain extent and facilitates life, and can also prevent electricity theft and smart power supply allocation. The second technology is photovoltaic power generation technology, a relatively mature technology. It can be laid on the roof, on the open space, or even on the sunny side of residential buildings. It offers high benefits in good weather conditions.

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Intelligent AI technology can be integrated into various systems to enhance their functionality. When added to the central computer system, it facilitates automatic deployment. When incorporated into photovoltaic power generation, it enables intelligent steering. Additionally, embedding AI chips into home appliances can lead to significant energy savings.

3. Optimization strategies for household electricity usage

3.1. Time-based optimization strategies

The intelligent control terminal is a vital component of the Home Energy Management System (HEMS), serving as a man-machine interaction system that integrates various information. It enables users to monitor the status of household electrical equipment, environmental conditions, and electricity prices. Users can make informed decisions and provide feedback to optimize energy use. The terminal supports human-computer interaction through displays and voice equipment, allowing users to manage and control home appliances. Additionally, mobile devices like smartphones and computers can be used as remote terminals for convenient control.

Electricity consumption is divided into rigid and flexible loads. Rigid load includes essential household appliances like refrigerators, lighting, and security systems that meet basic daily needs. Flexible load, which can be further divided into interruptible and non-interruptible loads, refers to appliances with flexible usage periods that do not significantly impact basic electricity needs or user experience. Interruptible loads, such as humidifiers and electric kettles, can be turned on or off during operation without affecting their tasks, allowing for flexible power allocation.

$$\mathrm{x_g} = \mathrm{P_g} \cdot h \tag{1}$$

In the formula, represents total load of rigid load g; represents rated power of rigid load g; represents total runtime of rigid load g. Rigid loads, essential for daily life, are typically unaffected by electricity price fluctuations. Once set, their operational state remains constant, excluding them from the household's smart electricity dispatch scheme. However, they are a significant part of household electricity consumption and must be included in the total power calculation.

Flexible load is divided into interruptible load and non-interruptible load. The mathematical model for interruptible load A in the i-th time period is shown in the following formula

$$\mathrm{x_a^i} = \mathrm{t_a^i} \cdot \mathrm{P_a} \quad \mathrm{t_a^i} = \begin{cases} \{0,1\}, & \mathrm{i} \in [\mathrm{a_{start}}, \mathrm{a_{end}}] \\ 0 & \mathrm{i} \notin [\mathrm{a_{start}}, \mathrm{a_{end}}] \\ \sum_{\mathrm{i}=0}^{\mathrm{H}} \mathrm{t_a^i} = \mathrm{s_a} & \\ \mathrm{a_{end}} - \mathrm{a_{start}} \geq \mathrm{s_a} - 1 & \\ 1 \leq \mathrm{a_{start}} \leq \mathrm{a_{end}} \leq \mathrm{H} & \end{cases} \tag{2}$$

In the formula, x_a^i represents a power in the i-th time interval; P_a represents rated power of a; a_{start} represents a at the start time of the operational period; a_{end} represents a at the end time of the operational period; t_a^i -represents the running status of a in the i-th time period; $\mathrm{t_a^i}$ =0 means that a is closed at the i-th time interval; $\mathrm{t_a^i}$ =1 means that a is turned on at the i-th time interval; s_a represents total runtime of a. Interruptible load must operate continuously during their designated working time and cannot be arbitrarily turned on or off. These loads have strict operational time requirements, necessitating consideration of the total power consumption of various electrical

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devices when adjusting their usage. Non-interruptible loads, such as rice cookers and washing machines, must complete their operations without interruption once started. The mathematical model of untransient load b in the i-th time period is shown in the following formula.

