ISSN 2706-655X Vol.5, Issue 1: 20-24, DOI: 10.25236/IJFET.2023.050104

Optimization of hybrid energy storage based on micro grid optical storage and DC in certain regions

Lu Tianqi, Gao Jing, Zhu Heyan, Yang Guochen

State Grid Liaoning Electric Power CO, LTD., Power Electric Research Institute, Shenyang 110015, China

Abstract: *It is of great significance to maintain the stability of DC micro grid bus voltage and improve the economic benefits of the micro grid system. A hybrid energy storage form of flywheel and battery is proposed as the energy storage form of the DC micro grid system of the optical storage charging station. The flywheel is used to smooth high-frequency power fluctuation and part of low-frequency power, and the battery is used to balance the reference power to maintain smooth and stable bus voltage. The hierarchical coordinated control strategy of DC bus is designed to achieve the coordinated control of photovoltaic power generation, electric vehicle charging and discharging, and load power demand in the microgrid system. According to the different working conditions of island operation and grid connected operation, the proposed control strategy is simulated and analyzed on the Matlab/Simulink software platform. The simulation results show that under all working conditions, the proposed control strategy can effectively switch the DC bus voltage between different voltage layers, maintain the DC bus voltage balance of the DC microgrid system of the optical storage charging station, and realize the flexible and reliable operation of the entire system. Therefore, the control strategy is feasible and effective.*

Keywords: *PV; DC microgrid; Hierarchical control; Coordinated control; Droop control*

1. Introduction

Solar energy is widely distributed, clean and pollution-free, and is internationally recognized as an ideal alternative energy. In the future, the local consumption of photovoltaic energy in the form of micro grid charging stations is of great significance for the reliable use of clean energy and the economic and stable operation of large power grids. It is a direct and effective way to achieve low carbon. As a form of microgrid connecting distributed power generation and main network, DC microgrid can effectively play the value and benefits of distributed power generation, and has more flexible reconfiguration capability than AC microgrid. In DC microgrid, the control of energy balance can be attributed to the adjustment of DC bus voltage and the management of power quality, and DC voltage is the only indicator reflecting the power balance in the system[1-3]. It is a simple and flexible control mode of DC microgrid to realize coordinated control among converters according to the hierarchical droop change of DC bus voltage. As droop control cannot achieve constant control of DC voltage, microgrid system inevitably faces voltage fluctuations caused by new energy generation fluctuations or load switching. In order to suppress energy fluctuation, solve the problem of energy supply fluctuation and improve power supply reliability, energy storage devices are usually required in microgrid systems. Although the use of energy storage device can restrain the power fluctuation to a certain extent, it is difficult for a single energy storage device to meet the requirements of power and energy at the same time. At present, for the hybrid energy storage system composed of super capacitors and batteries, there are many researches on stabilizing power fluctuations[4-5].The reasonable distribution of the output power of the super capacitor and the battery in the hybrid energy storage system is studied, so that the power quality of the system and the power demand of the load can meet the requirements when the microgrid operates in isolated islands; The super capacitor and battery are respectively used to compensate the high frequency component and the middle and low frequency component of the output power fluctuation of renewable energy, so as to realize energy buffering. At the same time, a power regulation system of wind farm based on super capacitor energy storage is introduced, which uses super capacitor banks as energy storage components to stabilize the power fluctuation of wind farm and reduce the impact of wind farm on power quality of power grid. However, although supercapacitors have the advantages of high power density and fast charging speed, they also have the disadvantages of low energy storage density, improper installation location or use, which will cause electrolyte leakage, large internal resistance and high price. Flywheel energy storage is a new energy storage technology. Compared with supercapacitor, flywheel energy storage device has the characteristics of high energy storage density, large power density, long life, wide operating temperature range, low loss, environmental protection, pollution-free and low maintenance. Compared with supercapacitor energy storage, superconductor energy storage and new battery energy storage, considering the economy of energy storage system in power quality, frequency support and load change, Flywheel energy storage has great advantages. Therefore, in recent years, many scholars have paid attention to the research and application of flywheel energy storage technology, especially the research on the smooth control of bus voltage in micro grid. In addition, a DC microgrid stability control scheme based on multi-agent system is proposed[6-7]. Flywheel energy storage can improve the hierarchical energy management and system stability control of the DC microgrid. Of course, due to the limitation of technology and material price, the price of flywheel is relatively high at present, which cannot reflect its advantages in small occasions. However, flywheel energy storage has been gradually used in aerospace, UPS power supply, transportation, wind power generation, nuclear industry and other fields for optical storage electric vehicle charging station DC micro grid system in the following occasions where large energy storage devices are required, The flywheel and lithium iron phosphate battery are proposed as hybrid energy storage to suppress power and energy fluctuations in the system. The flywheel is used to smooth high-frequency power fluctuations and part of low-frequency power, while the battery is used to balance the main energy flow and maintain the stability of DC bus voltage.

