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Development of Energy Storage System Communication Platform with Redundant Station Launched by Transmission Control Protocol/Internet Protocol Connection Detection

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With the increasing emphasis on low-carbon energy development, reducing carbon emission in the energy production process has become a top priority. In recent years, low-carbon power generation technologies such as solar and wind power have made significant progress, gradually replacing traditional fossil-fuel-fired power generation methods. The large-scale integration of renewable energy into the grid has become mainstream, but the intermittent issues it poses to the power grid affect the stability of the power system. The rapid development of energy storage systems has become a bridge between renewable energy and the grid, providing flexibility and scheduling capabilities to the power system. In this study, we developed a communication platform based on the DNP3.0 communication protocol rules specified in Taiwan Power Company's Enhanced Dynamic Regulation Reserve Service (E-dReg). The platform realizes multiple protocol conversions including DNP3.0, Modbus TCP, OPC DA, and VPN. Additionally, to enhance overall reliability, a redundant station startup mechanism based on transmission control protocol/internet protocol connection detection is proposed. This mechanism makes decisions based on the status of the master station, enabling redundant stations to rapidly start, automatically take over the master station, or determine whether to return authority to the master station. The results demonstrate that the communication platform can facilitate communication between Taiwan Power Company and users, ensuring the high reliability of the communication platform operation.

1. Introduction

In recent years, governments worldwide have been actively promoting the development of renewable energy to achieve energy diversification and self-sufficiency. Taiwan's energy development focuses primarily on reducing carbon emissions, increasing natural gas sources,

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and expanding green and non-nuclear energy to ensure stable electricity supply while reducing air pollution and carbon emissions.

In the past, to maintain a stable power supply, coal and nuclear energy were commonly used as the base load power, with natural gas and renewable energy serving as supplementary power during peak demand. However, to meet carbon reduction goals, renewable energy will gradually become the primary source of electricity in the future, with base load power transitioning to a supplementary role. Although integrating a large amount of renewable energy into the grid is the current mainstream practice, challenges such as the associated unpredictability, grid control difficulties, and intermittency persist.

The variability of renewable energy is considerable, particularly as the proportion of renewable sources in the energy mix increases, leading to a more pronounced fluctuation in electricity supply. Solar photovoltaic (PV) generation serves as a noteworthy example. It has been reported that on the day of the highest demand in 2019, solar PV production decreased by 1.28 million kWh over a three-hour period from 3 pm to 6 pm. In 2020, solar PV generation witnessed a decline of 1.72 million kWh, and on July 27, 2021, a significant drop of 2.8 million kWh was observed.[(1)]

To address these issues, Taiwan Power Company (TPC) has proposed an auxiliary service program aimed at maintaining the security and stability of the power system and providing the ability to restore normal operation in case of accidents. This service program falls within the realm of system quality and safety, with the goal of enhancing the reliability, quality, safety, and capacity adequacy of the power system.[(2)]

2. Introduction to Energy Storage Systems and Auxiliary Service Energy Storage Systems

2.1 Energy storage systems

Energy storage systems play a crucial role in the global trend of integrating renewable energy sources to address the challenges posed by intermittent power generation on the grid.[(3,4)] Energy storage systems, also known as industrial uninterruptible power systems, can convert energy into electricity and provide functions such as smoothing transition, peak shaving, and frequency and voltage regulation. Their primary objectives include integrating renewable energy, enhancing power supply reliability, and concurrently, contribution to stabilizing the power generation of renewable sources such as solar energy.[(5,6)] The primary objectives of energy storage systems include integrating renewable energy, enhancing power reliability, and reducing carbon dioxide emissions.[(7)]

The ongoing advancement of energy storage systems has broadened the research focus from a limited perspective to a wide array of applications. These applications span every facet of the power system, including generation, transmission, distribution, and utilization.[(8)] Their primary objectives are not only to facilitate the integration of large-scale renewable energy sources and enhance the efficiency of the power grid, but also to defer and reduce the costs associated with power generation and grid construction. This progression has played a pivotal role in optimizing power grid planning, dispatch management, and operational control.[(9–11)]

In the event of a disaster or system failure, energy storage systems can be dispatched rationally to provide backup power and islanding functionality.[12] This can be of great help and contribution to the reconstruction of the power system in disaster-affected areas[13] or to the establishment of the power system in remote areas and offshore islands.

