Design and Application of Energy Management Integrated Monitoring System for Energy Storage Power Station

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Abstract. According to the characteristics of huge data, high control precision and fast response speed of the energy storage station, the conventional monitoring technology can not meet the practical application requirements. In this paper, an integrated monitoring system for energy management of energy storage station is designed. The key technologies, such as multi-module integration technology, centralized energy management control technology, high concurrency group control technology based on IEC61850 and internal interaction mechanism based on User Datagram Protocol, are described in detail. Relying on the project site of Langli energy storage station, the secondary system architecture of the energy storage station, the secondary system architecture of the energy storage station is simplified, the stability of control operation and the fast response ability of power conversion system group are improved, and the reliability of output power of the energy storage station is guaranteed.

1. Introduction

With the rapid development of new energy, energy storage station (ESS), with its own characteristics, has played a great role in improving the power system voltage stability [1], frequency regulation [2-3], promoting the integration and consumption of new energy [4-5]. Since the first large-scale grid side energy storage station in Jiangsu was officially put into operation in July 2018, the energy storage station has developed rapidly in Jiangsu, Qinghai Province and other places [6-7].

In [1], proposes a novel framework for distribution network voltage regulation by integrating PV system with distributed ESS. In [2], this paper is on developing a dynamic model for frequency regulation studies, practical and useful for system operators, and study its effects on system stability. In [3], Based on the optimal response frequency regulation scheduling instruction of energy storage power station, based on K-means clustering method, the comprehensive performance. In [4], the paper aims to assess the impact of deploying ESS on the operational performance of the Portuguese transmission grid, mainly in terms operational flexibility and variable RES power support. In [5], the paper examines the case of large pulsed loads implemented on systems with relatively high source impedance; inertial energy storage is shown as a viable means of providing compensation and regulation in contrast to other forms of energy storage. In [6], analyzes the construction characteristics and station architecture of large-scale grid side ESS, studies the operation mode and control strategy of the ESS participating in dispatching. In [7], presents the design of a resilient energy storage platform to support the operation of power substation and ensure stable and reliable power support to their customers. In [8], integrates the function modules of monitoring, power prediction, active and reactive power control, and develops the intelligent power control system of new energy station, realizing the coordination of different functional
modules. In [9], a power allocation method is proposed. According to the dispatch instructions, total charging and discharging power is allocated among all energy storage units reasonably and optimally.

The existing energy storage station monitoring system is realized by the traditional substation monitoring system architecture, which is composed of monitoring background Supervisory Control And Data Acquisition (SCADA), energy management system (EMS), automatic generation control device (AGC), automatic voltage control device (AVC), remote control workstation and other equipment systems. There are huge differences in the indicators of different manufacturers, communication systems and communication protocols. At the same time, because there is no interaction mechanism between SCADA and EMS, EMS and Remote control workstation, SCADA can not obtain the detailed information of the control operation of the master station, and the on-site operation and maintenance personnel can not timely discover the hidden dangers of Remote control equipment, which seriously affects the safe operation of the energy storage station.

At present, the existing large-scale energy storage station has reached the level of one million battery information. According to the characteristics of huge data, high control precision and fast response speed of the ESS, higher requirements are put forward for the monitoring system, and the conventional monitoring technology can not meet the practical application requirements.

In the paper, an integrated monitoring system for energy management of energy storage station is designed and developed. The SCADA, AGC, AVC and EMS functions of the ESS as independent modules are integrated to realize centralized energy management and power control. Proposed high concurrency group control technology based on IEC61850 protocol. Internal interaction mechanism between the EMS and remote workstation is designed. Finally, the function and performance of the system are verified based on the field application of the ESS in Langli, Hunan Province.

2. Overall design of system software

The overall framework of energy management integrated monitoring system software is shown in Figure 1, including unified command control module, energy management module, front communication module and user-friendly interface.

