IAES Journal of Electrical and Electronics Engineering
Vol. 6, No. 1, June 2019, pp. 6~9
ISSN: 2338-7432, DOI: 10.11591/jeee.v6i1.pp6-9

Household electrical control: smart home automation, energy management, protection, and intelligent load regulation

Tole Sutikno[1], Zulfikar Ahmad[1], Watra Arsadiando[2]
[1]Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Embedded Systems and Power Electronics Research Group, Yogyakarta, Indonesia

Article Info

Article history:

Received Dec 11, 2017
Revised Jul 28, 2018
Accepted Aug 31, 2018

Keywords:

Demand response
Electrical protection
Home automation
Home energy management system
Household electrical control
Load scheduling
Smart home

ABSTRACT

Household electrical control has evolved from conventional switching and circuit protection into integrated systems capable of monitoring, coordinating, and optimizing residential electricity consumption. Increasing energy demand, distributed renewable generation, electric vehicles, and the development of smart grids have created new requirements for safe, flexible, and efficient residential electrical installations. This review examines developments reported up to 2018, focusing on household load control, home energy management systems, smart metering, communication technologies, electrical protection, and intelligent automation. It discusses the contributions of sensors, microcontrollers, programmable controllers, wireless networks, and optimization algorithms to residential electrical operation. Conventional control remains essential for switching, overload protection, and basic appliance regulation, while modern systems extend these functions through real-time monitoring, automated scheduling, and demand response. Research demonstrates that coordinated appliance control can reduce peak demand and electricity costs, although the outcomes depend on user behavior, tariff structures, communication reliability, and equipment interoperability. Cybersecurity, privacy, installation costs, and the complexity of integrating legacy appliances remain significant challenges. The review concludes that effective household electrical control requires a coordinated architecture combining electrical protection, reliable sensing, interoperable communication, and user-centered energy management.

This is an open access article under the CC BY-SA license.

1. INTRODUCTION

Household electrical systems have traditionally been designed to distribute electricity safely and provide convenient control of lighting, appliances, and other domestic equipment. Conventional installations rely on distribution boards, circuit breakers, switches, wiring, and basic control devices to deliver electrical power to residential loads. However, increasing electricity consumption and the growing number of electronically controlled appliances have made household electrical management more complex. Modern homes increasingly require systems that can monitor consumption, coordinate loads, respond to electricity prices, and integrate distributed energy resources.

The central engineering problem is how to achieve safe and efficient electrical operation without compromising occupant comfort or convenience. Household loads differ significantly in their operating characteristics, controllability, and energy requirements. Some appliances, such as refrigerators and lighting systems, require immediate availability, while washing machines, water heaters, and electric vehicle chargers may offer scheduling flexibility. These differences create opportunities for intelligent control, but they also require accurate monitoring, reliable communication, and suitable decision-making algorithms [1]–[3].

This review examines household electrical control from an electrical and electronic engineering perspective, using literature published no later than 2018. It covers conventional electrical control and protection, smart home architectures, home energy management systems (HEMS), communication technologies, demand response, and intelligent scheduling. Particular attention is given to the relationship

between sensing, control hardware, communication, and residential power management. The objective is to identify the technical developments and unresolved problems that influence the design of reliable and energy-efficient household electrical systems.

2. CONVENTIONAL HOUSEHOLD ELECTRICAL CONTROL AND PROTECTION

Conventional household electrical control provides the basic infrastructure for safe electricity distribution and appliance operation. A typical residential installation includes a service connection, distribution board, protective devices, branch circuits, switches, sockets, and electrical loads. Miniature circuit breakers protect circuits against overload and short-circuit conditions, while residual-current devices provide protection against certain earth-leakage faults. These devices remain fundamental because intelligent automation cannot replace the need for appropriate electrical protection and compliant installation practices.

Traditional control is generally decentralized and manually operated. Occupants use switches, thermostats, timers, and appliance interfaces to determine when electrical equipment operates. Although this arrangement is relatively simple and inexpensive, it offers limited visibility into real-time consumption and provides little coordination among independent loads. As a result, simultaneous appliance operation can contribute to residential peak demand, while inefficient operating schedules may increase electricity costs [4].