Currently, there are various types of energy storage systems available, with lithium-ion battery energy storage systems (BESSs) being the most mainstream.[14] These systems typically consist of energy storage components, BESSs, power conditioning systems (PCSs), energy management systems (EMSs), and energy storage controllers (ESCs), as illustrated in Fig. 1.[15]

2.2 EMS

An EMS is a crucial component within an energy storage system responsible for monitoring and controlling the energy storage equipment.[16,17] It monitors and collects information on the charge/discharge status of each energy storage controller or device, the temperature and humidity of battery storage, environmental conditions, fire control, and other relevant parameters. The EMS processes and analyzes such data, distributes energy flows within the system, and ensures effective management, system integration, and real-time monitoring. For energy storage systems, the EMS functions as the brain, and if not managed properly, it can lead to security vulnerabilities.[18]

2.3 Introduction to enhanced dynamic regulation reserve service (E-dReg)

During charging and discharging in energy storage systems, fluctuations can occur in the power grid. Greater fluctuations indicate a less stable grid frequency. To address this issue, TPC has introduced frequency regulation reserve services, aiming to stabilize the grid with power output every second. These services include static frequency regulation (sReg) and dynamic frequency regulation (dReg). sReg responds to low grid frequencies. In this case, the system

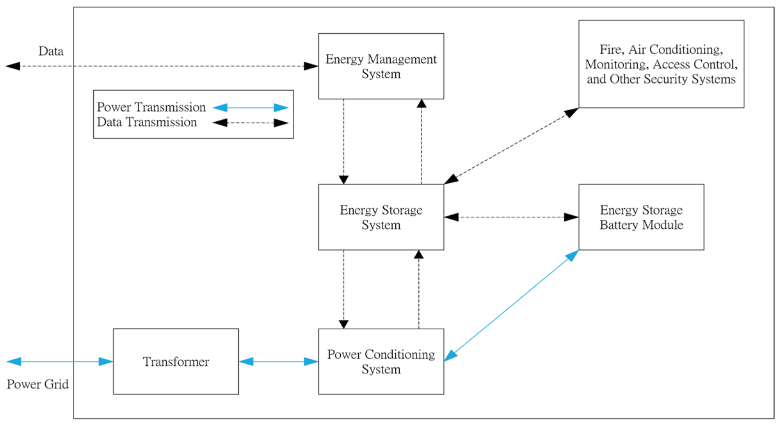


Fig. 1. (Color online) Diagram of energy storage system architecture.

should detect changes within 1 s and reach 100% power output within 10 s to prevent continuous frequency decline. dReg responds to grid conditions and completes both charging and discharging in response to frequency changes within 1 s. dReg is further divided into dReg0.5 and dReg0.25, where the numbers represent the positive and negative frequency deviation ranges. For example, in Taiwan's 60 Hz system, dReg0.5 corresponds to 60 Hz ± 0.5 Hz.

Typically, dReg0.5's primary operating range covers less than 50% of the time, while dReg0.25 operates around 75% of the time. To optimize the efficiency of dReg0.5, TPC has introduced the concept of E-dReg auxiliary services.(19)

E-dReg primarily utilizes composite batteries combining high-power and high-energy capabilities in an energy storage system. This allows it to rapidly respond, adjust frequencies, and engage in two-way frequency regulation during peak shaving and energy transfer. In other words, E-dReg serves to enhance the efficiency of dReg0.5 while providing multifunctional support for grid stability and frequency control.

3. Development of E-dReg Communication Platform

3.1 DNP3.0 communication capability for regulation reserve transfer

According to the communication capabilities specified in the electricity trading platform regulations, in the platform-communication system, communication is primarily established through a VPN channel between qualified traders and the platform. The platform acts as the client, while the qualified traders act as the server. Communication can use either the IEC 61850 or DNP3.0 protocol. The DNP3.0 communication content includes the following elements: Command Status (digital input, DI), Auxiliary Service Commands (digital output, DO), Electric Power Data (analog input, AI), Capacity of the platform to send auxiliary service instructions, Frequency Target Values, and Time (analog output, AO). These are commands sent by the platform for auxiliary services and can include various parameters.

