ENERGY MANAGEMENT FOR SMART HOMES WITH LOAD DEMAND RESPONSE

Musaab
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: musaabmuhammed30@gmail.com

Nabeel Thari
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: ahmednabeelthari@gmail.com

Aslam C V
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: aslu63609@gmail.com

Abdul Basid K P
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: abdulbasith8045@gmail.com

Maya G
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: mayag@mesce.ac.in

Nesihath M K
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: nesihathmk@mesce.ac.in

Nafeesa K
Department of Electrical and Electronics Engineering
MES College of Engineering
Kuttippuram, Kerala, India
Email: nafeesak@mesce.ac.in

***Abstract*—The concept of Smart Home Energy Management System using Internet of things (IoT) has emerged as a potential solution to reduce energy consumption and support sustainable living. The system incorporates real-time monitoring and control of energy usage, allowing house owners to optimize their energy consumption while minimizing wastage. Simulation of the proposed system which is dedicated to energy management with load demand response and energy optimization using Genetic Algorithms (GA) has been done in the MATLAB programming environment. The hardware implementation of the real.time energy monitoring system using IoT is also done. Optimized size of the smart home is obtained using GA through simulation and effective monitoring is done through IoT.**

I. INTRODUCTION

The main goal is to find the best ways to save energy and make homes more sustainable. A mathematical model and optimization algorithm to minimize operational costs while considering the variability of renewable energy generation and demand response potential[1]. This research offers valuable insights into efficiently managing microgrids with renewable energy sources and demand response capabilities. Discussion on real-time smart home management system emphasizing energy-saving strategies is done in [2. Paper [3] explore the architecture and functionality of an IoT smart meterl for home energy management systems. Investigation on the application of genetic algorithms for optimizing energy management in microgrids is discussed in [4]- [5]. Paper [6] focus on developing a low-cost Arduino-based smart energy monitoring system using the Internet of Things (IoT). This paper focuses on the integration of smart meters, energy storage systems, and renewable energy sources to optimize energy consumption and reduce electricity costs in residential settings. This explores how smart homes can be more energy efficient and eco-friendly. It uses genetic algorithms, which is an optimization tools inspired by nature, to manage energy in a better manner. The aim is to not only cut down on energy bills but ensure the power grid stays stable and also to make energy management in smart homes smarter and more sustainable.

II. METHODOLOGY

A. Energy Management With Load Demand Response & Energy Optimization Using GA

In this section, the methodology for energy management in a smart home scenario utilizing load demand response and energy optimization through a Genetic Algorithm (GA) is outlined.The simulation implementation for energy management with load demand response focuses on optimizing cost-efficient savings through GA algorithm. Smart homes include solar power solar power Solar power generation serves as a sustainable and renewable energy source in smart home energy management. Complementing solar power generation, battery storage systems store excess energy generated during peak solar hours for later use when sunlight is insufficient. Efficient management of battery storage enhances energy resilience, reduces peak demand, and optimizes cost savings in smart home energy systems. The energy management strategy considers peak and non-peak hour scenarios, integrating solar power generation and battery storage to optimize energy efficiency and cost saving. During peak hours, DR mechanisms can mitigate grid strain by shifting or curtailing energy usage, while non-peak hours offer flexibility for energy consumption patterns to enhance efficiency and cost savings.

1) Energy management algorithm: The energy management algorithm incorporates factors such as load profiles, solar power generation, battery capacity, and demand response strategies.

By formulating mathematical models and algorithms, the management process dynamically allocates energy from different sources to meet demand, minimize costs, and maximize renewable energy utilization. . The energy management algorithm initializes data and parameters, determines energy consumption, executes peak and non-peak hour energy management logic, calculates costs, visualizes results, compares total costs, and provides insights. During peak hours, the emphasis is on maximizing energy efficiency by considering factors like solar availability and load demand response. Load demand response (DR) is a pivotal aspect of energy management optimization, allowing for adjustments in appliance electricity consumption based on external factors like pricing signals and grid conditions.

