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Control strategy for micro grid in renewable energy sources

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ABSTRACT

This paper introduces an energy management strategy for a hybrid renewable micro-grid system. The efficient operation of a hybrid renewable micro-grid system requires an advanced energy management strategy able to coordinate the complex interactions between different energy sources and loads. This strategy must consider some factors such as weather fluctuations and demand variations. Its significance lies in achieving the overarching objectives of these systems, including optimizing renewable energy utilization, reducing greenhouse gas emissions, promoting energy independence, and ensuring grid resilience. The intermittent nature of renewable sources necessitates a predictive approach that anticipates the energy availability and adjusts the system operation. The aim of this study was to develop an energy management system for a hybrid renewable micro-grid system to optimize the deployment of renewable energy resources and increase their integration in the power system. Therefore, the main objective of this work was to develop an energy management strategy that controls the flow of energy between the hybrid micro-grid system and the load connected directly as well as the load connected to the utility grid using MATLAB/Simulink software. The second objective was to control the charging and discharging of the battery.

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Introduction

The global energy landscape is undergoing a paradigm shift, marked by a heightened focus on sustainability and a transition towards renewable energy sources [1]. Micro-grid systems, characterized by their localized generation and distribution capabilities, have gained prominence as a means to enhance energy resilience and efficiency [2]. Hybrid micro-grid systems combine multiple sources of energy, often integrating conventional and renewable sources, to create a robust and adaptive energy infrastructure.

This integration necessitates sophisticated energy management strategies to harness the full potential of diverse energy resources and ensure a reliable power supply. While the integration of renewable energy into micro-grid systems offers many benefits, it introduces challenges that must be addressed for effetive implementation. The intermittent nature of renewable sources, variability in energy production, and the mismatch between energy supply and demand pose significant hurdles [3].

Additionally, the integration of diverse energy storage technologies and the seamless coordination of multiple energy sources require advanced control strategies. Addressing these challenges is essential for realizing the full economic and environmental potential of hybrid micro-grid systems [4]. A thorough examination of the existing literature reveals a growing body of research dedicated to the optimization f hybrid micro-grid systems. Studies have explored various aspects, including energy management algorithms, control strategies, and the integration of different renewable energy sources [5]. Different contributions have been made in the areas of predictive modeling, real-time monitoring, and economic dispatch strategies. However, there remains a need for more comprehensive approaches that address the unique challenges of hybrid micro-grid systems, considering both technical and economic factors [6, 7]. This research aimed to contribute to the existing body of knowledge by developing an advanced energy management strategy for hybrid micro-grid systems using renewable energy sources. The study explored integration of solar, wind, and diesel generator, coupled with a battery energy storage, to create a resilient and effcient energy network. The focus was on addressing challenges related to intermittency, optimizing energy dispatch, and ensuring grid stability.

The motivation behind this research lied in the imperative to accelerate the adoption of sustainable energy solutions. By developing a robust energy management strategy for hybrid micro-grid systems, this study provides practical insights for engineers, policymakers, and stakeholders involved in the planning and implementation ofrenewable energy projects.

Related work

Hybrid microgrid energy management and control based on metaheuristic—driven vector decoupled algorithm considering

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energy management and control of hybrid microgrids is a challenging task due to the varying nature of operation between AC and DC components which leads to voltage and frequency issues. This work utilizes a metaheuristic- based vector-decoupled algorithm to balance the control and operation of hybrid microgrids in the presence of stochastic renewable energy sources and electric vehicles charging structure. The AC and DC parts of the microgrid are coupled via a bidirectional interlinking converter, with the AC side connected to a synchronous generator and portable AC loads, while the DC side is connected to a photovoltaic system and an electric vehicle charging system. To properly ensure safe and efficient exchange of power within allowable voltage and frequency levels, the vector-decoupled control parameters of the bidirectional converter are tuned via hybridization of particle swarm optimization and artificial physics optimization. The proposed control algorithm ensures the stability of both voltage and frequency levels during the severe condition of islanding operation andhigh pulsed demands conditions as well as the variability of renewable source production.

