An Overview of the Home Energy Management Systems Considering Different Types of Power Scheduling Techniques and Strategies

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Abstract - The growing demand for electricity, the implementation of renewable energy sources (RES), and the growing deployment of intelligent household appliances produce new prospects for home energy management systems (HEMS), which control and schedule household appliance use to enhance the total energy generation and use of households. Thus, the main target behind this work is to review an efficient scheduling strategy so that the electricity cost is reduced, peak demand is minimized, and the user's comfort is maintained. This review aims to systematically analyze and summarize the power scheduling strategies (PSS) of HEMS in recent years. This paper reviews the PSS history of the HEMS architecture and discusses the characteristics of several major techniques in the current HEMS infrastructure. This work reviews the HEMS on the basis of minimizing the electricity cost and peak demand while completing the 100% task required at the end of the day with a lower scheduling time response.

Keywords: *home energy management system, Power Scheduling Strategies, power demand, renewable energy system, Battery Energy Storage System.*

1. INTRODUCTION

The demand for a home energy management system (HEMS) grows as a result of worries about global warming and the availability of energy; this system aids in reducing the electricity demand, particularly during periods of peak load [1]. HEMS should be taken into consideration as a technique to manage electricity automatically in a home as well as a way to lower greenhouse gas emissions. To build HEMS systems, numerous attempts have been made, including controlling the functions of different household devices (such as water heaters, air conditioning systems (A/Cs), refrigerators, electric automobiles, lighting, and others) [2], [3]. Residential homes can have HEMS installed to help optimize the power supply by interacting with utilities and home appliances, monitoring records of energy consumption, and receiving data (e.g. tariff pricing) to minimize consumption of electricity by timing the use of home appliances [4], [5].

This system can integrate the operations of multiple sources of energy and storage, simultaneously optimizing the appliance operation schedule. [6]. The architecture of HEMS with power scheduling strategies is shown in Fig. 1. Consumers and providers can communicate by a smart grid through the internet and a smart meter, which is frequently installed in households [7], [8].

A HEMS is an element of technology that systematically increases the efficiency of the energy production-consumption of households by strategically scheduling household appliances [9]. Additionally, it enhances a home's overall circumstances for generating and utilizing energy, providing the energy produced by distributed energy resources (DERs) to be stored and managed through battery energy storage systems (BESS). [10].

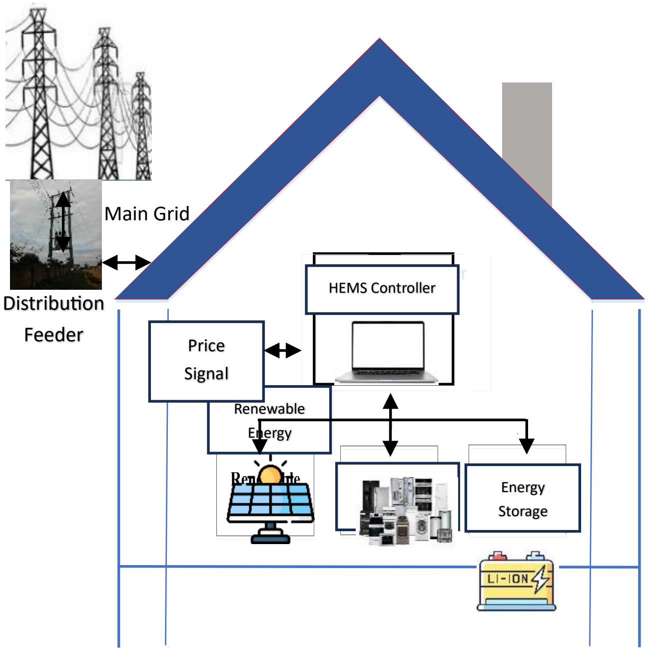

Fig. 1 - HEMS architecture

The result is generally achieved through the implementation of an optimized scheduling algorithm to determine the ideal time to turn on or off a device by taking into consideration variables such as outside information (such as updated grid cost and climate forecasts) and inside information (such as customer demands and historical usage data for home appliances)[11], [12]. Furthermore, HEMSs allow public utilities to analyze the future energy needs of customers to optimize the application of power and increase the reliability of power systems [13].

