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Role of AI Enabled Smart Meters to Enhance Customer Satisfaction

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Abstract- The critical role that smart meters with artificial intelligence (AI) capabilities play in transforming the energy sector and promoting higher levels of consumer satisfaction is examined in this review article. Smart meters have become essential elements in the rapidly changing digital energy market, utilizing AI technology to provide customers and utilities with previously unheard-of advantages. This paper offers a thorough examination of the ways in which AI-powered smart meters enhance energy management, boost operational effectiveness, and eventually improve the general consumer experience. Between 2018 and Oct 2022, data for this study was collected from several databases. The combination of artificial intelligence (AI) and smart meters will be crucial in building a more efficient, customer-focused, and sustainable energy environment as technology develops. Utility companies must embrace this change if they are to meet and surpass customer expectations in an increasingly digital environment, as well as do so as a matter of strategy.

Keywords- Artificial intelligence, AI, customer, satisfaction, smart meters

1. Introduction

Grid function and significance are being revolutionized today by the convergence of the increasing use of renewable energy, the advancement of electric cars, and, eventually, the electrification of the whole economy [1, 2]. The fundamental component of this change is how we handle various energy flows in an attempt to give the system more "flexibility [3]." Data from the electrical system and its related services, such as the grids, emerge as a key component that facilitates change in order to do this, with smart meters playing a key part in enhancing the system's efficiency, dependability, and security [4, 5].

Artificial intelligence (AI) has been incorporated into many areas of the energy industry's operations, resulting in a dramatic change in recent years [6]. The use of AI-enabled smart meters is one noteworthy development; these devices not only transform the conventional utility infrastructure but also significantly increase consumer happiness [7, 8]. Self-reading devices known as electronic or smart meters read the meter reading and display the data recorded in rupees, pounds, dollars, or pence [9]. Energy, water, and gas are all covered by smart meters. The main factors influencing energy usage are ingrained routines and behaviors that are difficult to break [1]. For this reason, it is important to closely examine the technological, social, and psychological elements that might support the modification of customer satisfaction [10, 11, and 12].

The insights gleaned from a thorough evaluation of the empirical literature on satisfaction issues related to smart meter and energy information feedback use are summarized in this study. Beyond the widespread deployment of smart meters, a number of satisfaction factors may influence how customers respond to information that allows them to modify their level of consumption satisfaction in response to dynamic pricing [13, 14, 15]. In fact, a great deal of empirical research has been done in many different nations to find out how customers react to criticism of their pricing and consumption [3, 16]. But users cannot hope to benefit from the potential presented by new technology if they do not exhibit a proactive attitude [5, 17].

This article aims to provide a deeper understanding of why consumers behave in a certain way when managing their demand—a process that ultimately benefits the electrical system in particular and society as a whole in general [1, 18, 19, 32]—by reporting a systematic analysis of bibliographic references. This analysis examines how smart meters with artificial intelligence (AI) capabilities are transforming the energy sector and promoting higher levels of consumer satisfaction. Smart meters have become essential elements in the rapidly changing digital energy market, utilizing AI technology to provide customers and utilities with previously unheard-of advantages.

2. Methodology

In-depth research of the ways AI-powered smart meters enhance energy management, boost operational effectiveness, and ultimately improve customer satisfaction is presented in this article. After the literature evaluation is finished, it's essential to be able to identify particular research questions that will allow us to add to the body of current research.

2.1 Data Strategy and keywords

The following keywords were used in pair searches for relevant research papers published between 2018 and Oct 2022 in the electronic database of Scopus: "machine learning," "AI," "smart meters," and "customer satisfaction." Boolean operators (AND, OR) were used to carefully combine these terms to generate a very focused and thorough search strategy.

The inclusion criterion—which required that papers be published in English—emphasized the review's dedication to accessibility and comprehensiveness. By taking into account articles released between 2018 and Oct 2022, the systematic review was able to incorporate the most current and relevant research in the field. When the relevant articles have been retrieved from the databases. The titles, abstracts, and full text readings were used to evaluate the publications. In the end, 8 papers were selected for further screening and quality assessment. Figure 1 shows the procedures for the elimination, systematic review, and article selection.

