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Energy Storage Systems for Frequency Regulation at Electric Power Plants in Korea

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SUMMARY

In an electric power grid, the power line frequency changes continuously due to the unbalance between generation and load. The frequency deviation from a stable frequency of 50 or 60 Hz results in instability of the grid system as well as failure or damage of sensitive load equipment. Therefore, the electric power grid should be able to provide services for balancing generation and load in order to maintain a stable frequency.

Frequency regulation is one of ancillary services to maintain the power quality in the electric power grid by balancing generation and load in real time. However, since the electric power cannot be stored directly without any installation for energy storage, the generators have to monitor the load and adjust the generation continuously. To this end, the generators can use governing system for individual turbine-generator and automatic generation control system for multiple generators at different power plants to adjust the power generation in response to load. However, in order to utilize these systems for frequency regulation, the generators have to reserve a fraction of power capacity for regulating reserve. This results in decrease of efficiency of the power plants.

As the battery technology has been advanced, energy storage systems (ESS) have attracted considerable attention to store the electric energy generated by power plants. ESS allows the electric power grid to store the electric energy when load is lower than generation and utilize the stored energy when load is higher than generation. Therefore, with the ESS, the efficiency of the power plants can be improved with allowing the power plants to generate electric power at a high level without regulating reserve while utilizing the electric energy stored in the battery for frequency regulation.

In this paper, we demonstrate our system architecture of the power management system (PMS) for frequency regulation which is installed in a substation in Korea. In our installation, the PMS consists of frequency regulation systems (FRS) and EES. The FRS monitors the condition of the electricity on the electric power transmission line and determines the power output to be additionally supplied to the electric power grid. Then, the FRS informs the ESS of the power

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output so that the ESS can supply the power output to the transmission line. For frequency regulation, the ESS has to operate in real time. Especially, the power conversion systems (PCS) in the ESS should be able to charge/discharge electric energy to/from the batteries when receiving the control signals from the FRS as well as the FRS should be able to communicate with multiple PCSs in real time. We demonstrate our system architecture of the PMS especially focusing on the performance of the communication between entities in the system.

KEYWORDS

Energy Storage Systems, Frequency Regulation, Power Management Systems, Time-Critical Communication

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1. INTRODUCTION

The unbalance between generation and load in the electric power grid causes the power line frequency to change from a stable frequency. This results in instability of the grid system as well as failure or damage of sensitive load equipment. Therefore, frequency regulation is one of ancillary services to maintain the power quality in the electric power grid by balancing generation and load in real time. However, since the electric power cannot be stored directly without any installation for energy storage, the generators have to monitor the load and adjust the generation continuously. However, to this end, the generators have to reserve a fraction of power capacity for regulating reserve. This results in decrease of efficiency of the power plants.

Energy storage systems (ESS) have attracted considerable attention to store the electric energy generated by power plants. The ESS allows the electric power grid to store electric energy when load is lower than generation and utilize the stored energy when load is higher than generation. Therefore, with the ESS, the power plants can utilize the electric energy stored in the battery for frequency regulation.

In this paper, we demonstrate our system architecture of the power management system (PMS) for frequency regulation which is installed in a substation in Korea. In our installation, the PMS consists of frequency regulation systems (FRS) and ESS. The FRS monitors the condition of the electricity on the electric power transmission line and determines the power output to be additionally supplied to the electric power grid. Then, according to the power output, the ESS supplies the stored electric energy to the transmission line. For frequency regulation, the FRS should be able to communicate with the ESS in real time. We demonstrate our system architecture of the PMS especially focusing on the performance of the communication between entities in the system. We first describe our system architecture of the PMS and data traffic for operation of the PMS especially focusing on the time-critical data. In chapter 3, we explain our methods to support the time-critical data and finally conclude in chapter 4.