Electrical safety monitoring can also be improved through electronic sensing and communication. Huang *et al.* [5] proposed a ZigBee-based monitoring and protection system for building electrical safety, addressing limitations of conventional distribution protection in detecting certain hazardous conditions. Their work illustrates how wireless monitoring can complement conventional circuit protection by providing additional information about electrical outlets and distribution conditions. Nevertheless, electronic monitoring should be treated as an additional safety layer rather than a substitute for certified protective devices and proper wiring practices.

3. SMART HOME ELECTRICAL CONTROL ARCHITECTURE

A smart home electrical control system integrates sensors, controllers, communication networks, actuators, and user interfaces into a coordinated architecture. Sensors measure electrical quantities and environmental conditions, while controllers interpret these measurements and determine appropriate actions. Switching devices, smart plugs, relays, dimmers, and variable-speed drives then execute the control commands. This architecture enables household equipment to be monitored and operated locally or remotely through a centralized or distributed control platform [6], [7].

The controller may be implemented using a microcontroller, embedded computer, programmable logic controller, or dedicated home energy gateway. Its responsibilities can include collecting sensor data, identifying appliance operating states, executing control rules, and communicating with external services. Han and Lim demonstrated a smart home energy management system using IEEE 802.15.4 and ZigBee technologies for appliance control and energy management [6]. Kim *et al.* [7] later investigated an IoT-based HEMS architecture operating over dynamic home area networks, illustrating the potential for flexible communication and device integration.

Interoperability is a major consideration when different manufacturers supply household appliances and automation equipment. Devices may use different communication protocols, data formats, and control interfaces, making direct integration difficult. A practical system therefore requires a suitable gateway or standardized communication architecture to coordinate heterogeneous equipment. Without interoperability, the installation of additional smart devices can increase system complexity and reduce long-term maintainability [6]–[8].

4. HOME ENERGY MANAGEMENT SYSTEMS

HEMS extends conventional household control by coordinating electricity consumption according to user preferences, energy prices, and available resources. A typical system combines smart metering, appliance monitoring, a communication network, a central controller, and a scheduling algorithm. Its main functions include monitoring consumption, identifying controllable loads, determining operating schedules, and communicating control decisions to appliances. Zhou *et al.* [9] reviewed HEMS configurations and scheduling strategies, emphasizing the role of smart grids, advanced metering, energy storage, and responsive household demand.

Energy monitoring is a necessary foundation for effective household control. Intrusive load monitoring uses individual sensors or meters installed at appliance level, whereas non-intrusive load monitoring attempts to identify appliance activity from measurements at a common electrical connection.

Abubakar *et al.* [10] reviewed these approaches and their applications in appliance energy management, highlighting their relevance to residential consumption analysis. Accurate monitoring helps identify high-consumption appliances and provides information for scheduling, fault detection, and energy-saving decisions.

A HEMS can also coordinate local generation and storage. Residential photovoltaic systems, batteries, and electric vehicles create bidirectional energy flows that complicate conventional household load management. Liu *et al.* [11] reviewed smart HEMS and identified demand response, load shifting, peak shaving, and integration with distributed energy resources as important functions. Shareef *et al.* [12] further examined demand response programs, smart technologies, and intelligent controllers, showing how optimization and artificial intelligence can support household energy scheduling.

5. DEMAND RESPONSE AND INTELLIGENT LOAD SCHEDULING

Demand response enables residential consumers to modify electricity consumption in response to electricity prices, incentives, or requests from the utility. Price-based programs may use time-of-use tariffs, critical peak pricing, or real-time electricity prices. Incentive-based programs may reward consumers for reducing consumption during specified periods. These approaches provide a mechanism for coordinating household demand with wider electricity-system requirements [13], [14].

The scheduling of household appliances is one of the principal control functions in demand response. Deferrable loads can be shifted to periods with lower electricity prices or higher renewable generation, while essential loads remain available according to user requirements. Chen *et al.* [15] investigated stochastic and robust optimization for real-time price-based demand response management of residential appliances [15]. Pipattanasomporn *et al.* [16] also developed an intelligent HEMS algorithm for demand response analysis, demonstrating how coordinated appliance operation can support residential energy management [16].