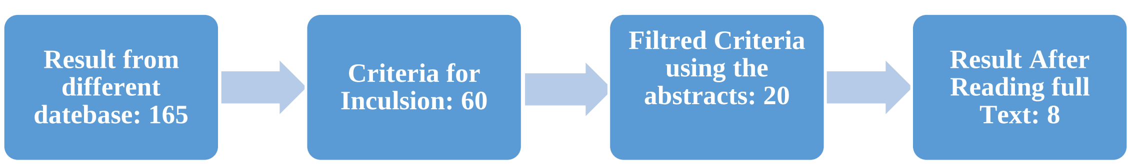

Figure 1: Literature Review process used

3. Result

The primary findings from the eight papers are presented in this part. These publications were chosen and categorized based on how important artificial intelligence (AI)-enabled smart meters are to transforming the energy sector and improving consumer happiness (Table 1). AI-enabled smart meters provide users more control over their energy usage, encourage energy saving, guarantee billing accuracy, and empower users with real-time information. When taken as a whole, these elements enhance the client experience and raise satisfaction levels [4, 6, 7, and 8].

Table 1: Summary of the Studies

No.	Author and Years	Aim	Model	Key Findings
1	(Bugden & Stedman, 2019)	Smart meter acceptance and engagement	General Concepts	➢ Age and wealth had the biggest effects on involvement, whereas climate change risk and smart meter knowledge have the strongest effects on acceptance.
2	(Alkawsi, Ali, & Baashar, 2021)	Smart meters continue to struggle from consumers' acceptance.	IVs & DVs in UTAUT2 model	➢ In order to increase the rate of acceptance, power suppliers utilize the smart meter acceptance model to update the criteria of consumers in their schemes.
3	(Alkawsi, Ali, Mustafa, et al., 2021)	the barriers to the adoption of IoT-based smart meters technology	hybrid SEM-neural network	➢ Smart meters to increase user needs and boost users' interaction with the equipment.
4	(Völker et al., 2021)	smart meter data analytics applications is targeted	Data Processing Algorithms	➢ Accurate information reporting is a need for smart meters and the associated data processing systems.
5	(Ponnusamy et al., 2021)	A safe and trustworthy method of detecting theft that makes use of deep federated learning (FL)	Deep learning model	➢ Protecting data privacy while improving the security and effectiveness of Smart Grid technologies.
6	(Alkawsi et al., 2020)	influence residential consumers' acceptance of smart meters	TAM and UTAUT	➢ The UTAUT2's explained variation in customer acceptability of smart meters is significantly increased by knowledge about energy conservation and environmental consciousness.
7	(Anupong et al., 2022)	monitoring individual consumers' power usage	Ad-Hoc On-Demand Vector	➢ AODV, and it has been demonstrated that the suggested method performs better.
8	(Xia et al., 2022)	understanding of the electricity theft issue	machine learning- and measurement mismatch-based	➢ Readings from meters in contemporary power networks, electricity theft tends to become even more problematic as it becomes more adaptable, secretive, and adjustable.

3.1 AI techniques in distributed smart grids

Well-known artificial intelligence (AI) approaches for classifying, predicting, networking, optimizing, and controlling strategies include the artificial neural network (ANN), reinforcement learning (RL), genetic algorithm (GA), and multi-agent systems [2, 7]. Many system activities are still carried out manually or with very rudimentary automation since there aren't enough sophisticated automatic controlled resources. On the other hand, the electrical grid would see advances and new directions with the integration of AI into the system. Figure 2-4 presents the whole distributed SG idea using AI approaches [1, 3, and 6]. Costs are decreased by the clever optimization of controllable loads. Using a genetic algorithm, for instance, might improve the controlled loads in the administration of freestanding micro-grids (MGs) [8, 19]. Artificial Intelligence (AI) tools are providing more effective and potent solutions to address the limitations of the old grid system due to advancements in computing power and data storage accessibility [9]. Furthermore, a number of security problems have been brought about by the use of distributed computing methods in SG [12]. Threats such as physical and cyberattacks have the potential to cause disruption, denial of service (DoS), privacy violations, and infrastructure failure [4, 5].