2. Optical storage microgrid system

The interconnection of power grids or microgrids is a trend of development. At this time, it can be used as a distributed power source or a grid controllable load, and through the unified dispatching of the grid, it can realize the two-way flow of the electric energy of the battery and the power of the grid, that is, the interaction with the grid. Therefore, it can not only be used as the load of the power grid to absorb energy from the power grid; It can also feed back electric energy to the grid, improve the operation reliability of the grid, so as to give full play to the role of energy storage. Optical storage charging station is a DC microgrid. It is a power supply mode combining photovoltaic power generation and energy storage system with grid power supply, which reduces the impact of load on the grid to a certain extent; At the same time, it can also make full use of photovoltaic power generation, generate more power when the sunlight is strong, sell the surplus electric energy to the grid, and improve the income of the charging station[8-10]. The micro network structure of optical storage charging station designed in this paper is shown in the figure. DC bus voltage grade is designed as 600 V, AC bus voltage is 380 V, and M is the driving motor. The optical storage EV charging station mainly operates in the DC micro grid structure, and is equipped with a hybrid energy storage system to coordinate and optimize the energy configuration of the micro grid to achieve the coordinated control of photovoltaic power generation and EV charging and discharging. At the same time, the AC side bus and the DC bus realize the bidirectional flow of energy through the bidirectional AC/DC conversion module, and realize the networking (i.e. grid connection) and off grid (i.e. island) mode switching between the microgrid and the main network through the solid-state transfer switch (SST). The optical storage electric vehicle charging station designed in this paper is composed of photovoltaic power generation system, hybrid energy storage, EV charging and discharging system, DC/DC and AC/DC converter, AC/DC load and central control unit. Among them:

① Photovoltaic power generation system is composed of photovoltaic array and unidirectional DC/DC converter, and maximum power point tracking (MPPT) is achieved by using disturbance observation method.

② The energy storage system adopts the mixed energy storage mode of flywheel and battery. Due to the intermittency and randomness of photovoltaic power generation, it is difficult for a single energy storage device to meet the requirements of power and energy at the same time. In the hybrid energy storage mode, the battery is responsible for smoothing the low-frequency power component in the system, while the flywheel is responsible for compensating the high-frequency power component in the system, so as to meet the power quality and load power requirements of the microgrid operation, and improve the service life of the battery. During island operation, the energy storage system plays a role in smoothing power and energy demand and supporting DC bus voltage. During grid connected operation, it is mainly used for charging and discharging and entering standby state.

③ DC/DC converter can be divided into unidirectional and bidirectional. Photovoltaic power generation can only be one-way energy flow, and one-way control output can be adopted; In order to

ISSN 2706-655X Vol.5, Issue 1: 20-24, DOI: 10.25236/IJFET.2023.050104

realize bidirectional energy flow, the energy storage system and EV charging and discharging system need to adopt bidirectional control to realize the interaction between the two sides.

④ AC/DC converter includes AC/DC converter in flywheel system and AC/DC converter at grid side. The former can be regarded as a part of flywheel energy storage system; The latter is used for the connection between the charging station DC bus and the AC side bus. According to the energy demand of the charging station, when the charging station is connected to the grid, the grid side AC/DC converter provides power and energy demand for the charging station or consumes excess electricity; In island operation, the converter provides voltage and frequency support for the AC side and power supply.

⑤ The charging station is equipped with AC and DC loads. Among them, AC load is the load under conventional mains power, usually constant power type; DC load is a load suitable for direct use under DC voltage, usually of constant resistance type.

⑥ The central control unit is responsible for the monitoring and control of each unit, including the monitoring of voltage, current and energy, to achieve central regulation and coordinate the optimal operation of each component in the charging station.