A novel and comprehensive mechanism for the energy management of a hybrid micro-grid system Renewable energy has gained enormous popularity in recent years. Both independent and grid-connected renewable energy generating capacity has increased. The potential to create green energy that is both ecologically benign and financially operative is the primary argument. To reduce the cost of maintaining a hybrid microgrid, this study provides a novel control algorithm as well as a suitable energy management system. The energy storage technologies are used in the hybrid microgrid system which consist of photovoltaic cell, fuel cell and supercapacitor. The optimal power flow in the hybrid microgrid component is developed using energy management system which consents control system to batteries, load and economic analysis with the input of electric grid. In this paper supercapacitor is which is directly connected to DC and provide fast response to load changing. DC voltage, current and hybrid microgrid is managed using the local control system.

Energy management of renewable energy-based microgrid system with HESS for various operation modes a ramp-rate control approach for a grid-connected MG with a hybrid energy storage system. Distributed energy sources (DERs), such as solar photovoltaic (PV) and wind, combined with energy storage (ES) and controllable loads, are critical to a power grid that can handle the intermittent nature of renewable energy sources. Therefore, the complexity of the system is increasing as researchers move towards a more renewable based power grid. An energy management system (EMS) for microgrids must consider the power available in RESs as well as the storage capacity of energy storage devices (ESSs). Modern MGs include a wide range of converters for a variety of applications, including distributed generation interconnection, grid integration, energy storage management systems, and demand management, among others. So, the ramp-rate control smooths fluctuations in photovoltaicpower, which increases system reliability. In the proposed system,

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80 V DC is used to supply high and low power DC loads. The suggested system can extract the maximum amount of energy from RESs, maintain efficient ESS management, and achieves quick DC-link voltage regulation with settling time of 230 ms throughout all

operating modes. These conditions are met by the energy management system, which gives the MG withoperational capability and ensures its reliability.

Methodology

Concept of hybrid micro-grid

A typical hybrid micro-grid system refers to a group of distributed generation (DG) systems based on renewable and/or non-renewable resources, including an energy storage system (ESS) as well as local controllable loads, usually connected to the distribution system. It can either operate in grid connected mode or island mode according to the load condition. Hybrid micro-grid systems can be classified in different categories based on the location, size, application, and connectivity. Three types of hybrid micro-grid configurations exist in general, which are remote, grid-connected and networked. Hybrid micro-grid systems can be principally classified into three categories according the system architecture and voltage characteristics, AC micro-grid, DC micro-grid, and Hybrid AC/DC micro-grid.

A hybrid micro-grid is composed of different distributed generation sources; the power from these DGs is collected, converted and distributed based on the load demands. To assure an effective operation of the system, a control strategy is required and it is important when power electronics interface with the system to constitute a single unit. The control system is very important because it also enables to conserve the specific energy supply and the power quality. Fig-ure1 gives a typical representation of a hybrid micro-grid system, where it can be seen that a micro-grid could also be interconnected with the main grid and includes a diversity of assets and power sources, which provide different services to a range of facilities.

According to the environmental concerns (like atmospheric, ground and water pollution, climate change), the use of fossil fuels, the finite and limited quantities of conventional fuels, the increase in the cost of electrical energy, the need of energy security and the independence of certain nations, increase the necessity to embrace and develop renewable energy resources. The decentralization of electricity supply brings production closer to the point of consumption, increasing system reliability, because when a fault occurs somewhere and as a part of thenetwork is insulated, this will

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not affiect the other branches. Additionally, it increases the efficiency of the entire system because the transmission losses are reduced Hybrid micro-grid systems are getting more attentions due to the increase in energy needs around the world, with a variable rate between nations and continents. For practical and sciatic advantages, important incentives are established to promote the integration of hybrid micro-grid projects for electrocution in remote areas and developing nations.