2. SYSTEM ARCHITECTURE OF POWER MANAGEMENT SYSTEM

In order to balance generation and load in the electric power grid, the power management system should be able to monitor the power line frequency and supply additional power output to the power grid when there is a frequency deviation from a stable frequency. In our power management system, the ESS stores electric energy when load is lower than generation and utilizes the stored energy when load is higher than generation. The system architecture of the ESS is shown in Fig. 1. In the ESS, there are multiple PCSs which control batteries to be charged/discharged electric energy from/to an electric power grid in order to balance generation and load in real time. The functions of the EES (i.e., charging and discharging electric energy) are controlled by a FRS. The FRS monitors the power line frequency of the electric power grid periodically. When there is a frequency deviation from a stable frequency, the FRS calculates the total power output which should be additionally supplied to the electric power grid to regulate the frequency. The FRS divides the power output among all PCSs so that the sum of the allocated power outputs of all power conversion systems (PCS) is equal to the required power output for the frequency regulation. Then, the FRS informs each PCS how much it should discharge electric power to the power grid.

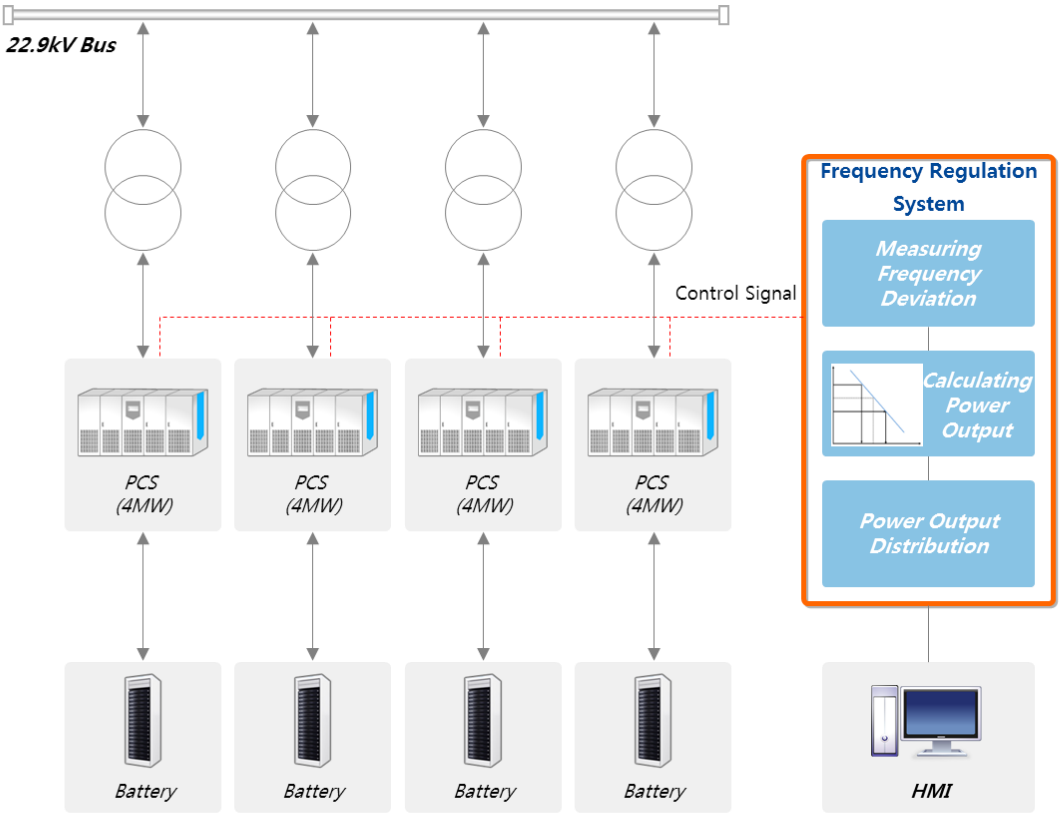

Figure 1. System Architecture of Energy Storage System

Fig. 2 shows the system architecture of the PMS. The PMS can be divided into three systems, i.e., PMS servers, FRS, and EES. The PMS servers include human-machine interface (HMI), data storage, and etc. The PMS servers store the data, which are received from the FRS and display the data through the HMI. In addition, the PMS servers accept the system operator's commands through human-machine interface (HMI) and deliver the commands to the FRS as well as the EES.