Fig. 2 - Different types of Electricity Tariff

The HEMS characteristic helps consumers save a lot of capital by offering every consumer the option to decide how to manage their electricity. According to the energy and consumer demand, the utility center uses a variety of pricing strategies, including TOU (Time of Use), RTP (Real Time Pricing), RPP (Regulated Pricing Plan), and FP (Fixed Plan), as shown in Fig. 2.

HEMSs have the benefit of automatically analyzing the cost of electricity, consumer demand, the uncertain nature related to external environmental factors, and personalizing suitable energy consumption strategies for managing the energy consumption of domestic appliances. To optimal energy control and management, HEMSs are becoming more and more appealing to end users, energy providers, and society. HEMSs may conserve energy for communities and lower the prices of electricity for their consumers by optimizing the consumption of energy in their residences by the cost of electricity and their daily routines. In addition, HEMSs enable public utilities to analyze consumers' expressed consumption of energy to optimize power usage and raise the dependability of power systems [7], [14].

2. OVERVIEW ON HEMS

There are numerous surveys and evaluations of HEMSs. Table 1 summarizes the most important review articles on HEMSs that will be published between 2015 and 2022. These studies can be roughly categorized into HEMSs, and architectures according to the various aspects of HEMSs [14], [15], functionalities [14], [15], [16], infrastructures [15], [17], [18], modeling approaches and categorizations [19], [20] and various optimization methods for scheduling [15], [19], [20] [21], [22] as well as HEMSs implementations in DR [23] and interdisciplinary meta-reviews about HEMSs [24]. However, categorization results reveal that, aside from the [15] presented in 2016, which analyzed every aspect of HEMSs in an overall manner, other studies focus on a few, even just one, components of HEMS. For reference, paper [16] focuses on NILM, which represents one of the HEMS monitoring functions, and [22] suggests a three-tier taxonomy for the usage of algorithms for learning in HEMS.

Table 1 - Existing review papers on different areas of HEMSs (2015-2023).

Ref.	Year	Description
[19]	2015	The author studied issues, solutions, and effects on HEMS modeling frameworks.
[15]	2016	The architecture, operations, infrastructures, scheduling methods and RES acceptance of HEMS were all reviewed in this study.
[25]	2016	This study analyzed 305 EMS situations related to architectural building energy management systems (BEMSs), and their important features and energy-saving outcomes in 276 articles published between 1976 to 2014.
[18]	2016	This study analyzed the conception of BEMSs, and the energy alignment communications technology applied to these.
[16]	2017	This study explored the primary application of non-intrusive load monitoring (NILM) and offered an alternative approach called advanced NILM to address the problems that came up when trying to implement an actual NILM.
[26]	2017	This article provides a thorough analysis of EMS, applications, infrastructures for charging, and charging technologies for electric vehicles (EVs).
[17]	2017	This study reviewed the many types of EMS, load classification, related technologies & standards, and an analysis of the system's implementation.
[23]	2017	The article discussed the essential characteristics, issues, and architectures of EMS aggregators.
[27]	2018	The article presented executions in the actual environment, analyzed various categories in optimization techniques, and described the construction and infrastructure for communication of EMS.
[24]	2020	This paper provided a HEMS review of their impacts, substances, and characteristics of maximize the energy-saving advantages of smart HEMSs,
[28]	2021	This study observes various power generation techniques, determined the reliability of the information available, and provided guidelines for the future related to smart HEMSs.
[21]	2021	This study analyzed and evaluated BEMSs management methods and possible challenges.
		The paper analyzed EMSs for islanded micro-

[20]	2022	grids concerning six essential optimization features and emerging trends.
[22]	2023	The article utilizes the scientific metric methodology to propose a 3-tier taxonomy of machine learning technologies for HEMS.