Architecture ofahybrid micro-grid system

In the pursuit of a resilient, sustainable, and decentralized energy system, hybrid micro-grid architectures have emerged as a cutting-edge solution that integrates the benefits of diverse distributed energy resources, storage

technologies, and intelligent control systems. Figure2 shows the structure of a hybrid micro-grid. The basic architecture includes a variety of

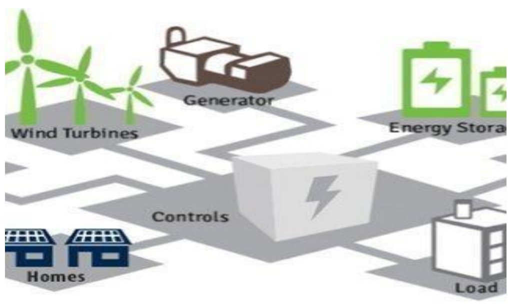

Fig. 1 Hybrid micro-grid

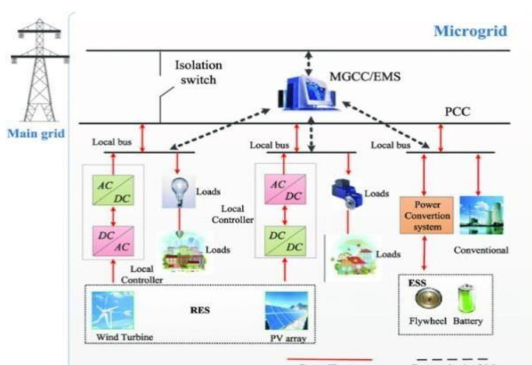

Fig. 2 Micro-grid architecture

renewable energy sources, a conventional generator and diferent types of loads as well as energy storage devices, which interface with the power electronic systems. For a proper system harmonization and control, the Point of Common Coupling (PCC) defines the operating mode, which can be either grid connected mode or islanded mode. It also allows to connect the micro-grid with the main grid. The PCC has as role to connect or disconnectthe hybrid micro-grid system

from, or to the main grid. To ensure overall system stability, different levels of control, utilizing micro-sources and central controllers support and coordinate the micro-grid.

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A hybrid micro-grid architecture represents an innovative approach to energy distribution and management that harmonizes renewable and conventional energy sources, storage technologies, and advanced control systems. Hybrid micro-grids are at the forefront of the global movement to change the energy landscape because they promote the local energy production, improve grid resilience, and contribute to environmental sustainability. Hybrid microgrids have a compelling potential to shape a more efficient and sustainable energy future as technology advances and the understanding of energy dynamics expands. An energy management system (EMS), which is software-based, manages and controls the flow of energy in a hybrid micro-grid system. It collects real- time data from multiple sensors, such as solar panels, wind turbines, and energy storage devices, and evaluates it to determine the best way to operate the system.

Energy management controls for hybrid micro-grid

For reliable, sustainable, and efficient energy systems, hybrid micro-grids have emerged as a transformative solution that uses the cooperation of diverse energy sources and storage technologies. For a successful operation of hybrid micro-grids, it is important to implement sophisticated energy management controls. These controls serve as the brains behind the system, coordinating the complex interaction of renewable and conventional energyresources, storage systems, and load demands to optimize the performance, resilience, and environmental impact. Energy management controls for hybrid micro-grids are dynamic, adaptive systems that include a range of hardware and software components designed to monitor, analyze, and direct the flow of energy within the micro- grid. At their core, these controls aim to achieve several key objectives. Different control strategies of the energymanagement are presented below.

Optimal resource allocation

Hybrid micro-grids often consist of diverse energy sources, including solar PV, wind turbines, fossil fuel generators, and energy storage. The energy management controls determine the most efficient combination of these resources to meet the current energy demand while considering factors such as availability, cost, and environmental impact.

Load balancing

The controls actively balance the energy supply and demand by adjusting the distribution of power from different sources. This ensures that the micro-grid operates smoothly, avoiding overloading or underutilization of any particular component.

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Islanding and grid connection

One of the unique features of hybrid micro-grids is their ability to switch between grid-connected and islanded modes. The energy management controls monitor grid conditions and initiate a seamless transition between thesemodes as needed, ensuring continuity of power supply and maintaining stability.

Storage management

Energy storage systems, such as batteries, play a pivotal role in hybrid micro-grids by storing excess energy and releasing it when demand exceeds supply. The controls determine the optimal times for charging and dischargingthese storage systems to maximize their lifespan and efficiency.

