Innovative Smart Energy Strategies for Park Microgrids: Unraveling Hybrid Storage Solutions

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Abstract: In the face of escalating global energy crises and mounting environmental pollution, there has been a heightened focus on the exploration and development of clean, sustainable energy sources, including solar energy, wind energy, and nuclear energy. These alternatives hold the promise of addressing the dual challenges of energy security and environmental sustainability. A pivotal technology in this pursuit is the implementation of micro grids, which serve as crucial components in the integration of renewable distributed generation systems, energy storage devices, and loads. Micro grids offer versatile solutions that can operate seamlessly both on-grid and off-grid, thereby contributing significantly to enhancing the resilience and reliability of modern energy networks. This paper presents a comprehensive overview of the role of micro grids in creating controllable sub-networks within the broader energy landscape. The inherent flexibility of micro grids enables the efficient management of energy resources, allowing for dynamic responses to fluctuating demands and supply variations. By acting as localized energy ecosystems, microgrids facilitate the integration of diverse energy sources, fostering a more sustainable and resilient energy infrastructure. This paper explores the multifaceted applications of microgrids, emphasizing their capability to operate autonomously or in conjunction with larger grids. Additionally, the discussion delves into the potential of microgrids to serve as a linchpin in achieving energy independence and mitigating the adverse environmental impacts associated with conventional energy production. Furthermore, the study investigates the technical aspects of microgrid implementation, addressing challenges and proposing solutions for seamless integration into existing energy systems. As the demand for cleaner energy intensifies, understanding the role of microgrids becomes imperative for policymakers, researchers, and industry stakeholders. This paper aims to contribute to this understanding by offering insights into the current state of microgrid technology, its applications, and its potential to revolutionize the global energy landscape.
Keywords: Microgrids, Renewable Energy Integration, Energy Storage, Distributed Generation Systems, Sustainable Energy

INTRODUCTION

With the increasingly serious global energy crisis and environmental pollution, clean new energy such as solar energy, wind energy, and nuclear energy has received more attention and expectations. As a key technology for integrating renewable distributed generation systems, energy storage devices and loads into controllable sub-networks, microgrids can work both on-grid and off-grid. Compared with the AC microgrid [1-5], the DC microgrid has a simple structure, high efficiency, good power quality, and does not have the problems of frequency offset, phase synchronization and reactive power compensation, which helps it to be widely popularized and applied. The intermittent power output and load variability of distributed generation devices will not only cause large-scale fluctuations in DC bus voltage, but also lead to power imbalance and reduce the reliability of system power supply. Therefore, energy management and coordinated control of DC microgrids It is one of the key problems to be solved to ensure its stable operation. A method for grid-connected converters to adjust the DC bus voltage is proposed [6-11], but this method does not consider photovoltaic modules and hybrid energy storage modules in the DC microgrid, so the reliability of the system is low and the dynamic response is slow. The energy management method of DC microgrid is the benchmark, but this method ignores the saturated and insufficient power of the hybrid energy storage module, and does not consider the situation that the DC bus voltage is too low when the load is heavy, which may cause the system to collapse. An energy management method based on DC bus voltage information is proposed. This method only considers DC load in DC microgrid and is not suitable for the current power supply mode. In order to stabilize the DC bus voltage and optimize the working process of each module of the system, this paper proposes a control method for coordinating energy between photovoltaic, hybrid energy storage, and large power grids. Based on the DC bus voltage, the power balance of the system is judged. In the grid-connected state, a grid-connected conversion module is introduced to realize the energy exchange between the DC microgrid and the large power grid to maintain the system power balance; in the off-grid state[12-17], consider hybrid The working characteristics of each energy storage unit and its charge and discharge margin, set the working thresholds of super capacitors and lithium batteries, manage the energy output of photovoltaic and hybrid energy storage, improve the dynamic response speed of the system, avoid frequent actions of power electronic devices, and prolong the use of life. The system can be divided into 6 energy management modes, and can switch smoothly between the 6 energy management modes, maintaining the stability of the DC bus voltage and ensuring the reliable and stable operation of the system [18-21].

