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Control System of PREPA's 20 MW BESS

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Abstract

This paper covers all aspects of the Facility Control System (FCS) at the PREPA 2OMW Battery Plant, including the control philosophy developed and implemented for this application. The FCS consists of distributed control processing units, fiber optic data highway, workstations and a cell voltage and temperature monitoring system. It provides interface between the battery system and the power conditioning system (PCS) microcontroller, in order to integrate the Battery Plant operation to the power system grid.

1.0 INTRODUCTION

The PREPA Battery Plant at Sabana Llana, Puerto Rico consist of the following three major components:

· Two 10 MW lead acid batteries, 3000 cells each

· Two 10 MVA Power Conditioning Systems (PCS-converters)

One Facility Control System (FCS)

Figure 1 shows a single line diagram of the facility.

This paper covers all basic aspects of the Distributed Control System at the Battery Plant, including the control philosophy developed and implemented for the PREPA application. Also, a brief description of the FCS architecture is presented.

The BESS Facility Control System (FCS) is based on a commercially available Distributed Control System (DCS) manufactured by MAX Control Systems, Inc.

2.0 FCS ARCHITECTURE

The control system concept for the BESS is as shown on Figure 2. The

figure illustrates the interface between the plant's components and the control system. In order to realize this concept, the FCS at the Battery Plant consists of four basic components:

· Fiber Optics Data Highway

· Distributed Processing Units

· Workstations

· Cell voltage and temperature monitoring

2.1 Fiber Optics Data Highway

The data highway consist of a token passing bus in a physical loop configuration. This bus is made of a fully redundant pair of 200 micron fiber optical cables which makes communication possible between work stations at the control room and the Distributed Processing Units at the FCS cabinets.

2.2 Distributed Processing Units

The DPU is a data highway resident, self contained control unit that plugs into an input/output rack. The DPU has an integral high speed input/output processor and a dedicated data highway processor. The DPU scans and processes information for use in reports, logs, calculations and graphics by other FCS devices. Each DPU can support one to one backup to provide maximum reliability.

2.3 Workstations

The workstation is the operational man-system interface. Each workstation consist of up to three PC processors, each processor having its own duty but working together to provide the operator/engineer with valuable information. These processors are connected together on each workstations via an industrial standard SCSI interface.

2.3.1 Graphic Processor

This is the operator's interface with the plant process. This processor runs with Microsoft Windows Operating System and a graphic screen builder. Among its functions is to:

- Monitor and display process information from DPU'S.

- Manipulation of process.

- Display trending that has been collected.

- Run pre-defined reports.

2.3.2 Application Processor

This processor runs under UNIX Multi-user operating system and a commercial relational database manager. Its functions are:

- Build control blocks, data blocks and EXCEL (Extended Control Engineering Language) code for customized control.

- Install control configuration into RTP's and DPU'S.

- Access and query all system data.
- Generate and print operational reports on demand or automatically.
- Implement historical database configurations.
- Access to and from Write Once Read Many (WORM) 800 MB optical disk.

2.3.3 Real Time Processor

This is a highway resident processor which represents the interface between the DPU's and the workstations. It collects and stores current analog or discrete trend points of information from various DPU's via the data highway and buffers the information on a hard disk for access by the Application and Graphic processors.

2.4 Cell Voltage & Temperature Monitoring System (OPTO 22)

This system is integrated with the Facility Control System. It monitors the voltage of 1,500 groups of four cells and the temperature of 72 individual cells in order to:

- Determine the overall capacity of the battery - Diagnose the "health" of the battery by singling out groups of cells showing low voltage.
- Determine if an equalizing charge is required.
- Determine if the battery charge voltage set point needs correction due to battery electrolyte temperature.

The OPTO 22 system consists of 8 control system DPU's connected via RS422/Fiber Optics to 72 enclosures containing 1, 500, + /- 1 0 volt 1/0 modules and Fiber Optic/RS422 communication devices.