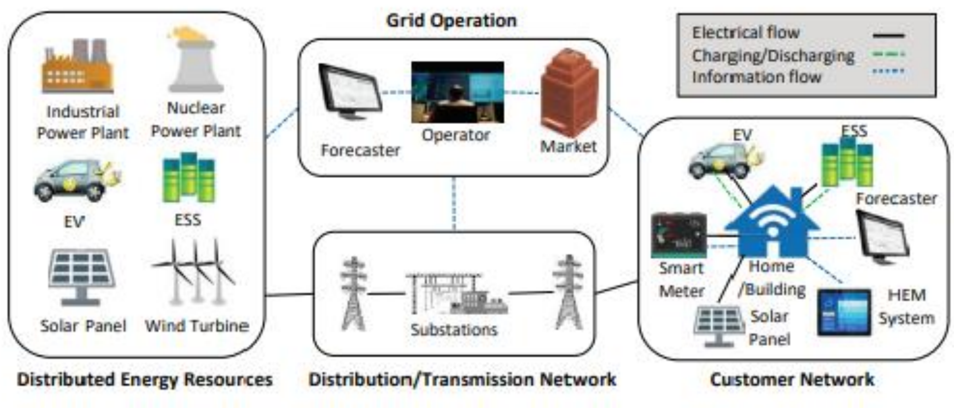

Figure 2: Distributed Smart Grids

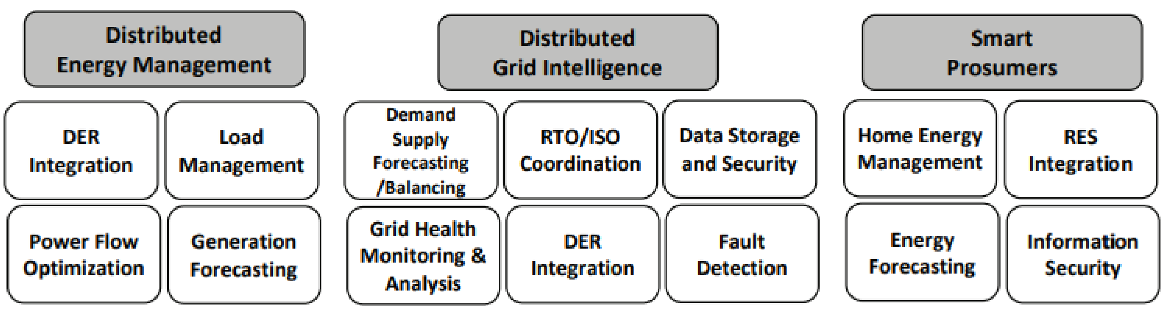

Figure 3: Application

AI Techniques Used	• Multi-agent system-based microgrid operation strategy for DR • Distributed grid intelligence using FREEDM system to manage the DERs • ANN for optimizing distributed grid operation • Consensus-based distributed intelligence for optimizing SG control • Optimization of distributed generation operation using GA	• ANN for forecasting local energy demand • Central Information Model (CIM) for implementing VPP communication and control architecture in SCADA • Deep Learning (Support Vector Regression (SVR), Recurrent Neural Network (RNN)) for electricity price forecasting • Markov Decision Process and RL based smart energy community management • Meta-heuristic algorithm for regulating voltage profile • ANN for detecting energy fraud • Multi-service energy storage for providing shared ownership of ESS between local network operator and customers	• ANN for DSM for smart consumers • ANN for forecasting day-ahead load profile • Machine Learning (support vector machine, ANN) for predicting electricity price • Deep learning (Conditional Restricted Boltzmann Machine (CRBM)) for forecasting building energy consumption • ANN and dynamic differential evolution for demand side management • ANN and RL for demand response of HEM

Figure 4: AI Techniques usage

Technology for the smart grid (SG) can facilitate the incorporation of RES in next power systems. With a high penetration rate of distributed generation in power systems, information and communication technology (ICT) advancements coupled with consumer data have the potential to completely change the electric power grid [3]. Artificial intelligence (AI)-driven smart energy markets can facilitate the creation of favorable regulatory incentives and enable customers and utilities to make effective decisions about their generation and consumption that lower CO_2 emissions [7]. Developing methods of communication between humans and controllers, creating automation technologies for heterogeneous devices that learn to adapt their consumption against pricing signals with user constraints, and creating simulation and prediction tools for suppliers and customers are the challenges facing AI in the electrical power system [5].

3.2 Energy Efficiency and Cost Savings

Real-time, detailed tracking of energy use trends is made possible by AI-enabled smart meters. By giving them access to actionable data into their consumption patterns, this gives customers the power to decide when and how best to use energy [1, 3]. Smart meters help users save a lot of money by offering individualized advice. Examples of these recommendations include recognizing energy-wasting items or suggesting the best times to use them [5]. This promotes financial responsibility and is consistent with the increasing emphasis on sustainable energy practices throughout the world [4]. Energy monitoring systems can detect areas of energy waste, equipment failures, and abnormal energy demand by utilizing artificial intelligence. This makes it possible to take timely corrective action, which lowers expenses and improves energy efficiency [7].