In this context, the term "platform" refers to the electricity trading platform, while "qualified traders" represent members who comply with platform management regulations and participate in auxiliary services. The following seven points define and explain the data types and communication elements involved in the communication between the platform and qualified traders.(20)

- The platform acts as the client, passively obtaining electric power data from qualified traders and various command status responses, and actively sending instructions related to auxiliary services.
- Qualified traders act as servers, actively uploading electric power data and various command status responses, and passively receiving instructions related to auxiliary services.
- DI: In the platform-communication system, it also refers to the status of relevant command responses from qualified traders.
- DO: In the platform-communication system, it also refers to the status of platform-related notifications and the execution status of auxiliary service instructions.

- AI: In the platform-communication system, it also refers to the individual quotation codes aggregated by qualified traders and the electric power data for trading resources.
- AO: In the platform-communication system, it also refers to the frequency, capacity, and time associated with platform-related notifications and the execution of auxiliary service instructions.
- Counter: An AI counter.

3.2 Introduction of E-dReg communication platform development software

In this research, we focus on studying and developing the communication capability regulations for auxiliary services in the TPC's electricity trading platform. The primary development environment used for the EMS is Indusoft Web Studio. Additionally, Triangle MicroWorks' Test Harness and SCADA Data Gateway are utilized to simulate receiving DNP3.0 data on the TPC's end and to act as protocol converters between the EMS and the simulated TPC's end, as illustrated in Figs. 2 and 3.

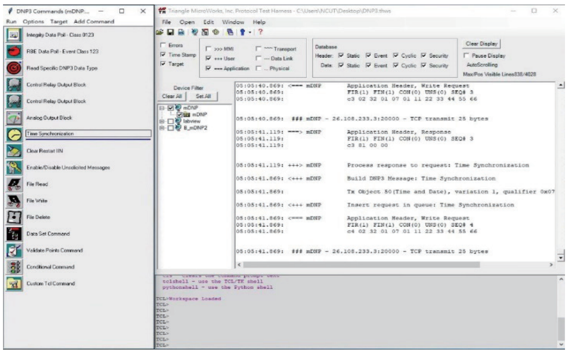


Fig. 2. (Color online) Test harness operation interface.

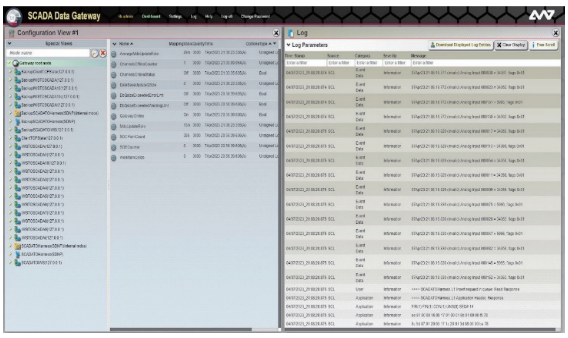


Fig. 3. (Color online) SCADA data gateway operation interface.

3.3 Main backup system architecture of communication platform

During the communication process, one of the most dreaded situations is when the computer host experiences unexpected anomalies or accidents while executing tasks. The reasons for these incidents can vary and may be related to factors such as the environment, human error, system updates, and more. The occurrence of such accidents can have various consequences. Mild scenarios may result in interruptions of ongoing services, leading to the loss of data that should have been uploaded. These interruptions continue until the system is restored, and services can resume in accordance with the schedule. Severe scenarios may lead to the complete loss of scheduled service tasks or disrupt the execution of urgent tasks such as following platform-issued frequency target values or charging/discharging capacity scheduling instructions. This can result in the inability to carry out emergency frequency or capacity dispatch tasks following the given instructions.