This outcome suggests the general discussion of HEMSs requires to be restructured and enhanced, as well as the fact that the analysis of HEMSs has become increasingly better over the past decade as an outcome of this extensive research.

2.1 Components of home energy management system

Home energy management systems (HEMS) depend on programmed and communication systems. Its various elements are seen in Fig. 2 and described in detail in Table 1 [29].

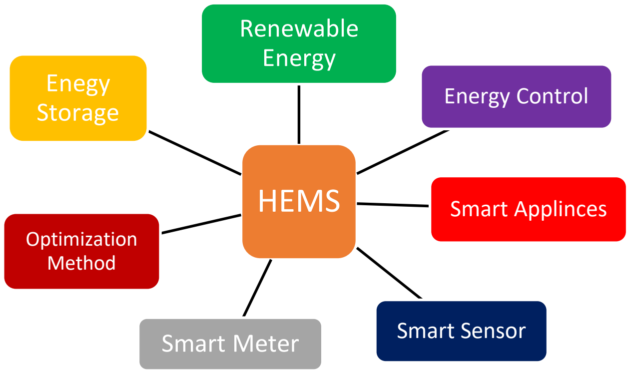

Fig. 3 - Components of HEMSs

Table 2 – Components of HEMSs

S. No.	Components	Operation
1	Smart Meter	To track electricity utilization in residences, smart meters have replaced outdated analog meters. The data on the consumption of energy is transmitted to the provider through a smart meter.
2	Sensing Devices	Sensors are used to measure temperatures, motion, illumination, and usage. As an example, proximity sensor, temperature sensor, infrared sensor, pressure, illumination, and ultrasonic sensors.
3	Appliances	EM mainly considers the home load schedule. Appliances for home use are thus, divided into two categories: conventional appliances and smart appliances (uncontrollable, semi-controllable, and controllable).
4	Controller/ Optimization Techniques	The fundamental element of HEMSs is methods for optimization, which depend on measurements, monitoring components, and consumer preferences.
5	RES (PV)/ BESS	Solar energy is HEMS's primary consideration because it is relatively easy to deploy on rooftops. The BESS is required for solar energy generation to storage of the energy for profitable scheduling.

3. RESIDENTIAL POWER SCHEDULING BASED ON THE DR PROGRAM IN HEMS

Recently, a lot of researchers have become interested in residential DR programs, which are essential for convincing consumers to voluntarily reduce their daily power consumption by scheduling resources and controlling load appliances [30], [31]. DR is defined as deviations from consumers' usual schedules for the consumption of electricity due to variations in the high selling price, and this encourages low electricity usage during periods of high electricity prices or assumed system reliability [32]. DR programs are widely used across Europe and the United States for adjusting timing, overall electricity consumption, and Day-ahead demand levels [33] and IEX and Adani Electricity Mumbai are two companies in India that follow this up [34], [35], and [36].

In the DR program, there are three ways to achieve a response from customers, every one of which takes into consideration the price and the sequence of actions the customer takes. Customers who choose the first option can use less electricity during pricey critical peak times. The level of comfort is temporarily impacted by this choice. The second option allows consumers to adjust their consumption of specific home appliances from peak to off-peak times in response to high electricity prices. The third choice involves a customer using distributed generation on-site. The customer's pattern of electricity uses change in this instance [37]. Customers who take part in DR programs can anticipate lower electricity bills by cutting back on consumption during peak times [38]. Household DR programs, according to the Department of Energy, can be categorized into price-based and incentive categories, as seen in Fig. 4 [39], [40].

