Development of an intelligent energy storage device for distributed distribution area

WAN Dai1,a*, LI Gang1, ZHU Guangming1, YU Bin1, QI Fei1, ZHOU Hengyi1, ZHOU Hengyi1, Zhao Miao1, Huang Yaoqi2

1State Grid Hunan Electric Power Company Limited Research Institute, Changsha, Hunan, China
2State Grid Zhangjiajie Power Supply Company, Zhangjiajie, Hunan, China
aemail: 280241509@qq.com  wand2@hn.sgcc.com.cn

Abstract. In order to solve the problem of seasonal distribution transformer overload in distribution network, especially in rural power grid, an intelligent energy storage device for distributed distribution station area is developed in this paper. The device is connected in parallel to the main line of 380V low voltage line in the distribution station area. The device can compensate the power of the overload distribution transformer, and alleviate the low voltage problem at the head end of the substation area caused by 10kV line overload or distribution transformer heavy overload. This paper introduces the working principle, control strategy, software and hardware design scheme of intelligent energy storage device in distributed distribution station area. The correctness and effectiveness of the device are verified by field operation.

1. Introduction

With China's economic development and social progress, the power consumption of industrial and agricultural production and people's livelihood is also increasing year by year, and the power demand is diversified, and the power supply requirements for the power sector are also higher and higher [1-3].

In many rural power grid areas covered by State Grid Corporation of China, due to the weak local grid structure, the guarantee of power supply is still an outstanding problem [4-6]. In particular, the annual power load rate is low, and the peak power consumption is periodic or seasonal, and the peak load is prominent in a specific period, which often causes substation distribution and transformer, line overload and low voltage of users, and the power supply capacity cannot be guaranteed [7-9]. How to solve the heavy overload operation of distribution transformer, avoid equipment accidents, improve the quality of power supply, power supply reliability and quality service level is particularly important.

The intelligent energy storage device developed in this paper can be used as both power supply and load. Based on the characteristics of energy storage system, according to the power demand and power consumption characteristics of users in different periods, the device is charged in the low power consumption period, and discharged in the daytime according to the real-time demand of the user load, so as to increase the power supply capacity locally [10-12]. The energy storage device can alleviate the seasonal distribution transformer overload and low-voltage problems of the distribution network, and meet the power supply requirements of the distribution network, such as uninterrupted operation, emergency power protection, temporary power supply, etc., with the characteristics of "mobile, large capacity, low noise, energy conservation and emission reduction, green environmental protection" [13-16].
In this paper, based on the existing electrochemical energy storage technology, a multi-functional intelligent energy storage device for distribution station area is developed to meet the actual needs of power production by adopting centralized compensation mode in station area.

2. Working principle and control strategy of intelligent energy storage device in radio distribution area

2.1. Working principle of the device
The device takes the battery as the power carrier and the central monitoring unit as the control core. It exchanges energy with the outside world by controlling the operation state of the power conversion unit, including two working modes of grid connected and off grid.

(1) Grid connected mode
As shown in Fig. 1, the device is connected to the 380V main line of the distribution station area in parallel to compensate the power of the overload distribution transformer, and at the same time, it can alleviate the low voltage problem caused by the overload of the distribution transformer on the 10kV line. The device adopts floor type or pole type installation mode, which can be connected to the power grid without power cut. During operation, the charging and discharging of the device is controlled by detecting the load current of the station area.

(2) Island mode
In the peak period of off load power consumption, the device can also be used for temporary power supply, emergency power protection and non power cut operation. In the off grid mode, the power conversion unit works in the independent inverter mode, and the load is connected to the AC side of the power conversion unit. The device is equivalent to a voltage source, as shown in Fig. 2.
2.2. Control and protection strategy

2.2.1. Charging and discharging control strategy of energy storage device

The device collects the load current of distribution network lines through the open type current transformer to judge whether the distribution transformer in the substation area is overloaded. When the load current is greater than the discharge set value, the central monitoring unit sends the discharge current command to the power conversion unit to compensate for the power of the overload part and reduce the power borne by the distribution transformer; when the load current is less than the charging set value, the central monitoring unit gives the charging current command to compensate the electric quantity of the device.

(1) Discharge strategy

When it is detected that the load power $P_L$ is greater than $r_1$ times the transformer capacity $P_T$ and the SOC of the energy storage battery is greater than $P_1$, the active power $P_d$ that can be discharged by the energy storage battery is calculated according to equation $P_d = \min\{P_L - r_1 \cdot P_T, P_{\max}\}$, and the corresponding control command is issued to the power conversion unit to control the energy storage battery to supply power to the grid through the power conversion unit. Where $P_L - r_1 \cdot P_T$ is the active power to be compensated and $P_{\max}$ is the maximum discharge power of the energy storage battery.

(2) Charging strategy

When it is detected that the load power $P_L$ is less than $r_2$ times the transformer capacity and the battery SOC is less than $P_2$, the active power $P_C$ of the energy storage battery can be charged according to equation $P_C = \min\{r_2 \cdot P_L - P_{\max}\}$, and the corresponding control command is issued to the power conversion unit to control the power grid to charge the energy storage battery through the power conversion unit. Where $P_{\max}$ is the maximum charging power of the energy storage battery.

2.2.2. Time sharing charging and discharging strategy

According to the local active power planning curve, the active power distribution is carried out according to the time period. The current program default active power planning curve is an active power value of 5min, a total of 288 points in a day. The program reads the curve value of active power plan in the history database every 1s, and determines which value to use for active power calculation according to the current system time. For example: if the current time is 11:13, the plan curve value of 11:10 will be found; when the time reaches 11:15, the plan curve value of 11:15 will be found, and so on.