3. Microgrid coordination control strategy

The energy storage system in this paper adopts the mixed energy storage mode of lithium iron phosphate battery and flywheel. By taking advantage of the fast charging and discharging characteristics of flywheel, the high-frequency power and part of low-frequency power in the system are compensated to smooth the input power of the battery, so as to maintain the smooth and stable DC bus voltage and improve the service life of the battery when the battery provides voltage support. In DC microgrid, DC bus voltage is the only index reflecting power balance in the system. Due to different system operation modes, the corresponding power balance points will also be different. Achieve no interconnection control, and set the voltage hysteresis at the switching, avoid frequent switching of working mode during operation. It can be seen from in the first layer of control, the power of the system is excessive, and the unidirectional DC/DC converter of the photovoltaic power generation system reduces the power to maintain the balance of the DC bus power and provide voltage support; The second and fifth layers are controlled by the voltage current droop control of bidirectional DC/DC converter through the energy storage of the battery to maintain the stability of the bus voltage; The third and fourth layers of control, the bidirectional AC/DC converter realizes the stable control of DC bus voltage through the exchange of power with the AC side. The specific coordination control strategy is as follows:when the DC bus voltage is at the third and fourth layers, the hybrid energy storage system enters the grid connected standby state for charging and discharging standby. In order to ensure the storage and discharge regulation capacity of the battery, this paper sets the target value of the remaining battery power to 70%, and uses constant current control for charging and discharging control. The flywheel, as the supplement of the battery energy, is maintained at 80% of the maximum speed. The charging and discharging control adopts constant power control. When the DC bus voltage is on the other layers, the bidirectional DC/DC converter adopts droop control with limited maximum current, that is, double loop control of voltage droop outer loop and current inner loop. The control structure block diagram of battery DC/DC. kbat is the DC/DC droop control coefficient of the storage battery. When the DC bus voltage is at the first layer, the excess photovoltaic power generation exceeds the energy demand of the system, resulting in an increase in the DC bus voltage to cut off part of PV array power to maintain system stability, PV array MPPT power reduction is used to maintain voltage stability. When the DC bus voltage is lower than the fifth layer, the load overload in the system exceeds the uniform energy supply leads to the drop of DC bus voltage. It is necessary to cut off the load in turn to ensure the rise of voltage. It can also achieve power balance through the bidirectional charging and discharging scheduling of electric vehicles. In the first voltage layer the electric vehicle only performs charging control; In the rest of the voltage layers, the electric vehicle conducts two-way charging and discharging control according to the demand. In this paper, the electric vehicle charging and discharging measures adopt stage type constant current control, that is, in order to facilitate the rapid switching of control strategies of different voltage level converters in hierarchical control, this paper adds a power monitoring link on the basis of hierarchical control without interconnection voltage droop. That is, when the voltage does not reach a certain voltage layer, but the actual power needs the balance control of this voltage layer, the control strategy of this layer is switched immediately to achieve the goal of smooth voltage transition. In addition, the capacity and energy of the energy storage device are important factors restricting the control strategy. As the coordinated control strategy in this paper is

ISSN 2706-655X Vol.5, Issue 1: 20-24, DOI: 10.25236/IJFET.2023.050104

realized through power balance and based on the droop of voltage current, the capacity of energy storage device needs to be reasonably configured according to the hierarchical distribution of voltage and the capacity of each component of the system, and its energy configuration meets the system power and energy requirements through the distribution of battery energy and flywheel energy in the hybrid energy storage.

4. Simulation analysis

During island operation, due to the limitation of system capacity, the operation characteristic curve of the system under the general mode of island operation. The flywheel quickly switches from the discharge mode to the charging mode, smoothing the sudden change of power; The battery continues to discharge and changes gently. When t=8.2 s, PPV decreases to 5 kW, L3 is cut off, load PL changes to 10 kW, and the system generates a small impact current, but it recovers quickly. It can be seen from condition 1 that in island mode, with the change of photovoltaic input power and system load, as well as the change of electric vehicle charging condition, the power complementation of flywheel motor and battery in the hybrid energy storage system can well maintain the electric voltage balance of the system working in the second and fifth layers, with smooth transition and obvious effect.Working condition 2 shows the operating characteristic curve of the system under island operation with full battery charge. It can be seen from that when t=1.2 s, the SOC of the energy storage battery reaches 80%. To protect the battery, stop charging; The flywheel motor follows the battery into the speed maintaining mode; The DC bus voltage rises and enters the first layer, and the balance of the bus voltage is maintained by the MPPT power reduction control of the photovoltaic converter. When t=2.2 s, the charging current of the electric vehicle changes from 15 A to 10 A, and the bus voltage increases slightly. When t=3.2 s, load L3 is switched on, PL changes to 15 kW, and the bus voltage decreases accordingly, still working in the first layer mode. When t=4.2 s, the photovoltaic input power is reduced to 10 kW, and there is a power shortage in the system. The flywheel quickly starts to supplement the discharge, and makes the DC bus voltage Udc gradually transition to the fifth layer. The battery discharge maintains the stability of the bus voltage. It can be seen from condition 2 that the MPPT power reduction control effect of the photovoltaic converter on the first layer of the system DC bus voltage is obvious, which prevents the DC bus voltage from rising continuously due to excess photovoltaic input power, and ensures the stability of the system.Working condition 3 (including battery overdischarge)shows the operating characteristic curve of the island operation system with battery overdischarge.It can be seen that after t=2.2 s, the DC bus voltage transits from the second layer to the fifth layer and enters the battery discharge mode. When t=5.8 s, the SOC drops to 40%. In order to prevent the battery from over discharging and affecting its life, L3 is cut off quickly. At this time, the battery is still discharging. After 0.05 s (t=5.85 s), continue to cut off the load L2. Under the smooth transition of the flywheel, the DC bus voltage Udc passes through the fourth and third layers and enters the second layer battery charging mode. It can be seen from condition 3 that under the condition of over discharge of the system energy storage battery, the system can effectively cut off the load, maintain the stability of the DC bus voltage, improve the charging and discharging environment of the battery, and further extend the service life of the battery.