Predictive analytics

Advanced energy management controls use predictive algorithms that anticipate the energy generation, consumption patterns, and storage needs based on historical data, weather predictions, and load profiles. This enables proactive decision-making and enhances the ability of micro-grid to adapt to changing conditions.

Environmental considerations

Energy management controls can factor in environmental considerations, such as reducing carbon emissions, when making operational decisions. This ensures that the operation of micro-grid aligns with sustainability goals. The complexity of hybrid micro-grid systems demands a multidisciplinary approach to energy management controls. This involves a fusion of control theory, power electronics, data analytics, communication protocols, and real-time monitoring. As technology continues to advance, artificial intelligence and machine learning techniques are increasingly being integrated into energy management systems to enhance their adaptability and decision-makingcapabilities.

Description of the developed hybrid microgrid system the developed hybrid micro-grid architecture was applied to supply a variable AC load. The power generation capacity of each distributed generation source was 500 kWp for solar, 500 kW for wind energy, 900 kWh for the battery and 1.5 MW for the diesel generator. The power generated from the PV and battery are DC, but for wind is AC, therefore,

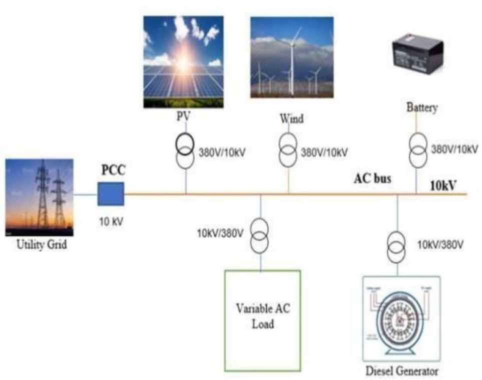

Fig. 3 Block diagram of the developed system

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Load profile

The developed hybrid micro-grid supplied the load directly by 380Vac through a transformer. The power system grid included generation, transmission, and distribution. According to the generation system, the total generated power, such as PV and Wind, were connected in parallel. The battery was used as a back-up system during peak demand and fluctuations in the power generated from renewable energy sources. Figure 3 illustrates the block diagram of the developed

Energy management strategy

The system consisted of two renewable energy sources (wind and PV power plants), an energy storage system, and a generator that supplied electricity to the load demand when the utility grid was unavailable. The followingformula in Eq. (1) was used to determine the net power generation:

PG = Ppv + Pwind + Pbatt (1)

where, PG the power generation; Ppv the power produced from PV; Pwind the power produced from Wind; Pbatt the power produced from Battery. When there was an excess of power generation, the battery was charged; when

there was not enough power generation to meet the load demand, the battery was discharged. According to the developed energy management system (EMS), the power generation was supplied the load demand through fourscenarios and with the help

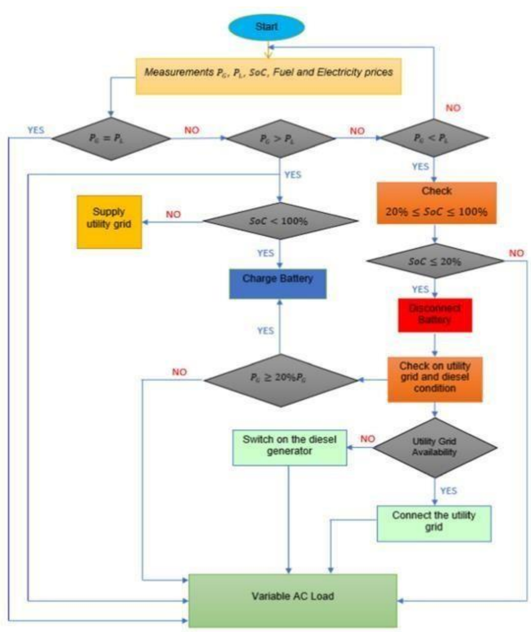

Fig. 4 Flowchart of the energy management strategy for the hybrid microgrid

of the battery, a diesel generator, and the utility grid. Figure 4. shows the architecture of the energy management algorithm flow chart. First, the power generated by various sources and the load demand was measured using thescenarios listed below.