FIGURE 3 shows the overall PREPA Facility Control System configuration.

3.0 FCS CONTROL STRATEGY

The FCS provides the supervisory control of two 10 MVA PCS'S. PCSL A controls battery strings 1 - 3 and PCSLB controls battery strings 4 - 6. Each string consist of 1,000 cells connected in series. Strings 1, 2 and 3 are paralleled at the PCSL A DC switchgear bus. Strings 4, 5, and 6 are paralleled at the PCS1 B DC switchgear bus. The FCS controls each PCS independently, but in parallel to one another. Since each PCS is controlled independently, the operation of one PCS will not effect the other PCS.

3.1 State of Charge Calculation

Most of the control strategy in our application is based on amp-hours and SOC percent calculation. The State of Charge (SOC) is the total amount of energy stored (AMP-HOURS) in the batteries. The SOC calculation is presented to the operator in AMP-HOURS (AH) and in PERCENT. The SOC is currently being calculated for each string's DC current and per PCS's main DC current. The operator can select to operate a PCS from one of the three SOC calculations:

-String SOC - Average SOC of individual strings

-Main SOC - Calculated for the current across the main breaker.

-Low SOC - Is the lowest string SOC for the associated PCS

The FCS accumulates each string's individual current (AMPS) every second, measured by current transducers at the feeder breakers, and then divides this reading by 3600 to give AMP-HOURS. It also calculates the percent SOC by taking the AMP-HOURS, and dividing this number by the energy storage capacity of each string, currently defaulted at 2000 AMP-HOURS. A similar procedure is followed to calculate the SOC based on the current flowing across the main DC breaker.

3.2. FCS/PCS Modes of Operation (see figure 4)

Operational modes are achieved when the FCS places the PCS in the RUN condition. Under these modes, the FCS will set the MW and MVAR demand signals to the PCS to perform the required mode of operation. Each MW & MVAR demand signal provided by the FCS have two 4-20 MA signals, one signal is a positive demand, which represents power from the battery, the other signal is a negative demand, which represents power to the battery. A + 1 00 % demand represents 1 0 MW and -100 % demand represents -10 MW. The various modes of operation are discussed below:

3.2.l. Normal Operation (MW Load Demand)

The main function of the battery during normal operation is frequency control. The FCS will perform a frequency control function to help regulate the system frequency within a range of about +/- 0.2 HZ. There are two curves for frequency control as depicted on figures F(x)4a and F (x)4b of Figure 4-3. Both frequency curves are operator selectable. Each curve has an associated deadband to avoid unnecessary cycling of the battery and to allow the battery to share the load more equitably with frequency control units.

If the SOC is greater than 70 percent and the DC bus voltage is above 1950 volts(l.95 vpc), the FCS will high limit the MW load demand at 50 % (5 MW), allowing the batteries to supply power to the system(see F(x)5b of Figure 4). Similarly, if the SOC is less than 70 percent and the DC bus voltage drops below 1950 volts, the FCS will set the MW load demand signal to 0 % (O MW), only allowing power to the batteries from the system. The 2 KV DC and MW load demand limit function curves are engineer adjustable.

During normal operation, a 'trickle charge' is provided to the battery to make up for charging losses. The FCS biases the selected MW negative demand signal, from 0 to -50 amps (0 to -2.5 %), per connected string, inversely proportional to the SOC, currently set at 70 % to 95 %. The current and selected SOC function curves are engineer adjustable. (See F(x)l, F(x)2 and F(x)3 of Figure 4-2).

The operator at the central dispatch center may set the MW output of the battery manually. The FCS will accept increase and decrease MW reference signals from the Remote Terminal Unit (RTU) at the dispatcher's location, in 25 % increments(5 MW, respectively, for each pulse received from the RTU). The operator has the ability to override the RTU MW reference signals and enter a MW demand signal (See Figure 4-1).