The FRS monitors the power line frequency periodically and calculates the power output to be added to the electric power grid for frequency regulation when there is a frequency deviation from a stable frequency. The FRS consists of frequency regulation controller masters (FRCM), frequency regulation controllers (FRC), and distributed network protocol (DNP) masters. In the FRS, there are two FRCMs for network redundancy. The FRCM periodically communicates with the FRCs in order to collect the state of charge (SoC) of the batteries in the ESS and the power line frequency, which is probed by the PSM. Then, the FRCM calculates the total power output to be added to the electric power grid for frequency regulation by using the speed droop curve [1], and divides the total power output among all FRCs.

Each FRC communicates with a container, where four PCSs are installed, via a DNP master that is a communication gateway and allows the FRC and the container to communicate by using DNP 3.0 protocol. The FRC collects the information such as state of charge (SoC) of batteries from the PCSs, which are connected to the FRC, periodically. The FRC also monitors the power line frequency by probing the electric power transmission line with current and power transformers, which are installed in the power sync and measurement (PSM) module in our system. Then, the FRC informs the FRCM of the SoC of batteries and the power line frequency periodically. In addition, the FRC divides the power output, which is allocated and informed by the FRCM, among the PCSs, which are connected to the FRC, based on the SoC of the batteries.

In the ESS, each PCS is communicated with a single battery to charge/discharge electric energy according to the control signals, which are received from the FRC by using DNP 3.0 protocol. In addition, the PCS receives the SoC of the battery and sends the SoC to the FRC periodically.