Regardless of the severity of the consequences, any abnormal incident can lead to communication interruption, resulting in poor communication quality between qualified traders and the platform. To prevent this, the platform recommends that qualified traders establish two communication systems to mitigate the occurrence of abnormal incidents.[21]

Additionally, the platform allows qualified traders to submit a standby suspension request only once a month using a single quotation code. If communication abnormalities occur on the qualified trader's end as a result of abnormal incidents and service interruptions reach a certain frequency, the platform may impose corresponding penalties on the qualified trader (such as suspending participation in auxiliary services or reducing auxiliary service fees).[22]

To prevent such incidents, we designed primary and backup systems. Both systems serve as communication platforms, and the protocol used between them is transmission control protocol/internet protocol (TCP/IP). This protocol is utilized to monitor the operational status of the communication platform's primary station and to receive the daily schedules for services set by the primary station or those currently in execution.

3.4 Main station of communication platform

The primary station of the E-dReg communication platform serves as the main communication hub with the platform and is responsible for communication handshake, data upload, receiving instructions, data reading and writing with energy storage system controllers, dispatching instructions, and retrieving electric power data. Therefore, this communication platform is in primary use for the majority of the time. It also archives the captured electric power data to ensure that missing data can be provided directly if needed for future replenishment.

At the same time, although both the primary and backup sides of the communication platform are online, only one of them is active at any given time. The switch to the backup side occurs only in the case of an abnormal incident or emergency wherein the communication platform (backup side) takes over operation.

3.5 Backup side of communication platform

When an abnormal incident or emergency occurs with the primary station of the E-dReg communication platform, the backup side of the E-dReg communication platform will be activated, taking over the completion of any remaining or ongoing service tasks for the day. This ensures that communication continuity is maintained. The primary method of detecting the status of the primary station relies on the time values transmitted from the primary station to the backup station via TCP/IP and the status of the TCP/IP connection. These factors are used to determine whether the primary station has encountered an abnormal incident or has lost connectivity.

When the backup system is activated and takes over the remaining tasks from the primary station, a green light on the monitoring screen indicates that the backup system is in the process of starting up and is taking over the execution of the remaining tasks or the reception and issuance of incomplete emergency dispatch instructions. This green light signifies the stability and accuracy of the entire primary and backup system's detection, takeover, and switching strategies in response to emergencies or abnormal incidents.

3.6 Communication action workflow of communication platform

After the primary and backup systems of the communication platform are online, the primary station takes precedence. Therefore, only the primary station is activated while the backup station remains on standby, following the primary station's actions. However, the backup station does not engage in data transmission with the test harness in the primary/backup control room or receive emergency dispatch instructions.

When the time approaches the day before the scheduling day, specifically, from 4:00 PM to midnight, the energy storage controller schedules the bidding time slots. After midnight (on the scheduling day), the program automatically updates the results of the scheduled time slots into the program for the standby execution of the service. It determines whether to execute service tasks based on the Unix timestamp time. If it is not a scheduled service time slot, both the primary and backup stations of the communication platform remain on standby. If it is a scheduled service time slot, the primary station begins transmitting electric power data to the test harness at 10 s intervals and archives the electric power data in the first second. During execution, if the primary station receives an emergency dispatch command (DO) from the test harness, along with AO content values (frequency or charge/discharge capacity, execution time), it transmits this command and AO content to the energy storage controller via Modbus TCP. It also sends a DI response command to the test harness and resets DO, AO, and DI to 0 after 2.5 s.

If an abnormal incident occurs with the primary station during this period, causing a system disconnection, the backup station will immediately activate the backup mechanism. The backup station takes over the execution of the remaining or scheduled service tasks, such as archiving electric power data and handling emergency dispatch instructions. If the primary station is repaired and comes back online during the scheduling day, the backup station continues to complete the remaining service tasks and dispatch instructions. It also synchronizes with the