3.2.2 Normal Operation (MVAR Demand)

During normal operation, the FCS performs a voltage regulating function by controlling the flow of MVARS from the battery to the 1 1 5 KV bus at the Sabana Liana Substation. The PCS accepts or supplies MVARS to maintain the voltage within a narrow deadband, adjustable by an engineer. The maximum MVAR capacity of the PCS is a function of the PCS MW's. MW demand is the master signal and MVAR's are limited by the capacity of the vector sum of MW and MVARS. The vector sum limit is equal to + /- 1 0 MVA for each PCS. (See F(x) 9 and F(x) 1 0 of Figure 4-5)

3.2.3 Maximum Discharge (Spinning Reserve)

The FCS will place the PCS in Maximum Discharge mode during any incidents of loss of generation, triggered by a low instantaneous frequency signal or as selected by the operator. Three different trigger conditions have been implemented. These are as follows:

- System frequency falls instantaneously to 59.0 Hz.
- System frequency falls gradually to 59.2 Hz and stays under this frequency but above 59.0 Hz for 30 seconds.
- A third trigger is generated by an underfrequency relay contact closure. This relay is located at the AC switchgear (one per PCS), and its trigger parameters are a frequency slope of df/dt = .25 Hz/sec and an operational window of 59.4 to 59.6 Hz.

The FCS will control the PCS at the constant power level and will initiate a 15 minute decreasing power ramp when one of the following conditions are satisfied:

- Maximum discharge is on for the minimum allowable time,

currently set for 60 seconds and system frequency is above 60.1 HZ for the minimum allowable time, currently set at 60 seconds.

- Maximum discharge has been on for the maximum allowable time currently set at 15 minutes

- Operator terminates maximum discharge.

- The 2 KV DC bus voltage drops below the minimum voltage, currently set at 1750 volts / 1.75 average volts per cell.

At the end of the 15 minute decreasing power ramp, maximum discharge will be reset and the FCS will be available to control frequency and MVARS, provided the SOC is above 70 %. If the selected SOC is less than 70 % at the end of the 15 minute decreasing power ramp, the FCS will set a flag, stating a refresh charge is required.

3.2.4 Charge Modes

Charging of the battery may be initiated manually or automatically.

Three charge modes are available:

- Intermediate Charge

- Refresh Charge

- Equalize Charge

The voltage set point for each charge mode is adjusted to correct for

electrolyte temperature.

a. Intermediate Charge Mode - As stated above, the operator can select the intermediate charge to initiate automatically or manually. If the charge selector is in automatic, the intermediate charge is initiated automatically if the following conditions exist:

- PCS is not in maximum discharge.

- Refresh charge is not required.

- PCS is running.

- Actual intermediate charge hour is equal to the hour set by the operator.

- Selected SOC is less than or equal to 70%.

Once the intermediate charge is initiated, the FCS will charge the battery to the preferred SOC by a modified constant potential charge method. The voltage set point for this charge is 2.28 volts per cell on the average, adjusted for the average battery temperature, with a current limit of 300 amps per connected string. The intermediate charge is terminated automatically, when the accumulated SOC is above an operator adjustable SOC value, currently set at 90 % SOC.

b. Refresh Charge Mode - As stated above, the operator can select the refresh charge to initiate automatically or manually. Every maximum discharge cycle must be followed by a refresh charge if the selected SOC % is less than 70 %. If the charge selector is in automatic, the refresh charge is initiated automatically if the following conditions exist:

- PCS is not in maximum discharge.

- Refresh charge is required due to maximum discharge, or an operator adjustable number of days have elapsed since the last refresh charge.

- PCS is running.

- Actual refresh charge hour is equal to the hour set by the operator.