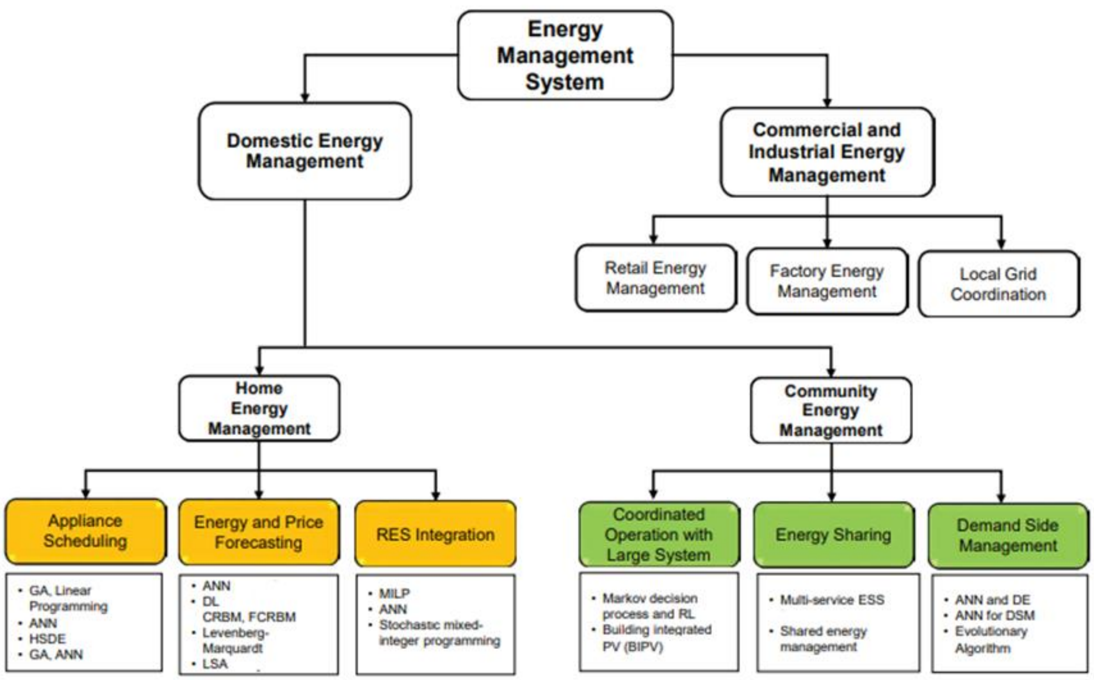

Figure 5: Energy Efficiency

3.3 Real-Time Monitoring and Control

Real-time insights into energy use are not possible with traditional energy meters. On the other hand, users may instantly get data about their energy consumption using AI-enabled smart meters [3, 20]. Users are able to watch their consumption patterns and modify their behavior in real-time thanks to this monitoring feature. Additionally, smart meters let users to remotely control linked equipment, such as turning off or adjusting appliances from smartphones [5, 21]. This leads to increased customer satisfaction because it not only improves convenience but also gives them more control over how much energy they use [4, 22]. Real-time data from many sources, including sensors, smart meters, and weather predictions, may be analyzed by AI algorithms. After processing, this data offers insightful information on trends in energy usage, times of peak demand, and prospective areas for energy savings [6, 13, and 23, 27].