$$\begin{cases} x_b^i = t_b^i \cdot P_b \\ t_b^i = \begin{cases} 1, & i \in [b_{start}^{'}, b_{end}^{'}] \\ 0, & i \notin [b_{start}^{'}, b_{end}^{'}] \end{cases} \\ \sum_{i=0}^{H} t_b^i = s_b \\ b_{end}^{'} - b_{start}^{'} \geq s_b - 1 \\ 1 \leq b_{start} \leq b_{start}^{'} \leq b_{end}^{'} \leq b_{end} \leq H \end{cases} \tag{3}$$

x_b^i represents b power in the i-th time interval; P_b represents rated power of b; b_{start} represents b start time of the operational period; $b_{end}^{'}$ represents b at the end of the operational period; $b_{start}^{'}$ represents the actual start time of b; $b_{end}^{'}$ represents the actual end time of b; t_b^i represents b the running status in the i-th time period; t_b^i =0 means that device b is off at the i-th time interval; t_b^i =1 means that device b is on at the i-th time interval; s_b represents total runtime of b; Intelligent power optimization for flexible load is an important part of home energy management system and the realization of residential side.

3.2. Device based optimization strategy

Distributed photovoltaic power generation has gained widespread adoption nationwide, with installations in industrial plants and residential roofs. This trend underscores the growing significance of PV in the global energy sector and its pivotal role in driving the energy transition [4]. In the realm of photovoltaic technology, further optimization can be achieved through the intelligent control of AI by calculating radiation conditions and light orientation. By integrating self-induction of irradiation with AI calculations, automatic operation can be realized without replacing existing components and equipment. Beyond PV, other forms of power generation can be added to maximize efficiency. For example, thermoelectric power generation technology can be added. A significant temperature difference is formed on both sides of photovoltaic panels, which can be harnessed for thermoelectric power generation. The core principle of thermoelectric power generation is to use the energy difference between two different temperature regions (heat source and cold source), and directly convert heat energy into electricity through a specific physical effect, without the intermediate conversion link "heat energy → mechanical energy → electricity" like traditional thermal power generation. It belongs to a kind of "direct energy conversion technology". It uses three effects, the Seebeck effect, the Peltier effect and the pyroelectric effect. Component level integration, specifically back bonding, is a widely studied and commercially promising solution. It involves directly integrating thermoelectric generator (TEG) modules with PV modules to form a composite unit that can be installed without altering the existing PV framework.

The core structure is designed top-down, starting with a PV layer made of crystalline silicon, which absorbs light energy and converts it into electricity. Behind this layer is a thermal conduction layer composed of high thermal conductivity materials like copper foil or graphite. This layer efficiently transfers waste heat from the PV module to the hot end of thermoelectric generators

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(TEGs) below, preventing heat buildup. Beneath the thermal layer, there are 2 to 4 small TEG modules, each generating 5 to 20 watts by absorbing waste heat at temperatures of 40 to 75 degrees Celsius. The cold end of the TEGs connects to a heat dissipation structure, which can be either passive or active. Passive heat dissipation involves aluminum fins that enhance heat release through natural convection, ideal for high-wind, low-temperature environments. In contrast, active heat dissipation uses a miniature DC fan, powered by the PV or TEG, to force air cooling, making it suitable for high-temperature, windless conditions, such as rooftop installations. This integrated design maximizes energy efficiency by harnessing solar and waste heat.

3.3. Optimization strategy based on user behavior

The university's AI-powered smart power management system integrates DeepSeek with the campus cloud platform, incorporating real-time data from weather patterns, seasonal cycles, class schedules, and laboratory usage. By leveraging intelligent algorithms tailored to regional characteristics through Internet Protocol (IP) networks, it enables remote monitoring of electrical equipment across all academic facilities, administrative spaces, and residential areas. The system displays comprehensive power consumption data on a centralized dashboard, providing clear visibility for energy management and achieving intelligent electricity conservation [5]. This approach can also be applied to office areas and residential buildings.