- Selected SOC is less than 70%

Once the refresh charge is initiated, the FCS will charge the battery to the preferred SOC by a modified constant potential charge method. The voltage set point for this charge is 2.38 volts per cell on the average, adjusted by the average battery temperature, with a current limit of 300 amps per connected string. The FCS determines the current set point by taking 300 amps multiplied by the number of strings connected. The refresh charge will terminate automatically, when the lowest strings accumulated SOC is above an operator adjustable SOC value, currently set at 104 % SOC and the 2 KV DC voltage has reached set point for an operator adjustable period of time. Upon termination of the refresh charge mode, the FCS will reset the connected strings and 2 KVDC SOC accumulators to

100 % SOC.

c. Equalization Charge Mode - The operator cannot select the equalization charge to initiate automatically. It can only be executed manually. This is done by measuring the average strings VPC at the tail end of a refresh charge and comparing to the 1,500 OPTO 22 voltage values. If more than 5 cell groups are in alarm due to a deviation of more that 200 mV per group (50 mV per cell), the control system will display a message indicating that an equalization charge is required.

Once the equalize charge is initiated, the FCS will charge the battery to the preferred SOC by a modified constant potential charge method. The voltage set point for this charge is 2.38 volts per cell on the average, adjusted by the average battery temperature, with a current limit of 300 amps per connected string. The FCS determines the current set point by taking 300 amps multiplied by the number of strings connected. The equalize charge will terminate automatically, when the selected SOC is above an operator adjustable SOC value, currently set at 1 10 % SOC. Upon termination of the equalization charge mode, the FCS will reset the connected strings and 2KVDC SOC accumulators to 100 % SOC.

3.3 FCS Miscellaneous System Operations

The FCS also controls miscellaneous loops throughout the plant. The

following is a general description of these loops.

3.3.1 Instrument Air System

The FCS is controls the start / stop sequence for the Battery Air Lift (Bubbling) Cycle. The bubbling cycle can be initiated automatically or manually by the operator. The automatic sequence will operate a solenoid valve, which will allow instrument air to mix the acid in each battery. The bubbling cycle will run continuously for 15 minutes, every six hours. All times are operator adjustable.

3.3.2 Battery Watering Cycle

The FCS is controls the start / stop sequence for the Battery Watering Cycle. The watering cycle can be initiated automatically, semi-automatically or manually by the operator. The automatic sequence will operate 18 solenoid valves, which will allow water to fill 176 cells per solenoid valve. The watering cycle will run continuously, cycling the 18 solenoid valves for 4 minutes each, every 30 days. All times are operator adjustable.

The semi-automatic sequence will operate 18 solenoid valves, which will allow water to fill 176 cells, per solenoid valve. The watering cycle will run once, cycling the 18 solenoid valves for 4 minutes each.

The manual sequence will allow the operator to select which solenoid valve will open to allow water to fill 176 cells. The solenoid valve will remain open for 4 minutes and will shut automatically.

3.3.3 HVAC and Fire Protection System

The FCS monitors inputs from the fire protection system. If fire is detected in either battery room , the FCS will issue a close command to the fire dampers. The operator will not be able to open the fire dampers until the fire detection alarm is cleared.

If fire is detected in the inverter room, the FCS will issue a close command to the fire dampers for the inverter room. The operator will not be able to open the fire dampers until the fire detection alarm is cleared. If fire is detected in the inverter / control room, the FCS will shutdown the HVAC system.

3.3.4 Battery Ventilation Fans

The FCS controls the start/ stop and high/low speed sequences for the Battery Ventilation Fans. There are a total of six ventilation fans, three per battery room.

The fans normally run at low speed until the FCS issues a start high speed command due one of the following conditions:

- two or more battery room temperature monitors are 5 DEGF greater than ambient air temperature.

- one of the four battery room hydrogen monitors are greater than 30%

- average battery cell temperature is greater than 120 DEGF.

3.3.5 Bess Efficiency Calculations

The Total Bess Efficiency and the Battery Efficiency accumulators are calculated for each operating cycle, except for Equalize charge. The accumulators start with the battery at 100 % SOC and end with the completion of any refresh charge.

The PCS Input Efficiency and the PCS Output Efficiency accumulators are calculated over each operating cycle, except for equalize charge. The accumulators start with the battery at 100 % SOC and end with the completion of any refresh charge. These efficiencies are also calculated using instantaneous values.

