One-line Technical Documentation

AMES BATTERY ENERGY STORAGE SYSTEM

Ebert, Sarah N
BURNS & MCDONNELL | SEBERT1@IASTATE.EDU

Table of Contents

1. Overview

The Ames BESS has a main power transformer (MPT) located in the existing adjacent substation. From this, two homeruns, or cables, connect the substation to the energy storage system. One of the homeruns connects three of the inverters in series, and the second homerun connects the other three inverters and the auxiliary power system in series. Each inverters converts AC power to DC power, and vice versa, for four battery containers. The auxiliary (aux) power system consists of a step-down transformer, a switch board, and the auxiliary power cabinet. This document will detail the justifications for the one-line of the Ames BESS.

2. Site and Equipment Values

Interconnection voltage: 138 kV

Site nameplate rating: 25MW (100 MWh) with 10% overbuild at BOL

24 Battery Containers: BYD MC10C-B5365-U-R4MO1

Discharge duration: 4 hours
C-rate: 0.25 C
BOL cell energy: 5365 kWh
Voltage range: 1081-1498 V
Recommended max discharge power: 1275 kW
Aux power usage: 38 KVA

6 PCS Skids: 6 Siemens Gamesa Proteus PCS 4600E

Minimum DC input voltage: 1182 V
Maximum DC input voltage: 1500 V
Number of DC inputs: 2
Max DC input current: 2x2227 A
Nominal AC power total @40˚C @1300 VDC: 4950 kVA
Nominal AC output voltage: 760 Vrms
AC side disconnection and short circuit current protection: 2 motorized AC breakers
DC disconnections: two motorized switches
DC short circuit protection: DC fast fuses
Overvoltage protection: Type 1+2 SPD

Cable Size Limitations: 1000 KCMIL is the largest cable option

Stay below 30 MVA on any string in the system

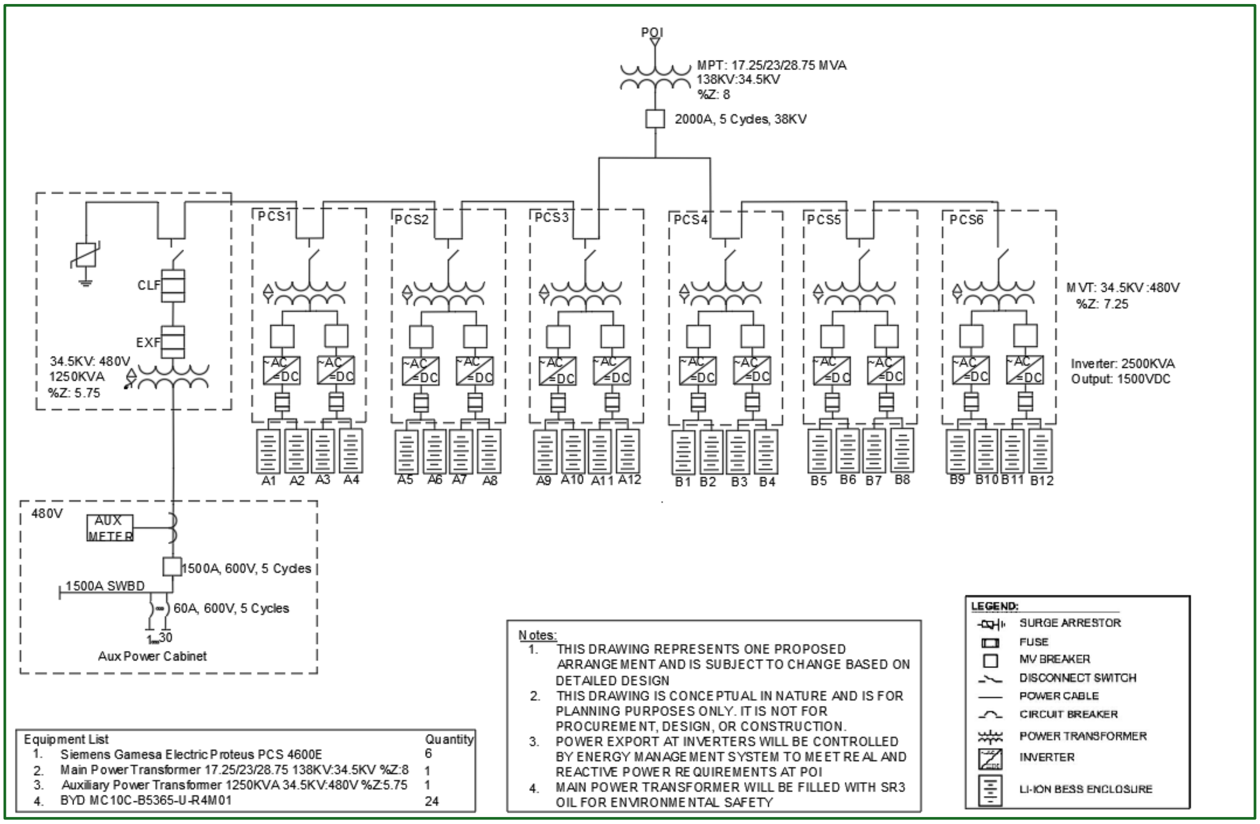

FIGURE 1: ONE-LINE DIAGRAM

3. Sizing and Configuration Justifications

3.1 Main Power Transformer and Feeder Breaker

The bidirectional MPT steps voltage down from the high voltage at the point of interconnection (POI), which is assumed to be 138 kV, to 34.5 kV. It will also step up the voltage when the batteries are discharging. The MPT has an impedance of 8%, which is typical for a power transformer of this size. The exact model has not been determined, but this approximation will be sufficient.

