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Artificial Intelligence Based Smart Home Energy Management System: A Review

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Abstract - Recently, countries are faced with an unreliable electric power supply to homes and the industry due to insufficient supply from the utility, causing load shedding. With the power utilities struggling to keep the lights on, there are initiatives to invest in backup power solutions and home energy management systems (HEMS) to manage this development. This paper analyzes energy consumption with the existing infrastructure of typical equipment used in homes. An approach called smart home energy management systems (SHEMS) is implemented to balance the power demand and the supply more effectively throughout the smart micro-grid by utilizing control algorithms simulated using MATLAB Simulink. This is achieved by utilizing real data from a home with commercial and residential load features in an urban area. The SHEMS revealed greater management and efficiency in electric power savings by reducing the utilities power demand. The framework adopts a local information management terminal as the core of data storage and scheduling in the home. Based on the timely purchase of electricity from the grid and the generation of electricity in combination with PV systems, an optimized simulation model for the scheduling of a new home energy management system is established. In addition, the application prospects of artificial intelligence in the HEMS are overviewed.

Key Words**:** Balance of Power Demand, Energy efficiency, Smart Distribution Board (SDB), Smart Home Energy Management System (SHEMS), Artificial Intelligence.

1. INTRODUCTION

Over the years, different concepts have been pursued to achieve energy management in buildings. For instance, simulation models forecast consumer electricity usage load profiles with a combined physical and behavioral approach [6]. Furthermore, the application of MATLAB to generate synthetic electricity load profiles of detached houses [2]. However, these methods include not limited to using renewable energy sources (RES), Home energy management systems (HEMS) using controllable devices, or a combination of both RES and HEMS methods. Each energy management method has its benefits and limitations, ranging from cost to practicalities of applying the systems to existing infrastructure or homes. Presently, there is a vast focus on developing power generation plants through independent power producers (IPPs) that rely on the use of available renewable resources [6], [2]. These renewable energy plants contribute 7 % to the South-African power grid. Despite these efforts of increasing the power supply capabilities, the ever increasing energy demand by the consumers makes it difficult to balance the supply versus the consumption needs [2]. To ensure optimization, these RES green energy power sources require efficient control algorithms. Sufficient energy management should use improved control schemes to improve the energy's effectiveness and not waste it. Reducing the current demand on the consumer side requires less energy, thus reducing the overall cost [3]. Energy management can be explained as optimizing the capabilities of the energy system.

There are many suggestions to optimize energy generation and distribution in literature; however, the demand side requires much more increased attention from researchers and the industry. The demand-side management (DSM) is a portfolio of measures to improve the consumption side's energy system [7]. In this regard, recently, a new HEMS area referred to as smart home energy management systems (SHEMS) has evolved as a possible solution, particularly to some of the DSM's problems.

Artificial Intelligence (AI) based methods have become popular in home energy management applications. Zeyu Wang and Ravi S. Srinivasan [24] reviewed the AI-based building energy prediction methods particularly, multiple linear regression, Artificial Neural Networks, and Support Vector Regression. This research revealed a range of limitations on modeling a new building as it relies on the input from the historical performance data, and extensive data is required for the model to be trained. Furthermore, the model would have to be retrained if there are modifications to the building's operation.

Another phenomenon that trends in today’s time is the smart metering method which enables consumers to manage the consumption efficiently, and on the other, the utility companies to manage the production competently. However, with this technology, the data that flows from the Smart Meter at the consumer premises to the utility company corresponds to consumers' utility usage patterns, raising a privacy concern for consumers [25].

This paper analyzes electric energy consumptions with the existing wiring infrastructure of buildings. A SHEMS approach executed using MATLAB Simulink software applying real data acquired from selected buildings in an urban area is proposed. It demonstrates energy-efficient measures that balance the power demand and the supply in buildings.

2. HEMS DESIGN AND DESCRIPTION

A. HEMS Architecture

Fig-1 is a design of the distributed-intelligence microprocessors' overall usefulness in the HEMS system and energy management control devices (EMCD). The multiple power sources integrated with the grid are illustrated in Fig-1. The Home energy management systems (HEMS) are achieved at the smart distribution board (SDB) to supply the demand. To achieve constant and reliable electric power functionality for the users in buildings, the system is simulated using MATLAB Simulink.

Programmable logic controllers (PLCs) and automation controllers are used to implementing controls for the SDB. With these controllers, readings can be retrieved, and controls can be implemented.