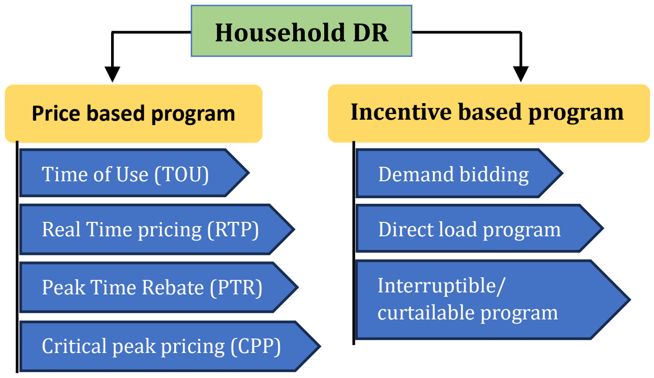

Fig. 4 – Categorization of Household Demand Response Program

3.1 Comparison of household Scheduling DR program

Table 3 provides a comparison of the benefits and drawbacks of various DR programs. The various household DR programs described in Table 3 support consumers in cost-saving, energy-saving, and infrastructure-reduction efforts. The following strategies can be used in the electricity utilization for consumers implementing in DR program: scheduled energy consumption over different periods; using a BESS for emergency backup to decrease dependence on the power grid and applying load reduction strategies to lower energy consumption [47].

Table 3 – Comparison of household DR program [41].

DR	Prices period	Advantage	Disadvantage
Time of use pricing [42]	Electricity cost for the customer varies every day.	According to price changes within a day, the end users may decrease their costs.	Customers should immediately respond if they want to lower their electricity bills.
Real-time pricing [43]	The Cost of electricity for the customer varies every hour in a day.	Price is increased during on-peak and decreased during the off-peak period, thereby the consumer to shift load.	Electricity hourly cost is transmitted to the consumer, and the price is compulsory to follow for end users.
Critical peak pricing [44]	The cost of electricity for the customer varies at any time.	Consumers receive information for a limited period to reduce costs.	A Consumer should be managed and shift household appliances for a limited period.
Direct load DR Program [45]	The cost of electricity for the customer varies at any time from the utility side.	Provider offers a special discount for consumers.	Utilities should switch out or scale back some equipment with customers' authorization to consume energy as efficiently as possible.
curtail-able DR Program [41]	consumer may change the electricity cost at any time.	Customers must respond certain time frame to receive discounts.	Consumers should be managed and shift household appliances for a certain period.
demand bidding [46]	consumer may change the electricity cost at any time.	Utility special offers to obtain discounts when shifting appliances.	A Consumer should be managed and shift household appliances for a certain period.

4. HEMS SCHEDULE OPTIMIZATION TECHNIQUES/ STRATEGIES

The HEMS executes operations with optimization and control strategies. It assists in minimizing the cost of energy while enhancing energy management in home appliances. The many types of optimization techniques and strategies are displayed in Table 4.

HEMS can reduce total power consumption by scheduling household appliances without compromising the comfort of consumers. When scheduling household loads, it is generally recommended to reduce the cost of energy utilized during peak hours and to use a dynamic hourly/monthly electricity price to reduce the overall price of electricity [48]. The most effective scheduling techniques are to turn on/off household appliances at a profitable time including air conditioners, water heaters, washers, clothes dryers, and electric vehicles, as well as non-schedulable household appliances including televisions, home lights, printing devices, ovens, laptops, and refrigerators [49]. The best appliance scheduling for consuming energy has been obtained by combining price-based, profitable scheduling, and optimization techniques [50], [51].

In general, the optimization technique determines the most effective responses to challenges after establishing the objective function with limitations. The objective of a function is frequently defined in terms of scheduled appliances and it could take a minimum error, lowest price, optimal design, and optimal operation [52]. Consumers can now schedule appliances to consume the least amount of energy according to a variety of electricity tariffs, pricing structures, and comfort levels. The four utilizes of fuzzification, defuzzification, rule base, and inference engine were utilized by the Fuzzy logic controller (FLC). In addition to being easy to use and handling both linear and non-linear systems based on linguistic principles, FLC is without a mathematical model [53], [54]. In the [55] study, four household appliances with RES-PV and storage systems were used in the system. Optimization results show that the FLC can minimize load demand by profitable scheduling of household appliances. Researchers in [56] architecture of FLC for HEMS to minimize power consumption. Further, the scheduling controller failed in end-user and pricing signals.