![Figure 1. Overall framework of software](image)

According to the relevant standards and specifications of active and reactive power control of energy storage station and the output response characteristics of PCS and battery management system (BMS), the energy management integrated monitoring system establishes the control algorithm model. Through the external communication interface with PCS, BMS, protection and measurement and control devices,
it can obtain the real-time data of the controlled equipment. Reading the interface input or plan curve to obtain the local control instruction or remote dispatching instruction can be obtained through UDP channel. After command analysis and AGC/AVC algorithm model control operation, the control command is output to the controlled equipment, and the operation status and control instruction execution of the energy storage station are displayed on the human-computer interface in real time.

3. Key technologies

3.1. Multi-module integration technology

The existing energy storage monitoring system has a variety of systems with high construction and operation costs, and its architecture is shown in Figure 2(a). On the one hand, the remote signaling and telemetry information of the equipment in the ESS is transmitted to the monitoring background for interface display, on the other hand, it is transmitted to the Remote control workstation, and then uploaded to the dispatching master station by the Remote control workstation. The control instructions are generally initiated by the dispatching master station and transferred to the AGC or AVC device through the protocol of IEC 104. IEC104 is an international standard, formulated by the International Electrotechnical Commission, which is widely used in the power industry. Finally, the instructions are analyzed and processed by EMS and distributed to PCS devices in the station for execution.

The multi-module integrated system structure is shown in Figure 2(b). Based on the multi-module integration technology, the system integrates SCADA, EMS, AGC, AVC functional modules. Through the unified IEC 61850 Communication Protocol, the system can realize the full data monitoring and storage in the station, and has the functions of interaction with dispatching and energy management of the whole station. The flat architecture is realized, the control efficiency is improved, and the construction and operation and maintenance costs are reduced.

3.2. Centralized energy management and control technology
The system energy management function module adopts the unified control of dispatching instruction and local instruction. Based on the unified command control technology, the integrated monitoring system realizes the coupling of control mode of the ESS and AGC/AVC command, realizes remote or local control and management functions of active power, reactive power, planning curve and other modes, which can be flexibly applied to various power system applications.

The control instruction is output to the controlled equipment after the AGC/AVC algorithm model control operation. The flow chart of the control algorithm is shown in Figure 3.

![Flow chart of active and reactive power control algorithm](image)

**Figure 3.** Flow chart of active and reactive power control algorithm

1) Active power control algorithm module

After receiving the current active power target command, the AGC algorithm module compares it with the actual active power of the current merging node. If it is within the dead zone \((\pm 1\% \ P_n)\), it will continue to monitor the active power command and the actual active power of the merging node. If the dead zone is exceeded, the line loss will be calculated and the total active power instruction will be corrected. It will judge whether the AGC function of the equipment is put into operation, eliminate the equipment not put into operation, and calculate the active power command of each PCS. According to this, the active power control command value is issued to each controlled PCS, and the continuous monitoring active power command and the actual active power of the merging node are returned.

The active power calculation equation of the system as follows:

\[
P_{cmd(i)} = P_{cmd} * \frac{SOC_i}{SOC_N} \tag{1}
\]

\[
SOC_{low} \leq SOC_i \leq SOC_{high} \tag{2}
\]

Where \(P_{cmd(i)}\) is active power command for the PCS i, \(P_{cmd}\) is active power command for the ESS. \(SOC_i\) is State of charge (SOC) for the PCS i. \(SOC_N\) is SOC for the ESS. \(SOC_{low}\) is lower limit of the SOC. \(SOC_{high}\) is upper limit of the SOC.

2) Reactive power control algorithm module

The AVC algorithm module compares the actual voltage of the merging node with the current target voltage value of reactive power. If it is within the dead zone \((-3\% \sim 5\% U_n)\), it will continue to monitor the actual voltage and target voltage of the merging node; if not, it will judge the current AVC working mode, calculate the reactive power control command according to the voltage target value, judge whether the AVC function of the equipment is put into operation, eliminate the equipment not put into operation, and according to the response working mode calculate the reactive power distribution command and send it to PCS. Return to continue monitoring the actual voltage and target voltage of the connecting point. Reactive power calculation equation as follows:
\[ q_{\text{cmd}(i)} = \frac{Q_{\text{cmd}}}{N} \]  

\[ Q_{\text{cmd}} = \begin{cases} 
Q_0 + K[U_{\text{act}} - (U_n - \Delta U)] & U_{\text{low}} < U_{\text{act}} < (U_n - \Delta U) \\
0 & (U_n - \Delta U) \leq U_{\text{act}} \leq (U_n + \Delta U) \\
Q_0 + K[U_{\text{act}} - (U_n + \Delta U)] & (U_n - \Delta U) < U_{\text{act}} < U_{\text{high}} 
\end{cases} \]