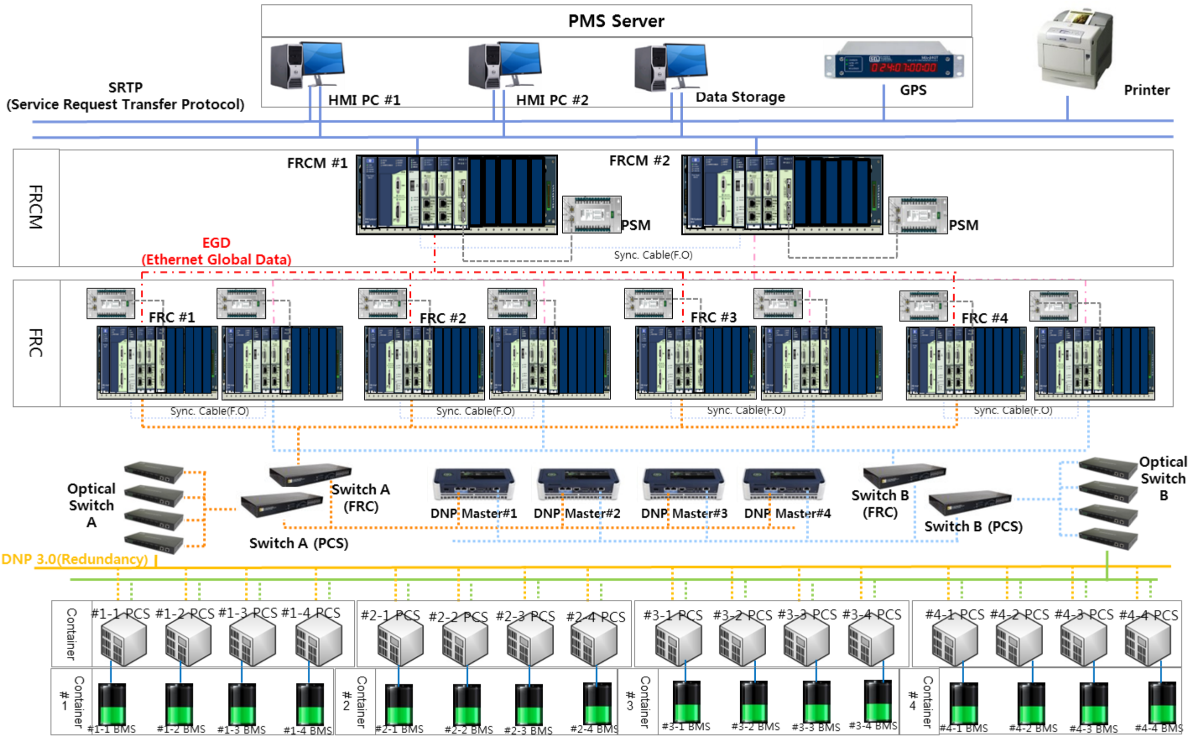

Figure 2. System Architecture of Power Management System

3. TIME-CRITICAL DATA FLOW IN POWER MANAGEMENT SYSTEM

In our power management system, there are four main data flows as follows.

1) Data Flow #1 (Data flow for collection and storage of the SoC of the batteries): the PMS servers collect the PCS's data such as the SoC of the battery periodically in order to store the data. The path of the data flow is 'Battery → PCS → DNP master → FRC → FRCM → PMS server'.

2) Data Flow #2 (Data flow for delivery of the system operator's commands): the system operator's commands are delivered to the PCSs through HMI. The path of the data flow is 'HMI → FRCM → FRC → DNP master → PCS'.

3) Data Flow #3 (Data flow for collection and storage of the PSM module's data): the PMS servers collect the PSM module's data such as the current, voltage, and frequency of the

electricity on the electric power transmission line periodically in order to store the data. The path of the data flow is ‘PSM module → FRC → FRCM → LPMS server’.

4) Data Flow #4 (Data flow for calculation and delivery of the power output): the FRS monitors the power line frequency, which is probed by the PSM module of the FRC. When there is a frequency deviation, the FRS calculates the power output to be additionally supplied to the electric power grid by using the algorithm for the frequency regulation. After calculating, the FRS informs the PCSs of the power output in order to discharge the battery. The path of the data flow is ‘PSM module → FRC → FRCM → FRC → DNP master → PCS’.

Since the power management system should keep a balance between generation and load on the electric power grid in real time, the data flow for calculation and delivery of the power output (‘Data Flow #4’) is time-critical. In our power management system, ‘Data Flow #4’ should be completed within 200ms, which Korea Electric Power Corporation (KEPCO) requests to satisfy. In order to satisfy such a harsh constraint, our company has taken actions to reduce the communication latency of ‘Data Flow #4’ especially focusing on the latency between the DNP masters in the FRS and the PCSs.