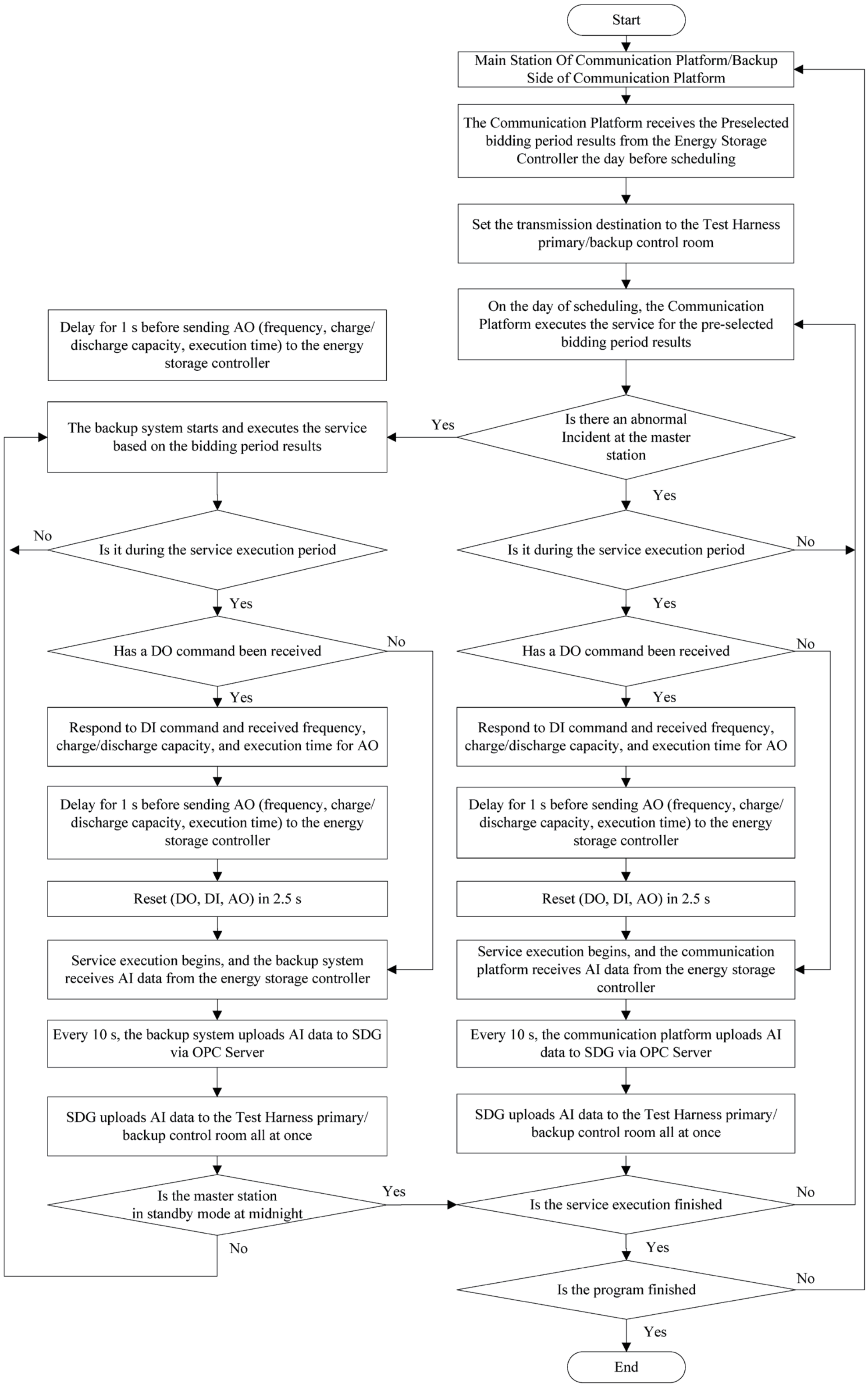


Fig. 4. DNP3 communication flow chart of communication platform.

results of the next scheduled bidding time slots sent by the primary station of the E-dReg communication platform. This continues until after midnight when the backup station transfers control back to the primary station. The primary station then follows the new schedule to continue executing service tasks, as illustrated in Fig. 4.