All the efficiency calculations are displayed to the operator / engineer. The FCS calculates the following efficiencies as required:

- Total BESS Efficiency- Divide the accumulated AC KWH Output to the system by the accumulated AC KWH input to the BESS.

- PCS Input Efficiency- Divide the accumulated DC KWH output from the PCS to the battery by the accumulated AC KWH input to the PCS from the system.

- PCS Output Efficiency- Divide the accumulated AC KWH output from the PCS to the system by the accumulated DC KWH input to the PCS from the battery.

- Battery Eff iciency- Divide the accumulated DC KWH output from the battery by the accumulated DC KWH input to the battery.

4.0 EXPERIENCES DURING FCS IMPLEMENTATION

In the early stages of implementation, the FCS Configuration Functional Specification was extremely simplified (approximately 50 % of the final Functional Specification). The main reason for the growth in the functional specification can be attributed to the lack of design, application and controls experience required to control the Battery Energy Storage System. As the project developed and implementation began, there were many questions raised on how to properly control the BESS. Through a concentrated team effort, all the questions were answered and the revised control philosophy developed. During the six week factory staging, the BESS control philosophy was subjected to extensive testing. As a result of these tests and subsequent lessons learned throughout the first few months of operation, various schemes of the control philosophy were changed and revised to develop the final BESS control philosophy described in this paper.

4.1 Converter Related Problems

The Battery Plant at Sabana Llana has been fully operational since November of 1994. Prior to that date, the Plant operated on a limited fashion from June 1994 to October 1994 due to frequent trips caused by several problems on both converter units. These problems affected the implementation of the control system. The causes ranged from defective electronic cards at all the PCM modules, to faulty firmware logic at the Distributed Micro Controller (DMC), to several GTO failures. Several modifications to the hardware and firmware were required to correct most of these problems.

4.2 Lessons Learned

With the experience gained through the first months of operation, several control philosophy schemes were modified to meet plant operation requirements. Among them are the following:

1 . Limits for charging and discharging the cells during frequency regulation, based on SOC and DC voltage, were included in the control logic as a protection against over discharging the cells.

2. Macros for additional frequency regulation curves were added in order to suit different system requirements and to allow the battery to share the control load more efficiently with the rest of the available power generation.

3. The cell charge logic was modified to improve the charge termination scheme. Timers and logic gates were incorporated to accomplish this.

4. Logic was added to prevent battery overcharge and incorrect calculation of SOC during frequency regulation. To achieve this, charge load is ramped down as the SOC approaches 95 percent and is totally disabled at 100 percent.

5. Incorporated small dead bands for the current integration due to current transducers inaccuracies around zero amperes.

6. Modified wiring Of the under frequency relay to improve the rapid discharge response time. The relay contact for rapid discharge goes now directly to the converter units instead of to the FCS. The control is then released from the converters to the FCS, three seconds after the rapid discharge has been executed.

7. Modified the logic for the determination of the equalizing charge necessity.

8. Added logic to make more flexible the implementation of programmed charge modes.

9. Other miscellaneous control logic and graphic additions and modifications were incorporated to make the system more user friendly and flexible.

5.0 CONCLUSION

The Facility Control System (FCS) provides supervisory control of all BESS functions. It allows operators to monitor, control and tune all the facility processes. The FCS is the main interface between the battery and the power conditioning system (PCS). By interfacing with the PCS microcontroller, the FCS sets operational modes to include battery discharge for frequency control and instantaneous reserve; battery charging, voltage control, as well as start-up and shut-down. Other critical processes provide for battery maintenance, such as electrolyte agitation, and watering of cells; and safety (fire protection and hydrogen concentration alarms). The implementation of control systems for utility battery storage plants is an unusual application. Therefore it requires extensive teamwork and cooperation between the facility designers, suppliers of the main components, utility personnel and control system integrators.