2) Energy management during non peak hours: Energy Management Logic:
-Energy from Solar:

$$TE_{Solar}(i) = min(SolarPower(i), TE_{Consumed}(i)) \quad (1)$$

Energy from Grid:

$$TE_{Grid}(i) = max(0, (TE_{Consumed}(i) - TE_{Solar}(i))) \quad (2)$$

Peak Hour Energy Management Logic: - If solar power generation is sufficient

$$TE_{solar}(i) = min(SolarPower(i), TE_{Consumed}(i)) \quad (3)$$

If solar power generation is insufficient, and battery storage is available:

$$TE_{solar}(i) = solarpower(i) + min(TE_{consumed}(i) - solarpower(i), fracBSBD) \quad (4)$$

- Update battery storage:

$$BS = max(0, BS - (TE_{consumed}(i) - solarpower(i)) * BC) \quad (5)$$

Non-peak Hour Energy Management Logic: - If solar power generation is sufficient:

$$TE_{solar}(i) = TE_{consumed}(i) \quad (6)$$

- If solar power generation is insufficient:

$$TE_{solar}(i) = solarpower(i) \quad (7)$$

$$TE_{grid}(i) = max(0, TE_{consumed}(i) - solarpower(i)) \quad (8)$$

Total Costs Calculation: -Total Cost without EM

$$TotalcostEMno(i) = \Sigma_{j=1}^{k} load_j(i) gridpricepeak \quad (9)$$

Total Cost with EM - For EM during peak hours:

$$TC_{solar} = TE_{solar}(i) solarprice \quad (10)$$

$$TC_{grid} = TE_{grid}(i) gridpricepeak \quad (11)$$

$$TC_{battery} = batteryusedbatterycost \quad (12)$$

$$TCEM(i) = TC_{solar} + TC_{grid} + TC_{battery} \quad (13)$$

- For EM during non-peak hours

$$TC_{solar} = TE_{solar}(i) solarprice \quad (14)$$

$$TC_{grid} = TE_{grid}(i) gridpricenonpeak \quad (15)$$

$$TCEM(i) = TC_{solar} + TC_{grid} \quad (16)$$

where (i) EM-ENERGYMANAGEMENT
(ii)TE- TOTALENERGY
(iii)TC-TOTALCOST
(iv)BS-batterystorage
(v)BD-BATTERYDISCHARGE
(vi)BC-BATTERYCHARGE
These equations are utilized to optimize energy management and calculate associated costs based on different scenarios, considering peak and non-peak hours, solar power generation, battery storage, and grid electricity prices.

3) Energy Optimization Using Genetic Algorithm: The energy management optimization algorithm employs a genetic algorithm to iteratively optimize power source allocations for efficient energy usage. Initially, the algorithm initializes parameters such as cost factors, power limits, and genetic algorithm settings. It then defines a fitness function to evaluate the cost based on random solutions, and the genetic algorithm loop begins. Within each iteration, the algorithm evaluates the fitness of each solution, selects the best individuals, performs crossover and mutation operations to create new solutions, and updates the population. The algorithm tracks power source consumption throughout the optimization process and visualizes the results. This iterative process continues until a termination condition is met, at which point the algorithm displays the optimized solution and the corresponding cost savings achieved. The algorithm's systematic approach enables the efficient management of energy resources to minimize costs and enhance sustainability. Objective Function: The objective is to minimize the total cost of energy consumption by optimizing the allocation of power from solar, grid, and battery sources. The objective function can be defined as:

$$TC = SU * SolarPrice + GU * GridPrice + BU * BatteryCost \quad (17)$$

SU represents solar usage, GU represents grid usage and BU represents battery usage Decision Variables: The decision variables represent the power allocation from solar, grid, and battery sources.he distribution of power from solar, grid, and battery sources. The population is initialized