4. Test Results of E-dReg Communication Platform

4.1 Taiwan power communication environment

The primary simulation uses the DNP3.0 Master of the test harness to mimic the role of TPC. It simulates communication and interaction between the communication platform and the TPC side. This includes tasks such as receiving electric power data and transmitting emergency dispatch instructions. Reference is made to TPC's communication documentation for the configuration of AO and DO to ensure that the overall communication environment closely resembles the actual participation in the E-dReg system. This setup is used to conduct simulated testing with the communication platform to verify its functionality and compatibility.

4.2 Before the execution of service begins

Before the execution of service begins, the Indusoft Web Studio side successfully establishes a connection with the test harness side. Additionally, a total of 193 data points are set up, including DI , DO, AI, AO, and counter points. This configuration is illustrated in Fig. 5, which shows the data window used to simulate the Taiwan Power side in the test harness.

4.3 Fulfillment service in progress

As shown in Figs. 6 and 7, at the time for executing the service, the system is officially activated. The communication platform starts organizing the electric power parameter values obtained from the energy storage controller in the format required by TPC. These values are then transmitted in units of 10 s to the SCADA Data Gateway while being uploaded to the test harness.

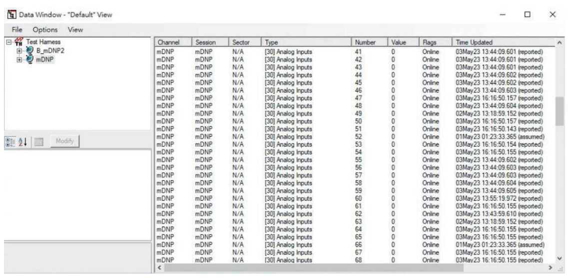


Fig. 5. (Color online) Data window used to simulate Taiwan Power side.

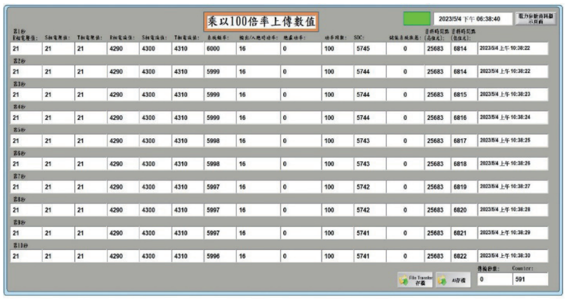
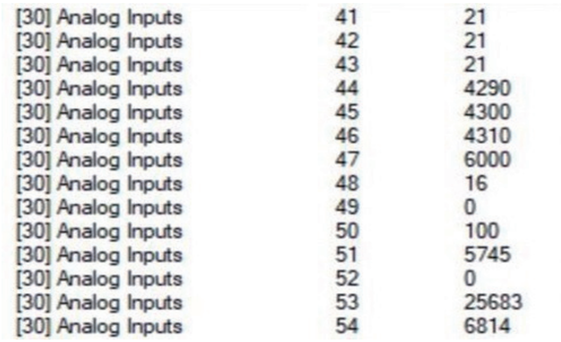


Fig. 6. (Color online) Power data uploaded to main station of communication platform.



[30] Analog Inputs	41	21
[30] Analog Inputs	42	21
[30] Analog Inputs	43	21
[30] Analog Inputs	44	4290
[30] Analog Inputs	45	4300
[30] Analog Inputs	46	4310
[30] Analog Inputs	47	6000
[30] Analog Inputs	48	16
[30] Analog Inputs	49	0
[30] Analog Inputs	50	100
[30] Analog Inputs	51	5745
[30] Analog Inputs	52	0
[30] Analog Inputs	53	25683
[30] Analog Inputs	54	6814

Fig. 7. First-second power data received by TPC side simulation.

During transmission, to avoid decimal points, TPC mandates that all data must be rounded down to the nearest whole number, considering three decimal places (including the third decimal place), and multiplied by 100 as the data transmission format.

4.4 Communication platform receives emergency dispatch instructions

During the execution of the service, the simulated Taiwan Power side begins sending emergency dispatch instructions in the form of DO and AO to the communication platform. The AO instructions include values for moving frequency reference and execution time. To avoid decimal points in transmission on the TPC side, all numerical values except time are multiplied by 100, as shown in Figs. 8–11.