DC microgrid structure

The structural block diagram of the DC microgrid is composed of photovoltaic PV (photovoltaic) module, hybrid energy storage (HES) module, grid-connected converter GC (grid converter) module and load 4.The photovoltaic module is connected through the Boost circuit. On the DC bus the hybrid energy storage module is composed of a super capacitor, a lithium battery and a Buck/Boost bidirectional converter, which can freely switch charge and discharge according to the real-time balance state of energy supply and demand in the microgrid system; the grid-connected converter adopts a three-phase bridge circuit, which can realize micro grid and large grid energy interaction between; local load DC/DC, DC/AC converter and resistive load simulation. In the overall structure of the energy management method, the photovoltaic module can be freely switched between the maximum power tracking (MPPT maximum power point trace) and the constant voltage mode, which improves the operating efficiency of the system; the hybrid energy storage module includes super capacitors and lithium batteries, using droop control and current The inner loop PI control method can freely switch between charging, discharging, standby and current limiting modes, avoiding unnecessary actions of power electronic devices caused by small-scale fluctuations in the DC bus voltage, and improving the service life of the hybrid energy storage module; grid-connected The converter module can switch freely between rectification, inverter and shutdown modes, and can determine the size and direction of energy transmission between the microgrid and the large grid according to the real-time balance of system power. Since the DC microgrid does not need to consider the reactive power, frequency, phase and other issues, the DC bus voltage becomes the main parameter reflecting the power balance of the microgrid. By monitoring the fluctuation of the DC bus voltage Udc, the energy exchange between the distributed power source, the energy storage module, the large grid and the load is managed in sections, reducing the frequency of frequent switching of some converters and ensuring the reliable operation of the microgrid. When it is detected that UL2≤Udc≤UH2 (UL2 and UH2 are the working critical values of grid-connected converters), the grid-connected converter (GC) stops and the system is in an off-grid state. According to the system power balance, the photovoltaic modules and hybrid The energy storage output is subdivided into 4 working modes; when the DC bus low voltage Udc≤UL2 or Udc≥UH2 is detected, the hybrid energy storage module adopts standby control, and the grid-connected converter determines the amount of transmitted energy and direction.

System energy management mode

The grid-connected converter adopts shutdown control, and the system is in an off-grid state; in order to prevent the frequent operation of the hybrid energy storage module caused by the small-scale fluctuation of the DC bus voltage, the super capacitor and lithium battery adopt standby control; the photovoltaic module adopts constant voltage control, which continuously provides load For power supply, the power generated by the photovoltaic module and the power consumed by the load are balanced. The grid-connected converter adopts shutdown control, and the system is in an off-grid state; due to the surplus system power, the hybrid energy storage module ensures the system power balance by absorbing power. When the voltage Usc at both ends reaches a certain value, the lithium battery is put into work again and begins to charge, maintaining the constant DC bus voltage; as the super capacitor and lithium battery continue to charge, neither of them reaches saturation, the photovoltaic module adopts MPPT control, the photovoltaic module emits power. The energy efficiency, the hybrid energy storage module absorbed power and the load consumption power are balanced. The grid-connected converter adopts shutdown control, and the system is in an off-grid state; due to the surplus system power, the hybrid energy storage module ensures the system power balance by absorbing power. When the voltage Usc at both ends reaches a certain value, the lithium battery is put into work again and begins to charge, maintaining the constant DC bus voltage; as the super capacitor and lithium battery continue to charge, both of them reach saturation, that is, the hybrid energy storage module When the state of charge is not less than 90%, the photovoltaic module adopts constant voltage control, and the super capacitor and lithium battery adopts current limiting control. The power emitted by the photovoltaic module, the absorbed power of the hybrid energy storage module and the power consumed by the load are balanced. The grid-connected converter adopts shutdown control and the system is in an off-grid state; due to insufficient system power, the hybrid energy storage module releases power to ensure system power balance. Super electric Rong first put into work, using discharge control, and began to discharge. When the voltage Usc at both ends reaches a certain value, the lithium battery starts to work again and begins to discharge, maintaining the constant DC bus voltage; with the continuous discharge of the super capacitor and the lithium battery, neither of them reaches the limit of power. If sufficient, the photovoltaic module adopts MPPT control, and the output power of the photovoltaic module, the power released by the hybrid energy storage module and the power consumption of the load are balanced. The grid-connected converter adopts inverter control, and the system is in grid-connected state; as the super capacitor and lithium battery are in standby state, the photovoltaic module adopts MPPT control, but the DC bus voltage cannot be reduced to near the rated value, so the grid-connected converter will The remaining power of the system is transmitted to the large power grid, and the photovoltaic module adopts MPPT control, so that the power generated by the photovoltaic module, the transmission power of the grid-connected converter and the power consumption of the load are balanced. The grid-connected converter adopts rectification control, and the system is in grid-connected state; as the super capacitor and lithium battery are in standby state, the photovoltaic module adopts MPPT control, but the DC bus voltage cannot rise to near the rated value, so the insufficient power of the system is determined by the large Power grid supply, so that the output power of photovoltaic modules, the input power of grid-connected converters and the power consumption of loads are balanced.