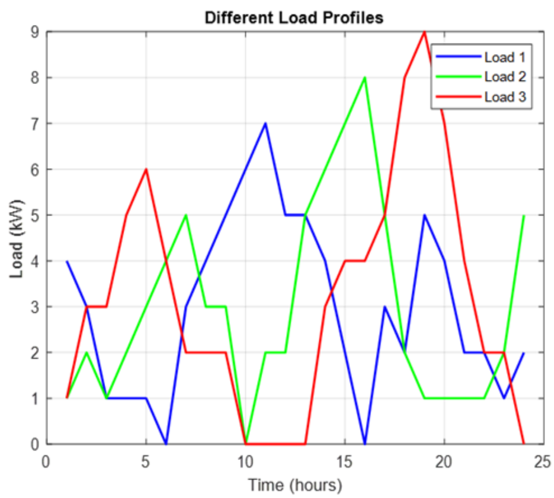

Fig. 1. Daily Load Pattern

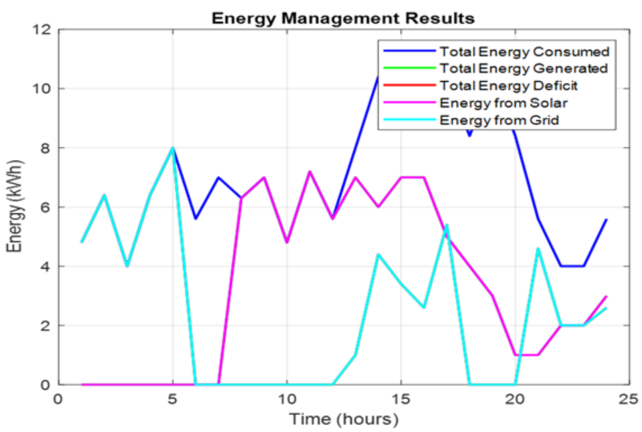

Fig. 2. Energy Management done for the system

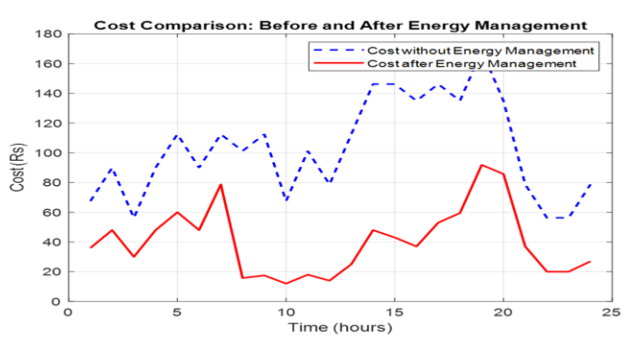

Fig. 3. Cost of electricity with and without energy management algorithm

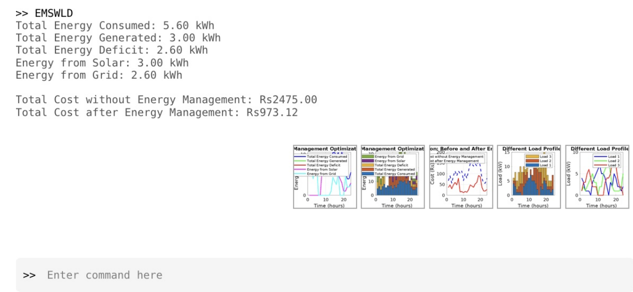

Fig. 4. Output of Energy Optimization with Load DR

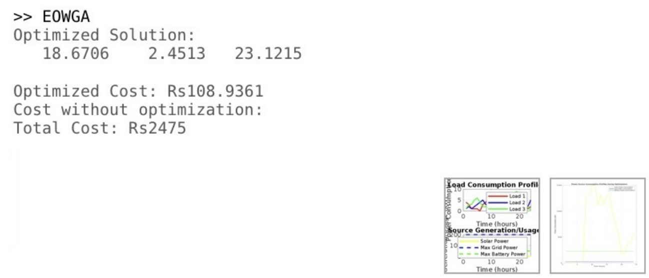

Fig. 5. Output of Energy Optimization using GA

4) Results and discussion: Fig. 1 shows the daily load pattern of load1, load2 and load3 in a smart home. Fig. 2 shows the energy management result of smart homes. Fig.3 shows the total cost of electricity with and without energy management algorithm. After the GA optimization process, the best solution with the lowest total cost is identified.The optimized solution represents the power allocation from solar, grid, and battery sources that minimize energy costs.The results demonstrate that the minimum cost achieved through energy optimization using GA (refer figure 5) has been significantly reduced by 95.6% (from Rs. 2475 to Rs. 108.93) compared to the previous energy management implementation.