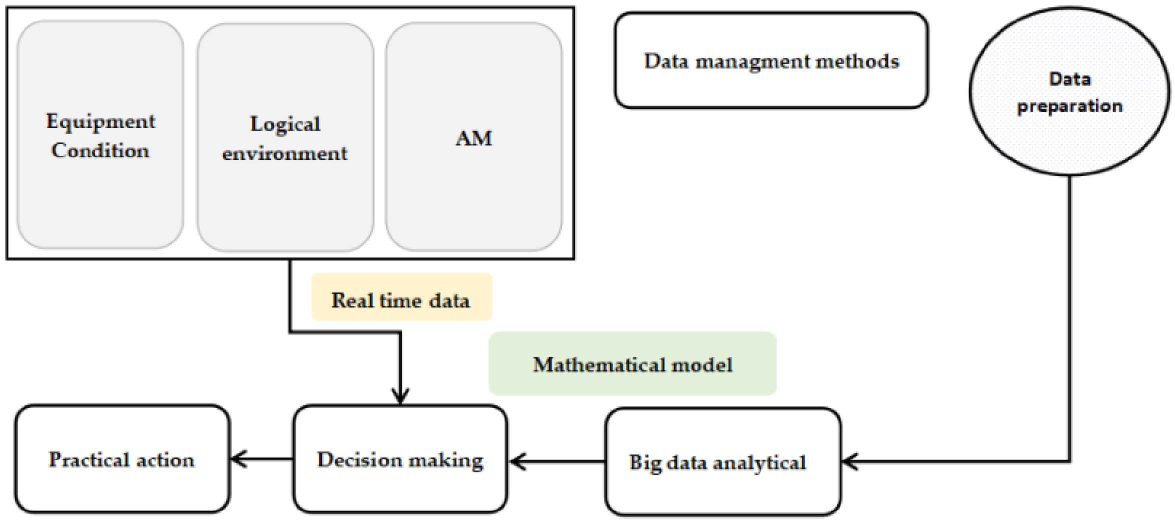

Figure 6: Monitoring and Control

3.4 Predictive Maintenance and Reliability

Smart meters with AI algorithms built in can examine use trends and identify any problems with the energy infrastructure [1]. Utility companies may provide a more dependable electricity supply for customers by anticipating maintenance requirements and taking proactive measures to solve them before a breakdown occurs [8, 9, 28]. Because customers see fewer annoyances and disturbances in their everyday lives, a decrease in downtime and fewer service interruptions greatly increase customer happiness [5]. Predictive maintenance is made possible by AI systems' ability to identify abnormalities in equipment performance and energy use trends [24]. This minimizes downtime, optimizes maintenance schedules, and helps prevent system failures [6, 15, 29]. The ability of smart meters to integrate with cellular networks, which provide extensive continuous coverage, dependable connectivity, and dependable data transfer from meters to utilities, is essential to their success. To provide even more protection, cellular networks use cutting-edge security procedures to safeguard the confidentiality and integrity of data being sent [4, 10].

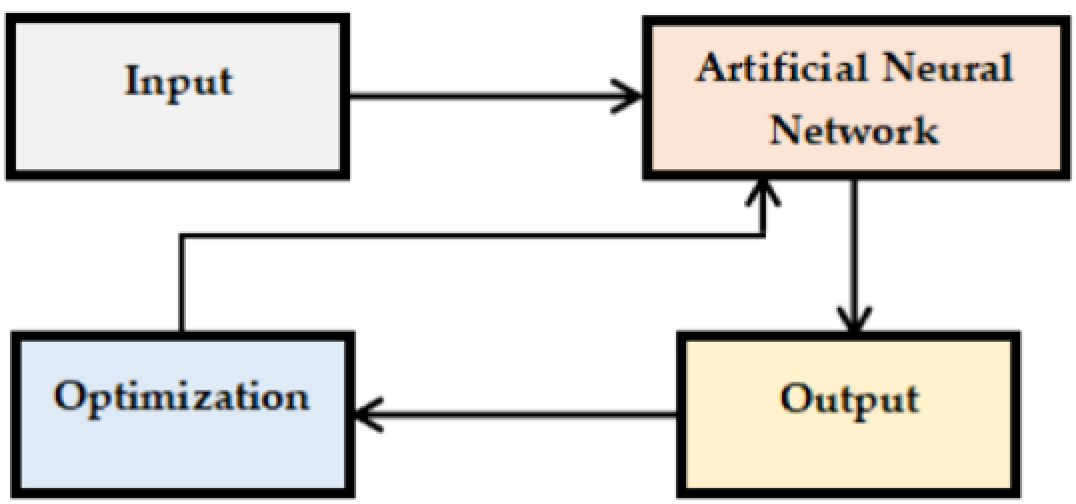

Figure 7: Personalized Insights

A neural network requires a large amount of training to produce the same output, and the production may differ even with the same input [1, 3]. The signal comprises all the steps that need to be done in order to evaluate the input signal and determine how much energy is there in it. It is routine procedure to use energy estimations from input signals to direct the subsequent steps of implementing hardware- and software-based SG features [4, 7]. Voice commands can be spoken into a mobile device and transmitted over Bluetooth and Wi-Fi to the building's energy management system [5]. Mobile phones may potentially be used by intelligent buildings to get voice commands for controlling electrical equipment [25].

