Energy management in smart homes

A critical element of HEMS is the use of smart energy meters, which, unlike traditional meters, allow for two-way communication. This two-way flow of information occurs between the meters and various strategies and among the meters themselves [4, 5]. The key benefits of this communication are:

The integration of these mechanisms forms the organization of HEMS. The system''s operations are overseen by a software platform that uses Information and Communication Technology (ICT) to coordinate between the core HEMS unit, sensors, and smart devices within the home. ICT plays a central role in data transmission, particularly in setups where intelligent load scheduling and pattern recognition are essential [6].

Many studies have highlighted the significance of thermostatic regulators and the physical management of energy loads within HEMS. Devices such as heaters, air conditioning units, also heat pumps, particularly HVAC systems, are major suppliers to energy consumption during peak periods. Deliberate scheduling and load shedding for these devices are promising techniques to reduce overall energy use, as explored in various studies on load management for domestic utilization.

In [11, 12], methods like Binary Particle Swarm Optimization (BPSO) and fuzzy Mamdani systems were designed to monitor and schedule electrical loads across ten single-family homes. BPSO optimized appliance usage during non-peak times, while fuzzy logic managed irregular-use devices such as air conditioners. While the thermostat settings are intended to improve energy efficiency, they sometimes compromise user ease. Literature has also recommended a fuzzy regulator for passive cooling in residential buildings.

A novel model for managing electricity loads in smart homes was proposed in [20]. The model incorporated load definition, backup mechanisms, and a clear interface, allowing users to classify and control loads efficiently. In a related study, a dynamic estimating system using the diverse knapsack technique placed consumer appliances on a variable peak pricing schedule, enabling households to achieve cost savings on electricity [21]. Techniques like co-evolutionary particle swarm optimization were also introduced for scheduling loads to maximize benefits for homeowners [22].

In [24], researchers discussed the development of a DC distribution system for homes centered on DC-powered devices connected through IoT. However, the widespread adoption of smart DC-powered homes faced obstacles due to the lack of common standards and protocols. Integrating IoT into such systems could potentially address these challenges.

In [25], the study explored the use of In-Home Display Systems (IHDs) and Automatic Meter Reading (AMR) for energy management communication. The research showed that smart home systems could select display methods such as TVs, smartphones, or tablets based on the environment and user preference. However, concerns arose about the need for a standardized user interface across all home systems to meet the diverse needs of users.

The authors in [28] proposed using programmed algorithms as a method for controlling lighting systems. They used a neural network model to show that this method can guarantee overall and specific savings in the energy of residential lighting systems. To forecast the efficiency of energy conservation, the obtained results of the input vectors were represented in the neural network. Moreover, another study [29] brought into use a household robotics system for home energy management along with the prediction layer that delivered energy as per the expected household events.

In a study, the authors transformed a load scheduling problem into a load commitment problem [30]. They redefined this complex problem as a multi-stage decision-making process, akin to a Markov decision problem, and developed a solution using reinforcement learning techniques to address it effectively.

A framework for managing energy consumption in multi-resident smart homes was also introduced in another study [31]. This system leveraged mobility-aware resources and applied game theory to minimize uncertainties by optimizing utility functions. The research team further created a demand-side management simulation tool that incorporated dynamic resource allocation methods [32, 33]. This hybrid energy management system was used in simulations with household appliances to implement resource management strategies effectively.