Case 1: When the load demand is met by the power generated.

$$PL = Ppv + Pwind \quad (2)$$

According to this scenario, the load was continuously supplied by the power generated from wind power plant and PV power plant sources as illustrated in Eq. (2).

Case 2: When the power generation was greater than the load demand.

$$Ppv + Pwind > PG \quad (3)$$

In this case, the power generation exceeded the load demand as presented in Eq. (3); as a result, the load demand was satisfied by the power generation, and the surplus was used to charge the battery. The SOC of the battery was firstly measured and see if it fell below the maximum value, which was 100%. When the condition was satisfied, the load was supplied and the battery was also connected to be charged until its SOC reached the maximum value. When the battery was fully charged, it was disconnected and waited the discharge phase as presented in Eqs. (4), (5), which show the charging condition. The excess of production was supplied to the utilitygrid. The conditions were formulated as below:

$$SOCmin < SOCbatt < SOCmax = 20\% < SOCbatt < 100\% \quad (4)$$

$$PG > PL = \text{Charging} \quad (5)$$

Case 3: when the power generation is not enough to meet load demand as presented in Eq. (6).

$$Ppv + Pwind < PG \quad (6)$$

The battery was used to supply the load, in this case because the power generation was less than what was required to meet the load demand as shown in Eqs. (6), (7) give the condition of discharge. The energy management system (EMS) calculated and checked the difference between the available power generation fromthe renewable energy sources and load. It also measured the SOC of the battery at the same time. When the powerfrom the battery was sufficient to meet the demand of the load, when the condition was satisfied, then the battery was discharged until its SOC reached the minimum point. In Eq. (8), the supply power formula is given where the battery is used to support the load. Equations (9), (10) and (11) presents the operating modes of the battery.

$$PG < PL = \text{Battery Discharging}$$

$$(7)\ PL = PPV + Pwind + Pbatt$$

$$(8)$$

$$SOCbatt = 20\% = \text{Battery Disconnected}$$

$$(9) SOC \leq 20\% = \text{Charge battery} \quad (10)$$

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SOC > 20% = Discharge battery (11)

Case 4: When the battery reached its minimum value and the generated power was less than the load demand.

PPV + Pwind + Pbatt< PL (12)

In this case, the SOC of the battery reached its minimum value, which was 20% thus, the battery was disconnected and Eq. (12) presents the formula of the power supplied with the support of the battery when this total amount becomes less than the demand of the load. At this stage, the load demand was provided by the help of the generator or the utility grid based on the availability of the utility grid. When the utility grid was available, then the utility grid supplied the load and when the utility grid was not available, then the diesel generator was switched on to supply the load. The EMS checked the availability of the generated power from the renewable energy sources to see if it was ≥ 20% of the total power produces from the renewable energy sources. When the condition was approved, then the battery was connected to be charged by the available power generation. In contrary, when the condition was not satisfied, then the available generated power from the renewable energy sources was added to the utility grid or generator to supply the load. For this study, it was specified that the battery could be charged when the available power was ≥ 20% of the total production, when it reached its minimum value. Charging a battery with a greater power input, compared to a smaller one, offers several advantages in terms of efficiency, charging time, and overall battery performance.

Simulation results

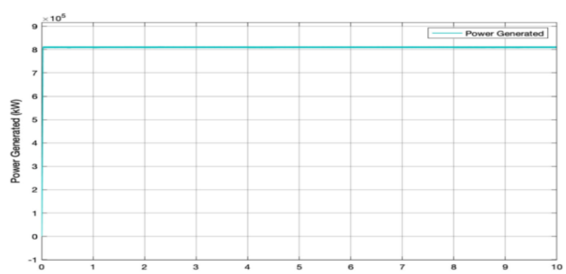

Fig. 5 Power generated by renewable energy sources

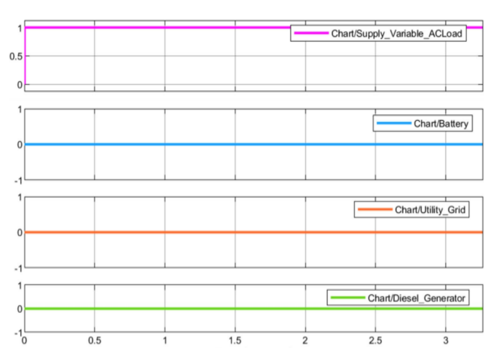

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Fig. 6 Statefow output results chart