3.5 Personalized Insights and Engagement

Smart meters are able to provide customers with individualized information thanks to AI-driven analytics [7]. Detailed analyses of energy consumption, comparisons with comparable homes, and suggestions for energy-saving techniques are a few examples of these insights [5]. When customers receive tailored information, they feel more involved and empowered and take an active role in the pursuit of energy efficiency [1, 11, 31]. Smart meters give consumers a more relevant and meaningful experience with their whole energy consumption process by customizing suggestions based on personal preferences and patterns [8, 10]. Energy monitoring systems with AI capabilities can assess each user's unique energy usage habits and offer tailored advice. People are empowered to make knowledgeable decisions about how much energy they use, which leads to energy savings [2, 26].

3.6 Improved Customer Service and Issue Resolution

Smart meters with AI capabilities provide faster problem detection and solutions [3, 9, 30]. Smart meters can notify utility providers and customers of abnormalities or disturbances, allowing for quicker reaction times [1]. Furthermore, the provision of comprehensive data on energy use facilitates customer care staff in better handling client inquiries [5, 8, and 10]. Higher levels of satisfaction stem from an overall increase in customer service brought about by this expedited communication and issue resolution procedure [2, 21]. Customers may get real-time data about their energy use through customer interaction websites made possible by smart meters. Customers are empowered by this openness to keep a careful check on their consumption and report any inconsistencies they see, serving as extra eyes to spot any theft [7, 18].

Domain	Challenges	Potential Solution
Architecture	Protection of smart grid, substations, and ICT gadgets from various cyber attacks	AI based load estimator using sensors
	Power theft	ANN based fraud detection
Operation	Fault detection and separation	Coordination among DERs, smart sensors smart device standards
	Reliability and resiliency	Pervasive computing architecture using ubiquitous devices based on a trust model
Data management	Data integrity and consumer privacy	Data encryption
	Data security against cyber-attacks (active and passive)	Distributed data randomization
	Secure generation, monitoring, storing, and analysis of data	Online voltage control using SCADA
	Denial of Service (DoS)	Hybrid fuzzy set based feed forward neural network
Environment	Consideration of environmental factors, responding to natural disasters (earthquakes, lightnings, tree falling, etc.)	Smart grid forensic science
Market liberalization and regulatory policies	Consumers awareness about the benefits of smart grid, RND investment, planning and regulatory policies by stakeholders, government support and private sector coordination in implementation, market liberalization and IPPs attraction	Social marketing, social norms approach

Figure 8: AI Techniques Security Challenges

4. Future Research and Limitation

The critical role that smart meters with artificial intelligence (AI) capabilities play in transforming the energy sector and promoting higher levels of consumer satisfaction is examined in this review article. Energy monitoring has a revolutionary possibility due to the merging of AI with smart metering. Organizations may monitor and optimize their energy use with never-before-seen precision by utilizing real-time data from smart meters and AI algorithms. This research includes publications that satisfy our inclusion criteria as well as an operational description of how AI-driven smart meters optimize energy management, increase operational efficiency, and ultimately improve the entire customer experience. In this study, only publications published in English during the preceding five years were taken into account. New methods based on knowledge detection, information theory, and machine learning need to be investigated by security protocols. The applicability of current security protocols to SG application needs, self-healing/adaptive security approaches, and integrative security protocols for dispersed components are a few possible research obstacles. Modern artificial intelligence techniques are made to enable a wide range of distributed sensing applications in the future, such as energy storage system integration, demand response management, home energy management, integration of renewable energy sources, and security. Scalability, taking algorithm efficiency into account, security and privacy, stability in the face of failures, algorithm efficiency, users' and network operators' comprehension of the intelligent tools, etc. are some common areas of constraint.

5. Conclusion

AI-enabled smart meter rollout is a major advancement for the energy industry, with several advantages for utility companies and customers alike. By giving precise data on energy consumption, smart metering facilitates energy-conscious decision making. Energy consumption is maximized and system overload is avoided using intelligent load control. Precise energy audits facilitates the identification of inefficient regions and makes practical optimization recommendations. Among the advantages of AI-driven systems are reduced energy consumption, enhanced performance, and a favorable effect on the environment. To reduce repair costs and avoid equipment breakdowns, predictive maintenance may be used by utilizing AI and precise monitoring data. AI-powered monitoring and metering systems provide a clever way to increase energy efficiency as the need for sustainable practices grows. We can all work together to create a more sustainable future while saving money and consuming less energy by evaluating real-time data and optimizing energy use.

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