By implementing GA optimization, the cost reduction is much more substantial, indicating its efficiency in minimizing costs. Comparing both simulation results (figure 3 and 5), it is evident that energy optimization using GA offers greater (refer figure 3) cost reduction benefits. Specifically, in the same load profile scenario, energy management with load demand response resulted in a 60.69% reduction from the non-optimized case, while GA optimization achieved a remarkable 95.6% reduction. This significant difference underscores the superior efficiency and cost minimization capabilities of energy optimization using GA.

III. Hardware Setup

This section details with the hardware setup. The load specification for setting up the hardware is given in the Table 1. The aim of the implementation is to ensure the collection of real-time energy consumption data accurately and to transmit data to a designated storage or processing unit seamlessly.

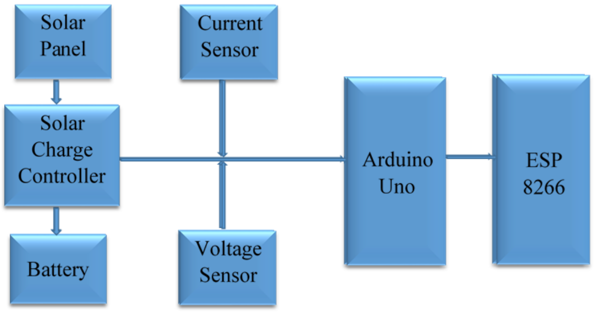

Fig. 6. Block diagram

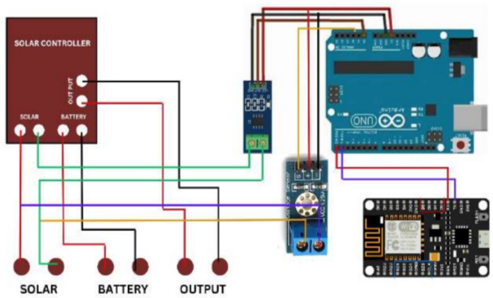

Fig. 7. Circuit diagram

Cloud Service is Integrated with the hardware for data storage and analysis. The cloud service is Configured to receive real-time energy data from the hardware components. A user interface or dashboard to monitor energy consumption data stored in the cloud service is developed, ensuring easy access and visualisation for users. Figure. 6 and Figure 7 shows the block diagram and circuit diagram of the hardware setup respectively. The solar panel chargers the battery through the charge controller. Thereby supplying the load uninterruptedly even during low sunlight conditions. Figure 8 shows the hardware setup. The controller collects the data from the sensors and ESP8266 Module enable data transfer to external devices and cloud where the data is stored. The real time data can be monitored and analysed at remote location. Ubidots cloud service enables users to efficiently manage and monitor their renewable energy system. The system operates by collecting data from sensors that measure amperes and voltage output from solar panels and a battery bank. The sensors continuously gather data at 5-second intervals, capturing real-time information on the performance of the solar panels and battery bank. The microcontroller processes this data and sends it to the Ubidots cloud service using either Wi-Fi or Ethernet connectivity. Once the data reaches the Ubidots platform, it is stored and displayed on a customizable dashboard that provides users with a comprehensive overview of their renewable energy system. The dashboard on Ubidots is updated every 5 seconds to reflect the most recent data received from the sensors. Figure 9. shows the Ubidot console. By monitoring these key metrics in real time, users can track the efficiency of their solar and battery system, identify any fluctuations or anomalies, and make informed decisions to optimise energy usage.

TABLE I
LOAD SPECIFICATION

Load	Specification	Quantity	Total Wattage
Bulb	9W	1	9W
Fan	5W	1	5W
Charger	20W	1	20W
Controller	2W(max)	1	2W
Total Wattage			36W