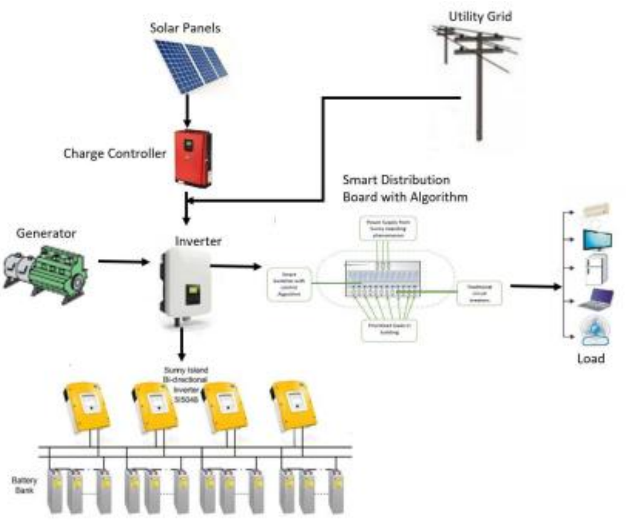

Fig-1: HEMS Architecture

B. HEMS of Smart Distribution Board (SDB)

The HEMS design set up in Fig-1 has the SDB as the main component that can balance energy consumption and supply. The SDB aims to suitably manage power consumption within some parameters ranging from the desired loads to the consumers' maximum demand margins. The HEMS design captures within the SDB control where most users define the parameters, i.e., house structures, occupancy patterns, type of power sources, power management, load assessment, and prioritization. In this manner, the system ensures that the consumer statically reaches the maximum possible accessibility of the power source and provides the best order to arrange the load disconnections.

3. HEMS SYSTEM OPERATION

The incorporation of the SDB is to suitably bring about power consumption with operational parameters under several smart controls. However, the operation procedure is first to inspect the structure and occupancy pattern of the chosen building. Equally, data of the number of rooms and usage, wiring, switching mechanisms, and type of energy efficient methods currently being implemented in homes are collected. Additionally, required are data of the type, capacity, and electrical power source installed for the home's power network.

A model that includes power demand data, consumption rate, and sensitivity to users for load assessment in different rooms concerning the energy demand and supply of a home can be obtained from the following equations [3]:

$$L_r = \sum_{i=1}^{N} HnC_i \qquad (1)$$

$$D = \sum_{r=1}^{N} L_r \qquad (2)$$

Where,

L_r = Load in kW for a particular room (r).

H = Scheduled hours per day.

n = Number of exact loads in a particular room.

D = Daily total load demand in kW by a home.

Ci = Hourly energy consumption from a particular load demand (i).

Equations (1) and (2) are further applied for load prioritization in the building. However, there are four levels of operations that establish the usefulness of the SDB in HEMS arrangement. These levels are obtained from categorizing the supplied power consumption pattern by the respective load demands in a home. Hence, these levels are explained below:

A. Maximum Level of Operation

For this level, the operation of the power supply to meet demand is at maximum. With this, the demand will be less than or equal to the power supply to the house. Hence, all the installed loads in the house are in operation at their full energy consumption level [3].

B. Moderate Level of Operation

The Moderate level of operation accommodates constraints in the consumption rate such that the supply is not exceeded. Some critical conditions may arise that lead to a shortfall in the supply or power management measures, where smart control of load demand will automatically be activated in the house. At this operation level, the SDB makes a smart decision in which only selected loads are allowed based on consumption priority and historical data [3].

C. Low Level of Operation

There is a shortfall of supply in the low level of operation, lower than that of the moderate level. Therefore, the power is not enough to meet all the prioritized consumptions in the house. Since there is still some power supply, only high-priority loads or selected loads operate at this level. However, no more prioritization of loads may be accommodated after this level without leading to an automatic shutdown of consumption [3].

D. User Define Level of Operation

The user in this operation level is an operator with access to control the power demand during emergency conditions. At this level, there is a permit for arbitrary change in consumption rate and switching on initially disconnected loads required for emergency conditions. The historical data of the consumption rate and load demands are not required on this operation level, rather an emergency prioritization strategy [3].

4. CONCLUSIONS

This review paper analyzed the application of the HEMS in a home with existing wiring infrastructure, particularly through the use of an SDB equipped with a controlled switching algorithm to balance the supply and demand of electrical power. The simulation of the different operation levels of the HEMS was simulated and verified using MATLAB Simulink software. The HEMS promotes energy efficiency, which ultimately translates to energy savings, reducing constraints to the consumers' grid and energy cost savings. The HEMS via the SDB can be adapted in energy efficiency initiatives with opportunities in the energy management sphere. It can support existing wiring in home with minimal retrofitting requirements.

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