2.2.3. BMS alarm protection strategy

The central monitoring unit adopts three-level protection mechanism for battery current protection, voltage protection and temperature protection. According to the alarm information uploaded by BMS, the power conversion unit is controlled. When the first level alarm occurs, the central monitoring unit controls the power conversion unit to reduce the power operation; when the second level alarm occurs, the central monitoring unit controls the power conversion unit to stop charging or discharging; when the third level alarm occurs, the central control and monitoring unit issues the tripping order of the grid connected circuit breaker, and the BMS automatically disconnects the relay after the delay of BMS.

3. Device design

3.1. Hardware design

The hardware of the device adopts modular structure, which is composed of a series of functional units, including central monitoring unit, energy storage operation management unit, power conversion unit and external auxiliary equipment. The central monitoring unit realizes data processing, control operation, real-time alarm, power control, picture monitoring and other functions. The energy storage operation management unit realizes the storage and release of electric energy and the state monitoring of battery. The power conversion unit can automatically synchronize with the power grid to realize
rectification and inversion. The system is connected to the auxiliary current monitoring and protection system.

The central monitoring unit includes industrial computer and router. The industrial computer adopts am335x microprocessor based on arm cortex-a8 core, including RS485, RS232, Ethernet and other communication interfaces. The router includes a high-speed 4G module, which supports remote monitoring of information transmission and WiFi hot spot coverage to meet the needs of local wireless debugging.

The energy storage operation management unit includes a battery and a battery management system. The battery adopts lithium iron phosphate battery, and the structure is composed of series and parallel cells to form a battery module. The battery modules are connected in series to form a battery cluster to improve the system voltage and capacity. The battery management system adopts the two-level structure of battery module management unit and battery cluster management unit to complete the battery state monitoring and management.

The power conversion unit adopts DC / DC and AC / DC two-stage architecture, with power of 30kW, DC side input range of 350-750v DC, output of 380ac, 50Hz, with grid connected and off grid working mode.

External auxiliary equipment includes: (1) grid connected circuit breaker, grid connected disconnector, grid connected cable, ammeter, current transformer; (2) smoke detector, temperature and humidity sensor, air conditioner, fire extinguishing patch, door magnetic lock; (3) AC switching power supply + transformer, surge protector, air switch, etc.

3.2. software design
The background of the software system uses Linux integrated development environment as the development platform, and the front end uses B / S architecture design. The software module mainly includes five functions: energy storage equipment monitoring, load monitoring, alarm management, external auxiliary equipment monitoring and strategy management.

The energy storage equipment monitoring module mainly realizes the real-time monitoring of power conversion unit and battery pack status, including real-time acquisition and display of equipment operation status, electrical quantity, temperature and other data.

Load monitoring module mainly realizes the monitoring of distribution transformer load, including voltage, current, power and other information.

The alarm management module manages the alarm information of power conversion unit, battery system, fire protection, access control, environment and other aspects, which can realize the alarm information statistics and query function.

The external auxiliary equipment monitoring module includes the status display of access control, smoke detection and air conditioning.

Policy management includes system setting and policy management. The system setting can set the grid / off grid operation mode of power converter and the opening and closing of grid connected circuit breaker. The policy management includes the parameter setting of peak regulation strategy and time-sharing power.

4. Analysis of advantages and application effect of the device

4.1. Advantage
(1) Treatment of heavy overload of distribution transformer
Using battery energy storage to realize peak shaving and valley filling can effectively solve the problems of heavy overload of distribution transformer and medium voltage line caused by the sudden increase of user load during peak load period, and the resulting shortage of power supply capacity of back-end users. Improve the operation status of distribution transformers and lines, and improve the reliability of power supply.

(2) Improving low voltage power quality
Through active power compensation and reactive power compensation, the problem of low voltage caused by overload of distribution transformer and low voltage problem caused by reactive power loss can be solved, and the power quality of users can be improved.

(3) Rapid deployment
It can quickly deploy and solve the sudden overload problem of distribution transformer and improve the power supply level and customer satisfaction. In contrast, it generally takes about one year to complete the power distribution transformer capacity expansion project from the demand report, approval to operation.

(4) Reusable
Different from the transformation scheme of distribution transformer capacity expansion only for fixed station area, the intelligent energy storage device in distribution station area can be flexibly deployed to the required station area according to the demand, and the device has a high degree of reuse.

(5) Various functions
In the off-peak load period, it can be used for temporary power supply, emergency power protection, non-power cut operation and other aspects, so as to reduce the cost of purchasing emergency power supply vehicles (about 1 million/set) for local companies.

4.2. Application effect
At present, the 30kW intelligent energy storage device in the distribution area of a company (capacity of 100kVA) has been put into trial operation. Under the setting of peak shaving mode, the overload discharge constant value is 98% of the distribution transformer capacity, and the light load charging setting value is 70% of the distribution transformer capacity. The power curve obtained is shown in Fig. 3. It can be seen from Fig. 3 that in the peak period of summer load, the smart energy storage device is connected to cut the peak and fill the valley. The capacity of the distribution transformer is increased by 30%, which can improve the overload of the distribution transformer and improve the power supply capacity of the power grid.

![Fig.3 power curve of 24 hour](image)

5. Analysis of advantages and application effect of the device
In this paper, an intelligent energy storage device based on electrochemical energy storage is designed. The working principle, control strategy, software and hardware design scheme of the device are introduced. Through the above design, the application of energy storage technology in overload treatment of distribution transformer is preliminarily provided. The popularization and application of the device can reduce and delay the power grid investment, and has the advantages of rapid deployment, safety and environmental protection, and can be used for emergency power supply. With the development of battery energy storage technology, it will be regarded as an important carrier to promote the revolution of energy production and consumption in the future. It is a technology and industry with great development prospects for energy Internet.
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