More recent residential studies have incorporated user preferences, storage systems, and controllable appliances into scheduling decisions. Fotouhi Ghazvini *et al.* [17] proposed a demand response implementation for smart households that coordinates controllable consumption and energy storage to reduce costs. Such approaches demonstrate that household electrical control is not simply a matter of switching loads off during peak periods. Instead, it requires balancing energy cost, peak demand, appliance operating constraints, and occupant comfort.

6. COMMUNICATION TECHNOLOGIES AND INTERNET OF THINGS

Communication networks enable household electrical devices to exchange measurement data and control commands. Common technologies include ZigBee, Wi-Fi, Bluetooth, power-line communication, and other wireless sensor network protocols. The selection depends on communication range, data rate, energy consumption, installation complexity, reliability, and cost. Han and Lim demonstrated the use of IEEE 802.15.4 and ZigBee for smart home energy management, while examined dynamic home area networks for IoT-based energy management [6], [7].

IoT technology extends household control by connecting appliances, sensors, meters, and gateways to local or cloud-based services. Al-Ali *et al.* [18] presented a smart HEMS based on IoT and big-data analytics, illustrating how connected devices and data analysis can support residential monitoring and energy management. These systems can provide remote access, consumption visualization, automated scheduling, and historical analysis. However, dependable operation requires reliable connectivity, appropriate device authentication, data protection, and resilience against communication failures.

7. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Despite substantial progress, household electrical control still faces challenges involving interoperability, cybersecurity, privacy, and implementation cost. Connected appliances may expose household networks to unauthorized access if communication and authentication mechanisms are inadequately designed. Energy consumption data can also reveal occupancy patterns and personal routines, making privacy protection an important system requirement. These concerns should be addressed during architecture design rather than treated as optional additions after deployment [8], [12].

Another challenge is balancing energy optimization with occupant comfort and convenience. An algorithm that minimizes electricity costs may produce unacceptable appliance schedules if user preferences and operating constraints are ignored. Shaikh *et al.* [3] reviewed optimized control systems for building energy and comfort management, emphasizing the importance of balancing energy performance with indoor environmental requirements. Household controllers should therefore incorporate user-defined priorities, appliance constraints, and manual override functions.

Further research should focus on low-cost interoperable systems, reliable local control, and improved monitoring of household electrical loads. Intelligent scheduling can be combined with forecasting, renewable generation, and storage management to improve residential flexibility. However, algorithms must be validated using realistic household data and practical hardware rather than simulation alone. Meyabadi and Deihimi's review of demand-side management also highlights the importance of reconsidering the technical and organizational framework through which consumer-side energy control is implemented.

8. CONCLUSION

Household electrical control has developed from conventional switching and circuit protection into integrated systems capable of monitoring, automating, and optimizing residential electricity use. Smart sensors, embedded controllers, communication networks, and HEMS provide the technical foundation for coordinated appliance operation and demand response. Research demonstrates that intelligent scheduling can reduce peak demand and electricity costs while supporting the integration of renewable generation and storage. Nevertheless, successful implementation depends on reliable sensing, interoperable devices, robust communication, and careful consideration of user comfort.

Electrical safety must remain the foundation of every household control architecture. Smart monitoring and automation should complement, rather than replace, correctly selected protective devices and compliant electrical installations. Future systems should combine secure communication, local fail-safe operation, adaptive energy management, and user-centered control strategies. Ultimately, effective household electrical control requires an integrated engineering approach that treats safety, energy efficiency, reliability, and occupant requirements as equally important design objectives.

REFERENCES

[1] P. Palensky and D. Dietrich, "Demand side management: demand response, intelligent energy systems, and smart loads," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 3, pp. 381–388, Aug. 2011, doi: 10.1109/tii.2011.2158841.

[2] J. S. Vardakas, N. Zorba, and C. V Verikoukis, "A survey on demand response programs in smart grids: pricing methods and optimization algorithms," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 1, pp. 152–178, 2015, doi: 10.1109/comst.2014.2341586.