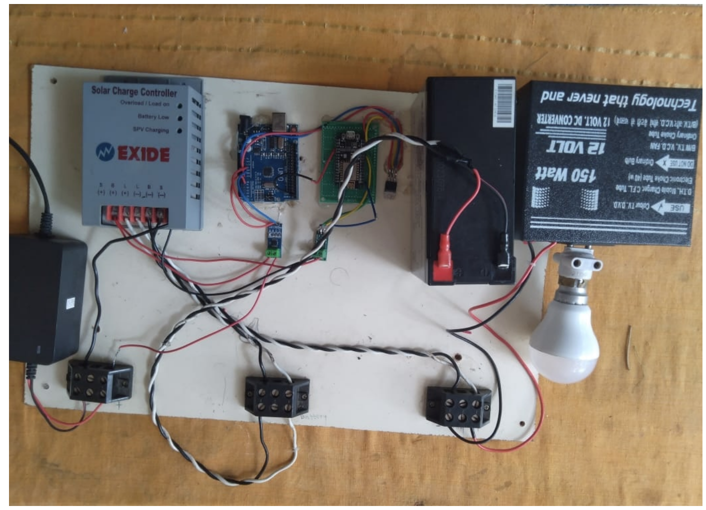

Fig. 8. Hardware setup

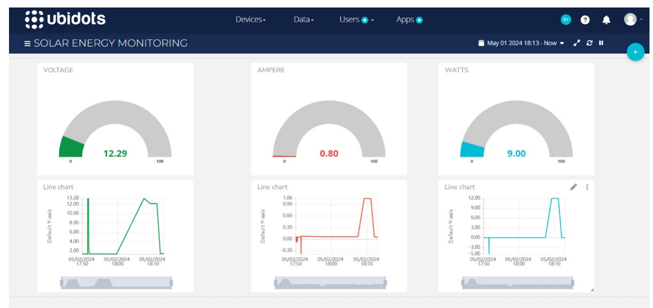

Fig. 9. Ubidot Display

IV. CONCLUSION

This paper effectively explored the effectiveness of genetic algorithms in optimizing energy management for smart homes using simulation-based approaches, focusing on load demand response strategies. It aligns with the growing trend of smart technology adoption and sustainability goals. The comparison of cost function without energy management and with energy management was done in MATLAB programming. Energy optimization using GA incorporating energy management with load demand response considering the cost factor was also done. The optimized solution represents the power allocation from solar, grid, and battery sources that minimize energy costs.The results demonstrate that the minimum cost achieved through energy optimization using GA. The implementation of the hardware system enabled the collection and monitoring of real-time energy data, facilitating proactive energy management practices. Based on the findings, it has been concluded that implementing energy management systems with load demand response in smart homes is a promising solution for efficient energy consumption. The hardware setup described provides a robust and efficient solution for real-time energy monitoring of solar panels and battery systems. By utilizing sensors, a microcontroller, and a Wi-Fi module to transmit data to the Ubidots cloud service, users can access detailed insights remotely and make informed decisions to optimize system efficiency.

REFERENCES

[1] Nwulu, Nnamdi I and Xia, Xiaohua, *Optimal dispatch for a microgrid incorporating renewables and demand response*, Vol.101, pp-16–28. Renewable energy, Elsevier, 2017.

[2] Elkholy, Mahmoud H and Senjyu, Tomonobu and Lotfy, Mohammed Elsayed and Elgarhy, Abdelrahman and Ali, Nehad S and Gaafar, Tamer S, *Design and implementation of a real-time smart home management system considering energy saving*, Vol. 14, no. 21, page-13840. Sustainability, MDPI, 2022.

[3] Munoz, Omar and Ruelas, Adolfo and Rosales, Pedro and Acuña, Alexis and Suastegui, Alejandro and Lara, Fernando, *Design and development of an IoT smart meter with load control for home energy management systems*, Vol. 22, no. 19, page-7536. sensors, MDPI, 2022.

[4] Torkan, Ramin and Ilinca, Adrian and Ghorbanzadeh, Milad, *A genetic algorithm optimization approach for smart energy management of microgrids*, Vol. 197, pp-857–863. Renewable Energy, Elsevier, 2022.

[5] Arabali, Amirsaman and Ghofrani, Mahmoud and Etezadi-Amoli, Mehdi and Fadali, M Sami and Baghzouz, Yahia, *Genetic-algorithm-based optimization approach for energy management*, Vol. 28, no.1, pp 162–170. IEEE Transactions on Power Delivery, IEEE, 2012.

[6] Govindarajan, R and Meikandasivam, S and Vijayakumar, D, *Low cost Arduino based smart energy monitoring system using internet of things*, Vol. 14, no. 1, pp 170–177. Journal of Engineering and Applied Sciences, 2019.