In order to realize the dynamic energy saving strategy, predicting base station service traffic to identify low-consumption periods is crucial. Current methods involve applying various algorithms to historical traffic data, including traditional time series algorithms, machine learning and deep learning algorithms, each with its own advantages and disadvantages. This paper proposes an algorithm to predict power saving time window by first clustering with dynamic time warping (DTW) algorithm, and then modeling different kinds of base stations with seasonal autoregressive integratedmovingaverage (SARIMA) model with different parameters [6].

Based on formula (1), the variable data can be adjusted to accommodate the varying electricity demands of different households. Additionally, an AI intelligent algorithm allows easy customization via an app, maintaining overall control requirements. This intelligent control can be installed throughout a building to meet diverse user needs, such as home and office modes. Overall, meeting the usage time and power requirements of smart control appliances is fundamental to achieving electricity savings.

There are more ways to use AI in power saving. Collecting fundamental data from 4G/5G wireless networks, including performance metrics, parameter configurations, alarm information, MR measurements, and operational parameters, enables comprehensive analysis of network coverage patterns and service load conditions. This facilitates the construction of overlapping coverage topologies. Deep learning algorithms are used to achieve both long-term and short-term service predictions. By integrating overlapping coverage results with service forecasting data, combined with 4G/5G collaborative AI-powered intelligent power-saving algorithms, three key tasks are complished: intelligent mining of multi-layer network overlapping coverage relationships; precise analysis of network service load tidal effect periods; and smart computation and localization of energy-efficient cell systems. These insights generate intelligent power-saving strategies, which are automatically programmed to execute sleep and wake commands. The system can automatically close power - saving cells during off - peak hours to achieve energy saving and emission reduction, providing support for 4G/5G collaborative power - saving management [7].

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4. Challenges and coping strategies

The first challenge is more about how to put such intelligent control facilities into the home appliances. For unfinished buildings, integrating such computing methods into the power supply of the entire building or room is feasible. However, for a completed building or a completed power line, such installation can be very difficult. In these cases, a small device that can be easily attached to the existing power grid can be developed, allowing for seamless integration without extensive modifications. Additionally, constructing photovoltaic systems in towns and villages can be explored. These efforts can complement the existing power supply methods and do not conflict with current electricity distribution systems. Traditionally, people think that their small actions can not affect the overall power supply or national level of electricity saving behavior. To change this mindset, promoting this new type of electricity-saving approach through government initiatives and platforms like short video apps is crucial. These channels are more accessible to the general public. By doing so, it is possible to help people break free from traditional concepts, foster inclusivity, and encourage more individuals to adopt and participate in this new way of saving electricity.

Beyond addressing these challenges, developers must also focus on reducing costs and conserving materials needed for constructing smart power supply systems. Collaboration with scientists working in other fields is necessary. This includes partnering with those developing materials to explore how to get photovoltaic materials that are more efficient at receiving radiation, and how to change the alloys to reduce the resistance of the wires. Staying confined to one's own profession and focusing solely on one's tasks is not sufficient. Instead, working in tandem with scholars and experts from other disciplines to enhance the overall scheme is essential. This interdisciplinary cooperation is crucial in overcoming the challenges faced.

The present year marks a period of transformation, emphasizing energy saving and emission reduction. This article discusses the necessity of household electricity conservation and smart grid development, focusing on improving photovoltaic efficiency. It highlights key parameters for effective energy savings and anticipates further advancements in intelligent building lighting systems, contributing to green building progress [8-9].

5. Conclusion

This article discusses the necessity of saving electricity in households and building smart grids, as well as how to build smart grids. It details how to improve photovoltaic power generation to achieve higher efficiency and more widely available benefits. Additionally, it highlights key parameters and changes that can facilitate more effective electricity savings through a systematic approach. However, this study still has some limitations. Firstly, it lacks in-depth analysis of specific regional and user behavioral differences, which may affect the universality of the optimization strategies. Future research could focus on developing more personalized smart management systems that incorporate diverse user data and environmental factors to enhance electricity savings. Additionally, exploring the application of new materials and technologies in photovoltaic generation and smart home systems is also a crucial direction for future studies.

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