In [57], a mixed-integer nonlinear optimization algorithm was developed for scheduling residential appliances with integrated battery storage. The optimization outcome demonstrated that users can save 22% on their utility bills by shifting their energy usage to off-peak hours. A MILP was also used by researchers in

Table 4 – Optimization Techniques/Strategies.

ref.	Optimization Techniques	Operations
[54]	Fuzzy logic Controller	The fuzzy logic technique is like basic arithmetic for nonlinear, integrated, and complicated systems.
[59]	Microcontroller	The microcontroller is implemented to manage the peak and off-peak hours using the integration of RES.
	GSM	The homeowner and the Utility server can communicate via a GSM modem.
[60]	Context-aware system	Context-aware system for scheduling and controlling household appliances depending on user preference and renewable energy production.
[61]	PIC microcontroller	PIC microcontroller controls and monitors energy output from RES.
	Zigbee	ZigBee is a standard for digital radios with low power consumption and high communication rates that is based on IEEE 802.15.4 standards for remote territorial networks.
[62]	MPPT	The use of Maximum Power Point Tracking (MPPT) can increase the efficiency of power production.
	Microcontroller	The microcontroller is responsible for making decisions.
[63]	IoT	Wireless connection enables remote control of home appliances from anywhere in the world.
[64]	Home Server	Home server used for decision-making.
[61]	Microcontroller (ARM9)	Microcontroller ARM9 is used for decision-making.
[65]	Bluetooth Low Energy (BLE) Algorithm	One of the more affordable algorithms is BLE. Numerous mobile devices and medical equipment applications have adopted BLE technology.
[66]	Wireless Sensor Home Area Network (HAN)	HAN communicates between the power company and the consumer while monitoring and controlling the consumption of energy.
[67]	Mixed Integer Linear Programming	MILP gives high-quality decisions. It focuses on statistical optimization issues with two different types of parameters (continuous domain & integer domain).
[68]	Arduino Controller	The Arduino Controller is an open-source component of equipment with a simple layout and low cost relative to other microcontrollers.
[69]	HEM Algorithm	The HEM Algorithm is implemented in household devices to function automatically.
[70]	Stochastic Dynamic Optimization	For situations requiring multiple stages of optimization and multiple parameters, stochastic dynamic optimization offers a better solution.
	Plug-in Electric-Vehicle Storage	Plug-in Electric-Vehicle Storage is an affordable storage technique.
[71]	Quality of Experience (QoE) Consensus Algorithm	The QoE Algorithm is a reasonably priced algorithm that aims to schedule the appliances by the consumer's profile.
[72]	K-Means Algorithm	K-Means algorithm to control household appliances.
[73]	Genetic Algorithm	In comparison to other techniques, genetic algorithm programming is quite simple and takes a short time.
[74]	Particle Swarm Optimization (PSO)	Optimizes a problem by repeatedly attempting to raise the quality of a potential solution about a specified criterion.
[55]	Linear Programming Method	The best approach for handling complex issues is the LPM technique.
[17]	Autonomous Energy Consumption Scheduler (AECS)	The AECS is a relatively easy solution that allows utility companies and consumers to communicate. AECS's primary goal is to reduce overall energy demand.
	DLC - Direct Load Controller	DLC is a demand response program using Registered home loads.
[64]	ADHAP -Action Dependent Heuristic	The ADHAP algorithm is utilized in many applications including scheduling, managing demand, automobiles, etc.
	Dynamic Programming	These optimization strategies can lower the total expense and be utilized for real-time pricing. The architecture of the ADHAP algorithm is constructed mainly utilizing neural networks.

Table 4 – (Continued.) Optimization Techniques/Strategies.