1. Photovoltaic module circuit and control

In order to avoid the frequent operation of the hybrid energy storage module caused by the small-scale fluctuation of the DC bus voltage, combined with the fast dynamic response of the super capacitor and the high energy density of the lithium battery, the DC bus voltage deviation reference is set, and the hybrid energy storage module allows the super capacitor to work and balance first. The instantaneous power of the system improves the dynamic response of the system, reduces the number of actions of the lithium battery, and prolongs the service life; after the lithium battery works, the DC bus voltage is adjusted with the super capacitor to prevent the super capacitor from reaching saturation too fast. In order to fully and efficiently utilize the output of the distributed power supply and the adjustment capability of the energy storage device, and improve the operation efficiency of the DC microgrid, the operating voltage threshold of the grid-connected converter is set so that it can freely switch between rectification, inverter and shutdown modes, avoiding the small range of bus voltage. The fluctuations cause frequent actions of the power electronic devices, which improves the power quality of the system. The system switches from mode 1 to mode 2.The output power of the photovoltaic panel is higher than the power consumed by the load, so that the DC bus voltage is raised. When it is detected that the DC bus voltage Udc reaches the working threshold for charging the super capacitor, the super capacitor starts to charge with a current of 1.9A, and the voltage across the super capacitor will increase as it continues to charge, but before reaching the working threshold for charging the lithium battery, The current of the lithium battery is still 0. When it is detected that the voltage across the super capacitor reaches the minimum working threshold of 11 V for charging the lithium battery, the lithium battery starts to work and its current slowly increases from 0.The super battery and the lithium battery work in coordination to absorb the excess power of the system, and the DC The bus voltage gradually decreases, which also reduces the charging current of the super capacitor.

Conclusion

The unstable output of the distributed power supply in the DC microgrid will not only cause large-scale fluctuations in the DC bus voltage, but also lead to power imbalance, which makes the system unreliable. In this regard, this paper proposes an energy management optimization method for DC microgrids including photovoltaic and hybrid energy storage, which can quickly stabilize the bus voltage fluctuations caused by the imbalance of system power supply and demand. In the grid-connected state, the DC microgrid exchanges energy with the large grid through the grid-connected converter; in the off-grid state, the photovoltaic module and the hybrid energy storage module coordinate and cooperate to supply power to the local load, avoiding the small-scale fluctuation of the DC bus voltage. Power electronic devices operate frequently, so that new energy and energy storage give priority to power supply to the load. When the load suddenly changes, the energy storage module allows the super capacitor to work first to stabilize balance the instantaneous power of the system, put the lithium battery into operation, adjust the DC bus voltage with the super capacitor, prevent the super capacitor from reaching saturation too fast, improve the dynamic response speed of the system, prolong the service life of the energy storage unit, and maintain the system power Balance, to achieve the optimal use of energy.

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