Where \( q_{\text{cmd}(i)} \) is reactive power target value for the PCS \( i \). \( Q_{\text{cmd}} \) is reactive power target value for the ESS. \( Q_0 \) is current output reactive power of the ESS. \( U_{\text{act}} \) is actual voltage of the PCC. \( U_n \) is rated voltage of the PCC. \( \Delta U \) is dead zone of voltage regulation. \( U_{\text{low}} \) is voltage lower limit of the PCC. \( U_{\text{high}} \) is voltage upper limit of the PCC. \( K \) is reactive power regulation coefficient. \( N \) is number of available PCS.

### 3.3. High concurrency group control technology

In the large capacity energy storage station, there are many PCS core controlled objects, and the synchronization of control commands for multiple PCS directly affects the power response characteristics of the whole ESS. The existing PCS control mode of the ESS mostly adopts single sequential control mode. The real-time PCS control can only ensure the optimal local time section, which results in the lag of PCS response time, the output power increases step by step, and the rated power output cannot be achieved in a short time, which has a fluctuating impact on the parallel network power of the ESS.

Therefore, this system proposes a high concurrency group control technology, and its group control flow is shown in Figure 4. Group control instruction is based on IEC 61850 Communication Protocol and completed by fixed communication program according to configuration file. The communication process includes establishing communication connection, confirming object, replying confirmation, issuing control instruction, writing data and replying control instruction.

There are 48 PCS in Langli ESS that need synchronous group control operation. If IED names of these 48 PCS devices are filled into the same group, the group control commands are sent to 48 devices at the same time, which reduces the command execution time when sending remote control instructions separately.

![Flow chart of high concurrent group control](image)

**Figure 4.** Flow chart of high concurrent group control

Based on IEC 61850 standard system, the high concurrency group control technology realizes the synchronization of group control instructions of multiple PCS, improves the fast response ability of PCS group, and ensures the reliability of output power of energy storage station. Through intelligent management of the start and end of threads, the reasonable cost of platform resources is realized.

### 3.4. Internal data exchange technology of energy storage station based on UDP

Aiming at the problem that there is no interaction mechanism between the energy storage monitoring background and the remote control workstation, this system designs an internal data interaction...
mechanism of energy storage station based on UDP, realizes the signal interaction between the monitoring background and the remote control workstation, which can adapt to the interaction requirements between multiple monitoring background and remote control workstation, and enhance the stability of remote control operation provides guarantee.

The internal data interaction process of energy storage monitoring system based on UDP is shown in Figure 5, and the implementation process is as follows:

1) The Remote control workstation and the background will send their own basic information regularly. For example, after receiving the basic information of the background, the Remote control workstation will store the basic information of the background into the information exchange table of the remote control, and write the status of the background as online.

2) After receiving the basic information of the other party, the Remote control workstation and the background judge whether the version of the forwarding table of the other party is consistent with the local one. If they are consistent, they will start to transmit data to the other party according to the equipment information in the information interaction table. If they are inconsistent, an alarm will be generated.

3) The timing transmission mode is adopted for the full remote signaling and full telemetry data, and the trigger transmission mode is used for the variable telemetry and telemetry data.

4) After the master station sends the remote control or remote regulation operation to the remote control workstation, the remote work station will forward the corresponding remote control or remote regulation operation to the monitoring background, and the monitoring background will reply the mirror image confirmation message to the remote control workstation after receiving the command, so as to enhance the reliability of the control operation interaction.

5) The EMS module in the background uniformly analyzes the control strategy, sends the remote control or remote regulation operation to the devices in the station, and finally returns the corresponding remote control or remote regulation results.

Figure 5. Internal data interaction process based on UDP
4. Engineering application and operation analysis
The system is first deployed the Langli ESS, in Changsha, Hunan Province, which adopts fully prefabricated cabin layout, with an installed capacity of 24MW/48MWh and 48 PCS with rated power of 500kW [10-11].