[73]	Multi-Objective Genetic Algorithm (MOGA)	The MOGA provides multi-objective optimizations and is simple to utilize. MOGA is an algorithm for immediate responses.
[57]	Wind-Driven Optimization (WDO)	The WDO is mainly employed for determining the speed and configuration of wind.
[47]	HEMS Algorithm	The HEMS algorithm is implemented to decrease energy costs, decrease demand during peak times, and improve efficiency.
[6]	Cognitive Radio Technology Genetic Algorithm	Cognitive Radio Technology is a wireless communication technology for smart homes. It gives superior safety for smart houses. The multi-objective is supported by genetic algorithms, which are basic to understand.
[69]	Mixed Strategy Game Theory (MSGT)	The MSGT is a category of applied mathematics. It may monitor users' competitive behavior.
[49]	Model Predictive Control (MPC)	The MPC is a numerical framework created to solve a real-time optimization issue that continuously analyses and controls.
[64]	Dynamic Programming	Dynamic programming is a valuable mathematical technique for making a set of interconnected decisions. It lays out a method for deciding the best combination of options.
[67]	Machine Learning Algorithm	Machine Learning Algorithm is suitable for a large volume of data. Less human interaction. It can handle multi-dimensional and multi-variety data.
[75]	New Binary Backtracking Search Algorithm (NBBSA)	NBBSA is used for multiple solutions with multiple paths.
[76]	GAMS Software	GAMS Software is a powerful problem solver.

[58] to schedule residential electrical appliances for energy efficiency and comfortable living. During the period that the appliances are in use, the PSO approach is also employed to optimize beneficial features[74]. This technique takes into consideration user preferences, environmental factors, and appliance objectives. In [75], the optimization of suitable real-time scheduling techniques for HEMS. For controlling and scheduling the usage of household appliances to off-peak hours while considering DR techniques, this controller utilizes a new binary backtracking search algorithm. The results show that the proposed scheduling method can minimize power consumption during high peak time by approximately 9.7138% by scheduling four household appliances every 7-hours.

The implementation of a genetic algorithm (GA) with monitoring and data collecting was done to schedule household loads with the lowest possible electricity demand and the best possible household energy usage [73]. The system integrates RES including wind turbines and solar panels along with shifting loads. Studies in [77], GA, and MILP under various conditions showed that GA minimizes energy more effectively than the MILP technique. Additionally, considering price volatility, effective optimization, and scheduling technique was implemented to schedule household appliances and save electricity costs.

The optimization of heuristic scheduling algorithms is crucial for obtaining the most effective results. To implement effective EMS to a schedule and management system for smart home appliances and energy storage systems for residential [78]. Home appliances were scheduled in [79] using a wind-driven optimization technique that maximized comfort while saving electricity costs. Due to the optimal scheduling of household appliances, the simulation outcomes showed that the wind-driven optimization technique reduces electrical consumption by 8.3% relative to the use of PSO.

5. BENEFITS OF HEMS

The following impacts using HEMS in the system [80]:

- Reduce the cost of electricity bill.
- Reduce electricity demand.
- Reduce the impact on the environment.
- simple monitoring and control.
- Integration with solar and wind (RES).
- Improve user comfort.
- Communication between utility and consumers.
- Optimizing pricing of scheduled demand response program.
- More accurate billing and improved customer service.

6. CONCLUSION

This review paper thoroughly reviews the field of home energy management systems by reviewing a wide range of research publications that cover many components, challenges, scheduling strategies, and environments. The main goal of these review papers is to clarify the many optimization and scheduling strategies used to reduce individual household power expenditures while maintaining user comfort.

As a result of this thorough review of the literature, it is clear how important home energy management systems are to maintaining an important equilibrium between user comfort and energy efficiency. This review has made significant contributions to the desire for affordable, sustainable, and comfortable living environments by analyzing a wide range of research publications. The results provide an encouraging perspective for the future of energy management in households and support the possibility of reducing home electricity consumption without compromising the quality of lifestyle. Additionally, the work reviewed various HEMS communication protocols, including WiFi, Bluetooth, and ZigBee, and also addressed the development of a HEMS schedule controller based on rules, GA, PSO, ANN, FLC, and ANFIS systems was done using artificial intelligence techniques.

The implementation of self-learning AI techniques and strategies in HEMS will probably grow in the future, taking the place of human involvement in system configuration.

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