[3] P. H. Shaikh, N. B. M. Nor, P. Nallagownden, I. Elamvazuthi, and T. Ibrahim, "A review on optimized control systems for building energy and comfort management of smart sustainable buildings," *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 409–429, 2014, doi: 10.1016/j.rser.2014.03.027.

[4] A. K. Nanda and C. K. Panigrahi, "Review on smart home energy management," *International Journal of Ambient Energy*, vol. 37, no. 5, pp. 541–546, Feb. 2015, doi: 10.1080/01430750.2015.1004107.

[5] L.-C. Huang, H.-C. Chang, C.-C. Chen, and C.-C. Kuo, "A ZigBee-based monitoring and protection system for building electrical safety," *Energy and Buildings*, vol. 43, no. 6, pp. 1418–1426, 2011, doi: 10.1016/j.enbuild.2011.02.001.

[6] D. Han and J. Lim, "Smart home energy management system using IEEE 802.15.4 and zigbee," *IEEE Transactions on Consumer Electronics*, vol. 56, no. 3, pp. 1403–1410, Aug. 2010, doi: 10.1109/tce.2010.5606276.

[7] J. Kim, J. Byun, D. Jeong, M. Choi, B. Kang, and S. Park, "An IoT-based home energy management system over dynamic home area networks," *International Journal of Distributed Sensor Networks*, vol. 2015, pp. 1–15, 2015, doi: 10.1155/2015/828023.

[8] A. R. Al-Ali, I. A. Zualkernan, M. Rashid, R. Gupta, and M. Alikarar, "A smart home energy management system using IoT and big data analytics approach," *IEEE Transactions on Consumer Electronics*, vol. 63, no. 4, pp. 426–434, Nov. 2017, doi: 10.1109/tce.2017.015014.

[9] B. Zhou *et al.*, "Smart home energy management systems: Concept, configurations, and scheduling strategies," *Renewable and Sustainable Energy Reviews*, vol. 61, pp. 30–40, Aug. 2016, doi: 10.1016/j.rser.2016.03.047.

[10] I. Abubakar, S. N. Khalid, M. W. Mustafa, H. Shareef, and M. Mustapha, "Application of load monitoring in appliances' energy management – A review," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 235–245, Jan. 2017, doi: 10.1016/j.rser.2016.09.064.

[11] Y. Liu, B. Qiu, X. Fan, H. Zhu, and B. Han, "Review of smart home energy management systems," *Energy Procedia*, vol. 104, pp. 504–508, Dec. 2016, doi: 10.1016/j.egypro.2016.12.085.

[12] H. Shareef, M. S. Ahmed, A. Mohamed, and E. Al Hassan, "Review on home energy management system considering demand responses, smart technologies, and intelligent controllers," *IEEE Access*, vol. 6, pp. 24498–24509, 2018, doi: 10.1109/access.2018.2831917.

[13] A.-H. Mohsenian-Rad and A. Leon-Garcia, "Optimal residential load control with price prediction in real-time electricity pricing environments," *IEEE Transactions on Smart Grid*, vol. 1, no. 2, pp. 120–133, 2010, doi: 10.1109/tsg.2010.2055903.

[14] A. F. Meyabadi and M. H. Deihimi, "A review of demand-side management: Reconsidering theoretical framework," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 367–379, Dec. 2017, doi: 10.1016/j.rser.2017.05.207.

[15] Z. Chen, L. Wu, and Y. Fu, "Real-time price-based demand response management for residential appliances via stochastic optimization and robust optimization," *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp. 1822–1831, Dec. 2012, doi: 10.1109/tsg.2012.2212729.

[16] M. Pipattanasomporn, M. Kuzlu, and S. Rahman, "An algorithm for intelligent home energy management and demand response analysis," *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp. 2166–2173, Dec. 2012, doi: 10.1109/tsg.2012.2201182.

[17] M. A. Fotouhi Ghazvini, J. Soares, O. Abrishambaf, R. Castro, and Z. Vale, "Demand response implementation in smart households," *Energy and Buildings*, vol. 143, pp. 129–148, May 2017, doi: 10.1016/j.enbuild.2017.03.020.