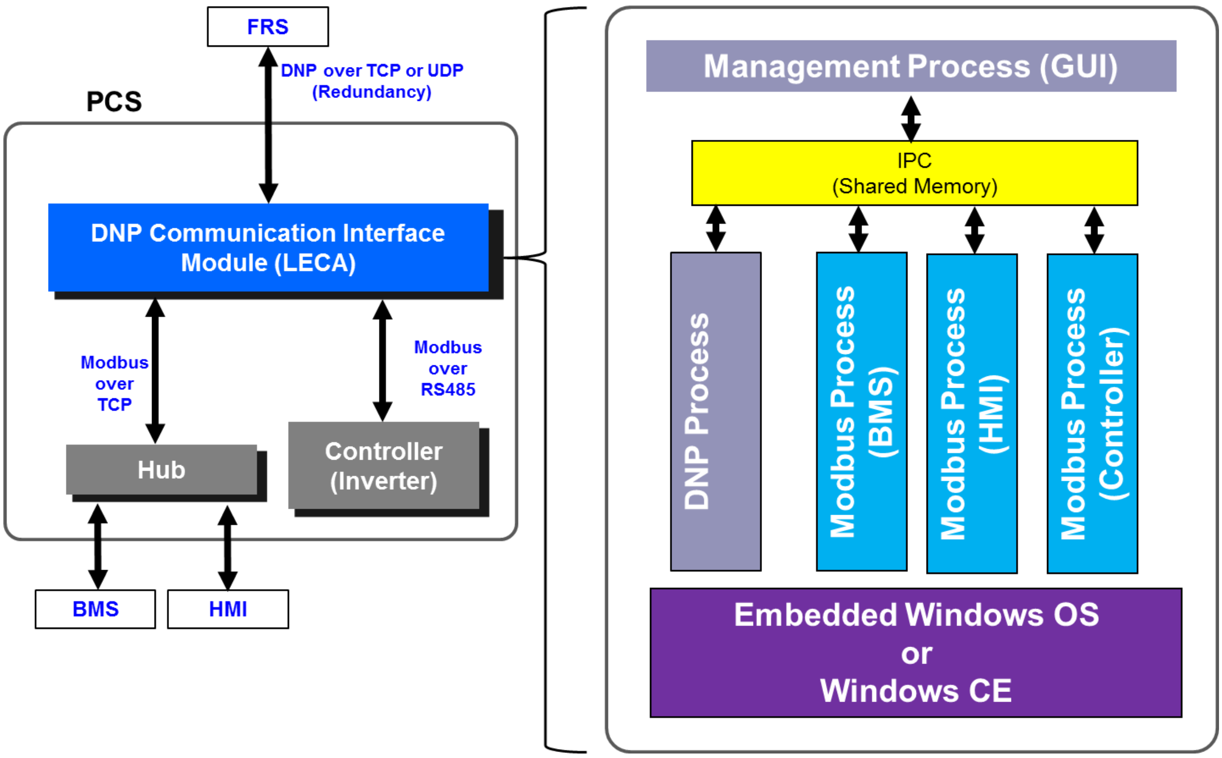

Figure 3. PCS Block Diagram and Software Structure

Fig. 3 shows the block diagram and software structure of the PCS. The battery management system (BMS) is connected with a battery and sends the SoC of the battery to the inverter periodically (‘Data Flow #1’). In addition, the FRS sends the power output to the inverter in the PCS in order to control the charging/discharging of electric power (‘Data Flow #4’). However, since the communication protocols used by the FRS, the inverter, and the BMS are different with each other, they communicate with each other through a communication interface module, which is called LSIS ESS communication assembly (LECA) in our system. The LECA also shows the information of the PCS to the user through HMI. Therefore, as shown in Fig. 3, there are four processes for communication, i.e., DNP process, Modbus over TCP process (BMS and HMI), and Modbus over RS485 process (Controller).

In order to reduce the communication latency of 'Data Flow #4', the following actions are taken on the LECA to enhance the communication performance between the DNP master and the inverter.

1) We use a high-end industrial PC for the LECA in order to reduce the processing delay.

2) The priorities of the processes for the communication between the DNP master and the inverter, i.e., DNP process and Modbus over RS485 process (Controller) are set higher than others.

3) A real-time operating system (OS) is installed for the LECA's OS.

4) In order to enhance TCP performance, we use the option called 'TCP_NODELAY'. The use of this option disables the Nagle's algorithm to reduce the latency [2].

5) The processes in the LECA use a shored memory to reduce the delay for the inter-process communication (IPC). In addition, Semaphore [3] is applied to synchronize multiple processes acting on the shared memory.

4. CONCLUSION

In this paper, we described the system architecture of the power management system which is installed in a substation in Korea. In the system, the EES is used to regulate the power line frequency when there is a frequency deviation from a stable frequency. We also enumerated the data traffics to support the functions for monitoring and control of the system. Among the data traffics, the data traffic for frequency regulation should be supported in real time. We described our method to enhance the communication performance of the data traffic so that its latency requirement can be satisfied.

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