5. Conclusion

The coordinated optimal control of flywheel and battery hybrid energy storage has obvious effect on the smooth transition of DC bus voltage, can improve the power quality of microgrid system, and is more conducive to the coordinated control between converters and the improvement of the service life of electrical equipment in the system. In the hierarchical control of DC microgrid voltage, the DC voltage is the important basis for realizing droop non interconnection control between different converters in the system. However, only relying on DC voltage for response control will make the system control unstable when switching different modes, resulting in irrecoverability.Therefore, it is necessary to set a higher level of power monitoring to improve control performance and control flexibility.The basic structure and corresponding control strategies of the optical storage electric vehicle DC microgrid proposed in this paper are universal, and they have good reference and practical value for the grid access and local consumption of new energy, as well as the interaction between electric vehicles and the grid. As a new type of energy storage, flywheel energy storage has developed.The advantages of simple control, high energy storage density, high efficiency, fast response, long service life, low maintenance, green and environmental protection are incomparable with other energy storage methods. Although the one-time purchase cost is relatively high,the cost of operation and maintenance

ISSN 2706-655X Vol.5, Issue 1: 20-24, DOI: 10.25236/IJFET.2023.050104

is very low in the later period, which is an important development direction of energy storage mode in the future.

References

[1] WANG Yi, ZHANG Lirong, LI Heming, et al. Hierarchical coordinated control of wind turbine-based DC microgrid [J]. Proceedings of the CSEE, 2013, 33(4): 16-24.
[2] Liu X, Wang P, Loh P C. A hybrid AC/DC microgrid and its coordination control[J]. IEEE Transactions on Smart Grid, 2011, 2(2): 278-286.
[3] ZHU Xiaorong, ZHANG Huihui. Reasearch on coordinated DC voltage control strategy of DC microgrid based on photovoltaic generation [J]. Modern Electric Power, 2014, 31(5): 21-26.
[4] QIN Wenping, LIU Xuesong, HAN Xiaoqing, et al. An improved control strategy of automatic charging/discharging of energy storage system in DC microgrid[J]. Power System Technology, 2014, 38(7): 1827-1834.
[5] ZHANG Ye, GUO Li, JIA Hongjie, et al. An energy storage control method based on state of charge and variable filter time constant[J]. Automation of Electric Power Systems, 2012, 36(6): 34-38.
[6] LU Xiaonan, SUN Kai, HUANG Lipei, et al. Dynamic load power sharing method with elimination of bus voltage deviation for energy storage systems in DC micro-grids[J]. Proceedings of the CSEE, 2013, 33(16): 37-46.
[7] LI Junhui, MU Gang, CUI Xinzhen, et al. Control strategy design of dual lithium battery-capacitor hybrid energy storage system[J]. High Voltage Engineering, 2015, 41(10): 3224-3232.
[8] LI Xiao, HU Changsheng, LIU Changjin, et al. Modelling and controlling of SCES based wind farm power regulation system [J]. Automation of Electric Power Systems, 2009, 33(9): 86-90.
[9] Sundararagavan S, Baker E. Evaluating energy storage technologies for wind power integration [J]. Solar Energy, 2012, 86(9): 2707-2717.
[10] Weissbach R S, Karady G G, Farmer R G. A combined uninterruptible power supply and dynamic voltage compensator using a flywheel energy storage system [J]. IEEE Transactions on Power Delivery, 2001, 16(2): 265-270.