The communication platform receives these emergency dispatch instructions and simultaneously issues them to the energy storage controller. It also sends a DI response back to the simulated TPC side to confirm the receipt of the instructions.

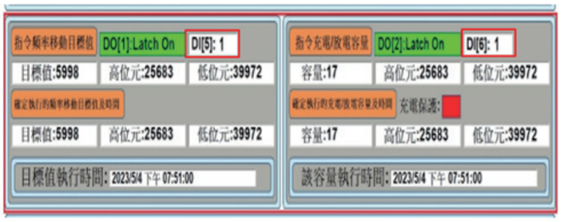


Fig. 8. (Color online) Emergency dispatch instructions received by communication platform.

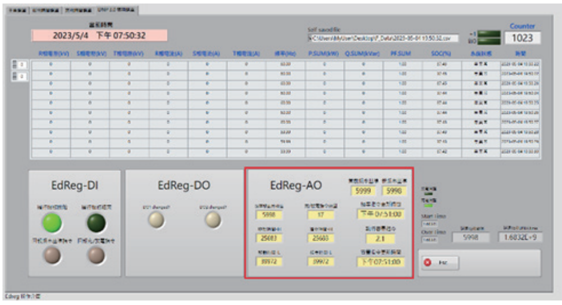


Fig. 9. (Color online) Emergency dispatch instructions issued to energy storage controller by communication platform.

Fig. 10. Emergency dispatch instructions issued to energy storage controller by communication platform.

Fig. 11. (Color online) Power data upload performed by backup system.

[30] Analog Inputs	167	21
[30] Analog Inputs	168	21
[30] Analog Inputs	169	21
[30] Analog Inputs	170	4290
[30] Analog Inputs	171	4300
[30] Analog Inputs	172	4310
[30] Analog Inputs	173	5996
[30] Analog Inputs	174	16
[30] Analog Inputs	175	0
[30] Analog Inputs	176	100
[30] Analog Inputs	177	5741
[30] Analog Inputs	178	0
[30] Analog Inputs	179	25683
[30] Analog Inputs	180	6822

Fig. 12. Final power data received by Taiwan Power side simulation.

4.5 Abnormal incident occurs on the communication platform's main station

When an abnormal incident occurs on the communication platform's main station during the execution of the service, the backup system mechanism is immediately activated. It takes over the execution of the remaining service schedules and the reception of emergency dispatch tasks.

4.6 End of fulfillment service

The backup system no longer retrieves power data from the energy storage controller, uploads power data, or receives emergency dispatch instructions from the platform. The data received by the simulated power company's end will remain as the last uploaded data, as shown in Fig. 12. If the main station has been repaired and is back online, when the next bidding day arrives, the main communication platform will continue to execute the service tasks and receive emergency dispatch instructions.

5. Conclusions

This study was primarily focused on the development of E-dReg and an EMS to address frequency regulation reserve requirements. This was achieved by retrieving the necessary power data from the energy storage controller, mapping it into the DNP3.0 Outstation, and then transmitting it back to the platform. Additionally, the communication platform can issue emergency dispatch tasks to the energy storage controller and transmit dispatch content and execution time in accordance with the emergency dispatch instructions received from the platform, fulfilling the platform's emergency dispatch functionality.

The communication platform also incorporates an automatic switch to the backup system in case of abnormal incidents. This not only prevents disruptions in fulfilling the platform's tasks owing to abnormal incidents but also significantly enhances the overall reliability and communication quality of the communication platform, reducing the consequences of incidents and, in turn, establishing a stable communication system architecture between the power company and the energy storage system communication platform.

In the future, considering that the current mainstream communication protocol of TPC is IEC 61850, the emergency charge/discharge command is extended to the API communication protocol. In response to this, in order to meet the TPC‘s more comprehensive and flexible data transmission requirements and support the more complex automation control system requirements, the platforms communication capabilities must be strengthened to support IEC 61850 and API communication protocols. This will enable the platform to more effectively transmit data and control its devices, thereby improving the reliability and efficiency of power grid operation.

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