It is sized based off the nameplate rating of the site, which is 25 MW. Using factor of 0.69 to determine the minimum operation limit, 0.92 for the nominal rating, and 1.15 for the peak operation limit, the transformer can be sized to perform optimally in many different conditions. These factors are an industry standard for the design of a BESS.

Minimum operation limit: $0.69 \bullet 25 = 17.25\ [\mathrm{MVA}]$

Nominal rating: $0.92 \bullet 25 = 23\ [\mathrm{MVA}]$

Peak operation limit: $1.15 \bullet 25 = 28.75\ [\mathrm{MVA}]$

MPT Rating: 17.25/23/28.75 MVA

The feeder breaker connected to the MPT protects the downstream equipment from overcurrent. Medium voltage circuit breakers are typically either 1200 A or 2000 A. A 1200 A breaker would be sufficient considering the current in this part of the system, but to allows for future expansion, a 2000 A breaker was used in our one-line

3.2 Auxiliary Power System

The auxiliary (aux) power system powers the HVAC equipment, communication devices, and fire detection equipment among others in the battery containers and PCS skids. It draws a significant amount of power, which needs to be accounted for in the one-line. The equipment involved in this system operates on 480 V, so a transformer is needed to step down the string voltage of 34.5 kV. In this BESS, only one auxiliary transformer and cabinet are necessary.

The BYD battery model specifies that the auxiliary power system usage is 38 kVA at its peak. The total auxiliary power consumption is found with the following equation considering that there are 24 battery containers. The PCS doesn't need power from the aux system. Its aux system is powered parasitically, so it is accounted for in the power nominal AC power total value of 4950 kVA in the spec sheet. The auxiliary transformer is rated based on the power consumption value with a 25% overbuild. In the one-line, the transformer rating is 1250 kVA, which is the calculated rating rounded up to the nearest standard size.

Aux power consumption: $38[\mathrm{kVA}] \bullet 24 = 912\ [\mathrm{kVA}]$

Transformer rating: $912[\mathrm{kVA}] \bullet 1.25 = 1140\ [\mathrm{kVA}]$

To protect the aux transformer and downstream equipment, the system uses a surge arrestor, current limiting fuse (CLF), and an expulsion fuse (EXF). The surge arrester protects against overloading by limiting voltage through discharging surge current. The CLF and EXF work together to protect the transformer because the CLF can interrupt very large shorts while the EXF is fast-acting. The specific size of these devices is not determined here.

The aux power cabinet contains a switchboard to allow for control the flow of electricity in the BESS and protect form overloading and shorts. It is made up of circuit breaker and switches and is sized based on the total current in this part of the system. Considering the aux power consumption and voltage level, the current is given below. A 25% overbuild is also necessary here, and so the final switch board rating is given as 1500 A in the one-line. This is again due to rounding up to the nearest standard manufactured size.

Auxiliary current: $\frac{912[\mathrm{kVA}]}{\sqrt{3} \bullet 480[\mathrm{V}]} = 1100\ [\mathrm{A}]$

Current with overbuild: $1100[\mathrm{A}] \bullet 1.25 = 1380[\mathrm{A}]$

The final part of the aux power system is the that needs to be sized are the feeder breakers, which protect from overloading on the cables running to each battery container and PCS's auxiliary power input. There are 30 of these breakers because is one for each of the six PCSs and 24 batteries. The current rating is found from the equipment's rated aux power usage with a 25% overbuild. These feeders are not shown on the diagram. Instead, they are numbered 1 to 30 with a note on the bottom.

Switchboard feeder breaker rating: $\frac{38[\mathrm{kVA}]}{\sqrt{3} \bullet 480[\mathrm{V}]} \bullet 1.25 = 46[\mathrm{A}] \bullet 1.25 = 58[\mathrm{A}] \approx 60[\mathrm{A}]$

3.3 Medium Voltage Cables

In this system, the nominal voltage level on the homeruns, which run from the substation to the energy storage system, are 34.5 kV. There are two homeruns which will daisy chain the PCS skids and aux power system. Using two homeruns limits the current, and daisy chaining avoids connecting too many pieces of equipment to one bus, which both increase the system's resiliency.

The maximum loading on one string is determined by dividing the power rating of a 1000 KCMIL cable by the power of one PCS skid. The AC power of the Gamesa Proteus PCS used is 4950 kVA. Considering that the auxiliary equipment needs to be attached at the end of one of the strings, its power consumption of 1.25 MVA needs to be factored in as well.