Under the continuous operation condition, the equipment operates normally without fault and alarm, the initial SOC of energy storage is 50%. The power command of the ESS by local manual setted is used to adjust the PCS output power of the ESS, and the regulation ability of the active and reactive power of the ESS is tested. In the follow test, when the active command value is negative, it means charging, and the active command value is positive, it means discharging.

4.1. Active power regulation capability test
The active power output of the ESS is adjusted by manually setting command. The low-power continuous charge and discharge test of the ESS is shown in Figure 6 (a), and the high-power alternating charge and discharge test is shown in Figure 6 (b). The measurement results of active power are shown in Table 1.

![Figure 6(a). Active power measured value and set value response curve 1](image1)
![Figure 6(b). Active power measured value and set value response curve 2](image2)

**Table 1. Test results of active power control response**

| Set value (MW) | 0 | -6 | -12 | -18 | -24 | -12 | -6 |
|----------------|---|----|-----|-----|-----|-----|----|
| Measured value (MW) | -0.12 | -6.09 | -12.08 | -18.12 | -24.10 | -18.08 | -12.08 |
| Steady-state deviation (%) | -0.5 | -0.38 | -0.33 | -0.5 | -0.42 | -0.33 | -0.33 |
| Set value (MW) | 6 | 12 | 18 | 24 | 18 | 12 | 6 |
| Measured value (MW) | 5.85 | 11.80 | 17.71 | 23.85 | 17.68 | 11.77 | 5.85 |
| Steady-state deviation (%) | 0.63 | 0.83 | 1.21 | 0.63 | 1.33 | 0.96 | 0.63 |

**Table 1(b). Test results of active power control response**

| Set value (MW) | 0 | 21.6 | -21.6 | 19.2 | -24 | 24 | -24 | 24 | 0 |
|----------------|---|------|-------|-----|-----|----|-----|----|---|
| Measured value (MW) | -0.11 | 21.25 | -21.72 | 18.86 | -24.10 | 23.57 | -24.11 | 23.56 | -0.12 |
| Steady-state deviation (%) | -0.46 | 1.46 | -0.50 | 1.42 | -0.42 | 1.79 | -0.46 | 1.83 | -0.50 |

Through the test, it can be seen that the PCS can timely respond to the group control instructions issued by the integrated system. The minimum steady-state deviation is -0.33% and the maximum value is -1.83%.

Due to the fact that some electrical equipments in the ESS, such as Uninterruptible Power Supply (UPS), air conditioning, communication cabinet, etc., are under the same bus with PCS, BMS and other equipments, the measured value of charging power of the ESS is slightly greater than the set value, and the measured value of discharging power is less than the set value. It can be seen from table 1 that when the setting value is 0, the power of station electrical equipment is about 0.1MW. Due to the power consumption of station electrical equipment, the steady-state deviation exceeds the control dead zone.
4.2. Reactive power regulation capability test

Figure 7 shows the response curve between the measured value of reactive power and the set value, and the measurement results of reactive power are shown in Table 2. Figure 7 (a) shows that the ESS generates reactive power to increase bus voltage. Figure 7 (b) shows that the ESS absorbs reactive power and reduces bus voltage.

The test results show that The energy management integrated monitoring system of energy storage station can execute the reactive power control command well, but the maximum steady-state deviation of reactive power regulation is - 5.04%, and the reactive power response ability of PCS needs to be further improved.

Table 2. Test results of reactive power control response

| Set value (MVar) | 0  | 6  | 12 | 18  | 24  | 18  | 12  | 6  | 0  |
|-----------------|----|----|----|-----|-----|-----|-----|----|----|
| Measured value (MVar) | -0.05 | 5.95 | 11.72 | 17.64 | 22.79 | 17.37 | 11.63 | 5.82 | -0.13 |
| Steady-state deviation (%) | -0.21 | 0.21 | -1.17 | 1.50 | 5.04 | 2.63 | 1.54 | 0.75 | -0.54 |

4.3. Charge discharge conversion time test

Under normal operation conditions, when the ESS charges at rated power, it sends the discharge command at rated power to the ESS, records the time from 90% of the rated power to 90% of the rated power; then sends the command of charging at the rated power to the energy storage station, records the time from 90% rated power discharge to 90% rated power charging, and repeats the above steps twice, charging response The time and time are the maximum of the three test results.