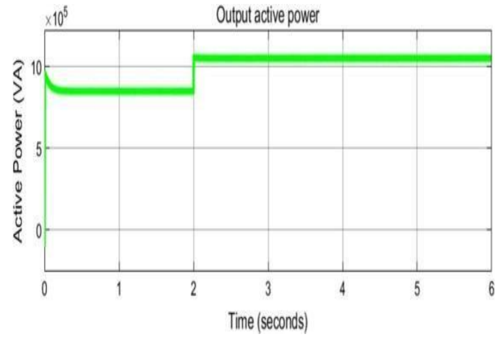

Fig. 7 Power generated by renewable energy sources

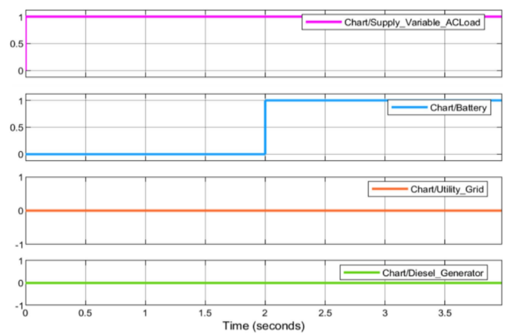

Fig. 8 Stateflow output results chart

As it can be seen in Fig. 5, the power generated is equal to the load demand power. Figure 6 presents the chart

of the output results for this first scenario, in which all the results are displayed graphically. It is shown that only the load is supplied and other outputs, which include the battery, utility and diesel generator are not operational. Scenario 2 In this second case, the total power generation from the renewable energy sources became higher than the load demand power. As shown in Fig. 7, the power produced from the renewable energy sources is more than the expected load demand power. Thus, the battery is charging according to the charge / discharge condition andwhen the maximum value was reached then it was automatically disconnected from the system and the excess ofproduction was directed to the utility grid

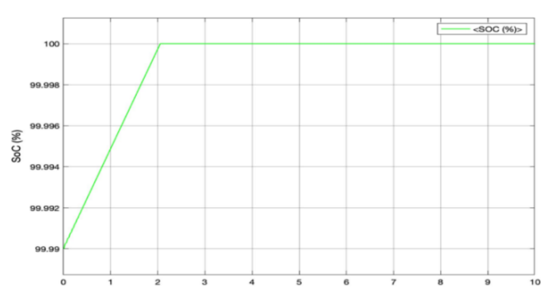

Fig. 9 Battery fully charged

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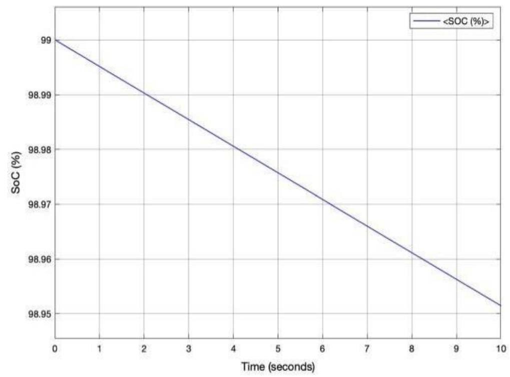

Fig. 9 Battery discharging

Conclusion

This paper presented an energy management strategy for hybrid microgrid system using renewable energy. Different scenarios were used during the simulation to show the robustness and the effectiveness of the developed energy management system control to handle the load in both islanded mode and grid connected mode and ensure the proper operation of the battery energy storage system in hybrid microgrid system. The variable AC load for the developed hybrid microgrid system was fxed to 800 kW and the total generation power from the renewable energy sources was 1 MW. To achieve the aim and objectives of the research, a hybrid microgrid model was implemented and developed using MATLAB/Simulink software and an energy management system algorithm was developed using State flow logical programming environment in MATLAB/Simulink software.

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