Maximum number of PCS skids per string: $\frac{30\ [\text{MVA}]}{4.95\ [\text{MVA}]} = 6.1 \approx 6$

Number of PCS skids on string with aux equipment: $\frac{30[\text{MVA}]-1.25[\text{MVA}]}{4.95[\text{MVA}]} = 5.8 \approx 5$

According to these calculations, fewer than 6 PCS skids should be on one string. Because the BESS uses six PCS skids and one aux power system, three of the PCS skids will be daisy chained on one string, and the aux power and the remaining three skids will be daisy chained on the other. This will provide balance to our system and limit the power on any one part.

3.4 Power Conversion System and Battery Containers

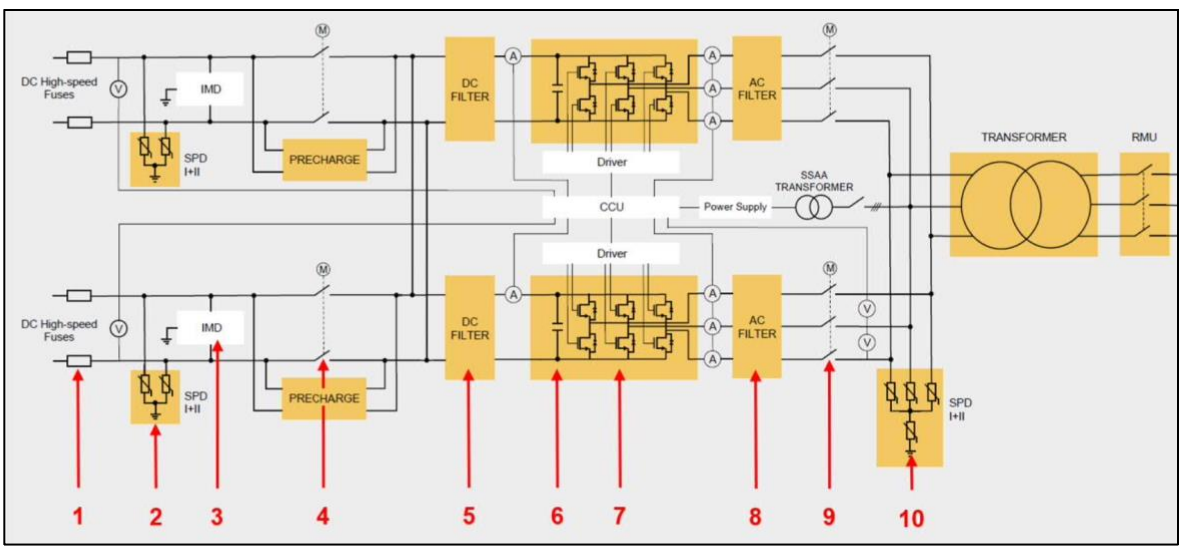

FIGURE 2: SIEMENS GAMESA PCS CONFIGURATION

The power conversion as seen on the one-line is a simplified version of the schematic depicted in the Siemens Gamesa Proteus spec sheet. They contain a bidirectional transformer, which steps the voltage down from 34.5 kV to 480 V. There are two DC outputs which allow for easier connection of more battery containers. Because of this, there are two parallel motorized AC circuit breakers, bidirectional inverters, and DC fuses. The bidirectional inverter is rated at 2500 kVA and has a DC input voltage of 1500 V.

The BYD battery containers in this system have an output DC voltage range of 1081-1498 V and a maximum discharge power of 1275 kW. Because each DC input of the PCS skid has a maximum current of 2227 A and the maximum voltage level is 1500 V, two batteries can be attached to each input. This results in four battery containers on each PCS skid.

Maximum power per DC input: $2227[\mathrm{A}] \bullet 1500[\mathrm{VDC}] = 3{,}340[\mathrm{kW}]$

Number of battery containers per DC input: $\frac{3340[\mathrm{kW}]}{1275[\mathrm{kW}]} = 2.6 \approx 2$

4. AutoCAD Drawing

The one-line diagram for this project was created using AutoCAD software. The configuration is based on the above calculations and reasonings. Its layout is very similar to other BESS project's one-lines. This is so other engineers will be able to easily understand it. The spacing between components is sufficient so that it doesn't look too cluttered, but the labels and notes are still legible without having to zoom in. The dashed boxed enclose components that will be placed on the same equipment pad.

At the bottom of the diagram, there are three boxes labeled "Equipment List", "Notes", and "Legend". The equipment list specifies which power conversion system, battery container, main power transformer, and auxiliary power transformer used. It also notes the quantities of all these pieces of equipment. The notes are standard qualifications for a preliminary one-line diagram. Finally, the legend explains which electrical components the symbols in the one-line corelate with. This is so anyone, even those unfamiliar with this type of diagram, will be able to understand the functionality

5. Conclusion

This document details the justifications for the values and configuration in the one-line diagram for the Ames battery energy storage system. These explanations and notes are meant to assist the team of engineers working on this project to keep track of their design decisions and to communicate them with other engineers. It is a preliminary diagram, and may change after system testing, including short circuit and load flow analysis, is completed.

This diagram was developed as a part a senior design project by a team of electrical engineering students at Iowa State University. This project is hypothetical, and there are no plans to build this Ames BESS.