Figure 8(a) is the response time test curve of discharge to charge, and the test curve of charge to discharge response time is shown in Figure 8(b). The average value of charge discharge conversion time is taken as the test results are shown in Table 3.

According to the test data, the maximum charge discharge conversion time of Langli energy storage station is 136.2ms, which is much longer than the response time of conventional thermal power and hydropower, which further verifies the great advantage of ESS in participating in frequency regulation and peak shaving of power grid.
Figure 8. Response curve of charge and discharge conversion time

Table 3. Test results of charge and discharge conversion time

| No. | Charge to discharge | Discharge to charge | Conversion time | Limits  |
|-----|---------------------|---------------------|-----------------|--------|
| 1   | 102.8ms             | 97.6ms              | 100.2ms         | 400ms  |
| 2   | 183.1ms             | 89.3ms              | 136.2ms         | 400ms  |
| 3   | 182.5ms             | 89.6ms              | 136.1ms         | 400ms  |

4.4. System processing time test

EMS control instruction processing of energy management integrated monitoring system is divided into four processes: UDP transmission, EMS algorithm processing, group control instruction sending and IEC61850 MMS message transmission. In order to test the time consumed in each processing process of the control command of the integrated monitoring system, the test is carried out. Under normal operation conditions, through EMS program log printing and Wireshark packet capturing to analyze UDP and MMS communication messages, in order to reduce the test error, a total of five tests were carried out, and the test results were taken as the average value. The processing time of each process is obtained as shown in Table 4.

Table 4. Test results of system processing time

| Test No. | UDP  | EMS  | Group control | MMS   | Total   |
|----------|------|------|---------------|-------|---------|
| 1        | 23.5ms | 69ms | 39.08ms       | 348.46ms | 480.04ms |
| 2        | 25.25ms | 136ms | 44.77ms       | 500.41ms | 706.43ms |
| 3        | 33.68ms | 117ms | 43.29ms       | 548.97ms | 742.94ms |
| 4        | 57.59ms | 172ms | 55.34ms       | 467.55ms | 752.48ms |
| 5        | 14.66ms | 73ms  | 42.33ms       | 385.43ms | 515.42ms |
| Average  | 30.94ms | 113.4ms | 44.96ms       | 450.16ms | 639.46ms |

It can be concluded that the average time consumption of UDP channel is 30.94ms from sending UDP message by remote control to receiving UDP message by integrated monitoring system of energy storage and energy management. Through EMS log printing, the average processing time of EMS program is 113.4ms from receiving dispatching remote dispatching instruction to sending allocation instruction to group control interface. From packet capturing MMS message analysis, the high concurrency group control of two adjacent PCS is obtained. The command interval is about 1ms. The average time of group control command of 48 PCS in Langli station is 44.96ms, which is much lower than that of conventional sequence control. The average time from 61850 Communication program receiving the group control command sent by EMS to sending MMS message takes 450.16ms. The energy management integrated monitoring system receives the dispatching command value transmitted by remote control, processes it by EMS and group control program, and sends MMS message by 61850 Communication program. The average total time is 639.46ms, and the second level response control of energy management of energy storage station is realized.
5. Conclusions
This paper focuses on the energy management integrated monitoring system design, key technology, engineering application and operation analysis of energy storage station.

The multi-module integration of the system makes the station control layer system centralized, simplifies the secondary topology of the energy storage station, and reduces the construction, operation and maintenance costs. At the same time, the high concurrency group control technology based on IEC 61850 and the internal data exchange mechanism based on User Datagram Protocol in the energy storage station make the relevant control operation such as power conversion system more accurate and fast, enhance the stability of remote control operation, and provide guarantee for the safe operation of energy storage station.

The system based on this paper has been applied in Langli energy storage station, Hunan Province, Yinjiabang energy storage station in Shanghai and Xuancheng energy storage station in Anhui Province.

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