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Integration of Energy Storage into High-Capacity Power Converters for Provision of Ancillary Services

Question S.2

Is there any practical experience around the world with the construction of supercapacitor banks and associated protection? Are there pilot projects to demonstrate the supercapacitor-enhanced STATCOMs?

GFM(Grid-forming control) VSC with ESS (Energy Storage System) is one of the promising solution for future PE-based ancillary service. Matching the ESS and converter is critical, taking into account the state-of-the-art of energy storage devices, safety, maintenance, redundancy, etc..

First, the standard insulation level of current supercapacitor module is in the range of 500 V ~ 2000 V and design modification / development is required if the system DC voltage rating is higher than this value. High voltage (e.g. 20kV~) supercapacitor module will require a significant design change from current module (for example, module housing). ESS power supply and communication (e.g. voltage monitoring) design should also change for such a high voltage system. In addition, it will be challenging for supercapacitor manufactures to perform in-house testing for such a high voltage supercapacitor module/cubicle.

Protection of ESS is also an important item to be considered for determination of an appropriate system DC voltage rating. As supercapacitor has low ESR (Equivalent Series Resistance), large fault current flows when fault occurs within ESS. The system DC voltage rating doesn’t change the fault current amplitude significantly because it is determined by the ratio of ESR to the source voltage of the series unit and it also doesn’t change when the system DC voltage rating is changed as shown in equation (1).

$$\boldsymbol{i(t) = \frac{E}{R} e^{-\frac{1}{CR}t}} \quad (1)$$

Even though the fault current amplitude isn’t changed by the system DC voltage rating, it reaches more than 10 kA for each string, as shown in Figure 1. This means that both severe current and voltage requirements are imposed to protection equipment for a high DC voltage system. Protection devices, such as fuses or dc breakers, are not currently commercially available for high-voltage / high-current dc in this range, so represent a second development hurdle.

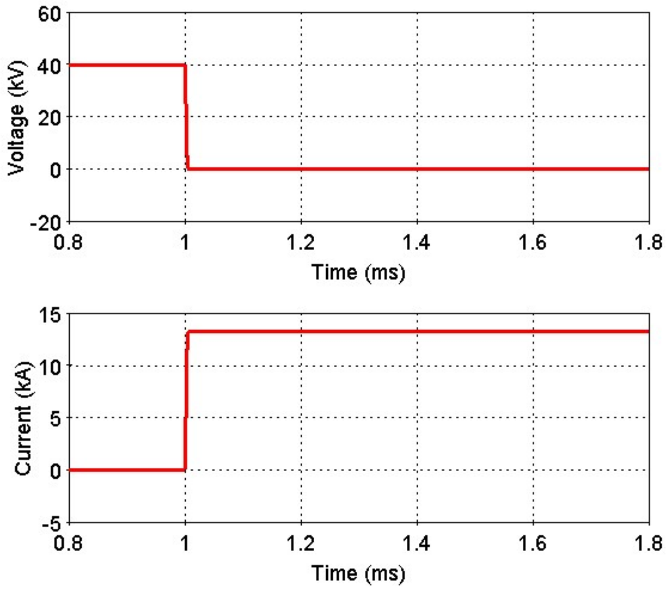

Figure 1: Protection equipment requirement in case of short circuit fault in DC +/- 20 kV ESS

The system DC voltage rating has a large impact on system footprint also. Power converters typically used for solar PV or Battery Energy Storage (BESS) applications have a relatively low voltage, so would be suitable for these systems (in the range of 500 ~ 1,400 V). However, their capacity is also relatively low (1~2 MW / unit). This means that a large number of converter and ESS units are required for high-capacity systems which satisfies inertia and other requirements. For example, 50 units with 2 MW converter are required to compose 100 MW system. Since the space between units is required for access and maintenance, etc., it is inevitable that the total footprint of high-capacity system with lower DC voltage converter becomes huge.

On the other hand, it should be also considered that higher DC voltage rating increases the scale of converter and supercapacitor. As for the converter especially, cubicle design is not applicable and large valve tower is required when it has several tens of kV DC voltage rating. This is also reflected to the clearance requirements for the ESS. The clearance distance between wall to equipment need to be guaranteed and it also increases the total system footprint.

Finally, it is worth to highlight the relationship between system redundancy and the system DC voltage rating. Figure 2 shows the relationship between capacity loss in fault case and converter number in system. As mentioned above, there is a relationship between converter DC voltage and converter capacity. It can be seen from Figure 2 that the capacity loss in the system with small number and high capacity / high DC voltage converters becomes large in case of a failure. In the severest case, to achieve an N-1 redundancy level when the system consists of just one-unit, another full capacity unit is needed to maintain 100 % capability.

It should be noted that it is difficult to guarantee device redundancy in this type of system. Although some of the converter designs are equipped with semiconductor device bypass method for device redundancy, it is not effective to apply this type of bypass method to ESS because of the number of supercapacitor module inside ESS and short circuit current level required for the bypass method. Therefore, unit redundancy is important in this type of system.

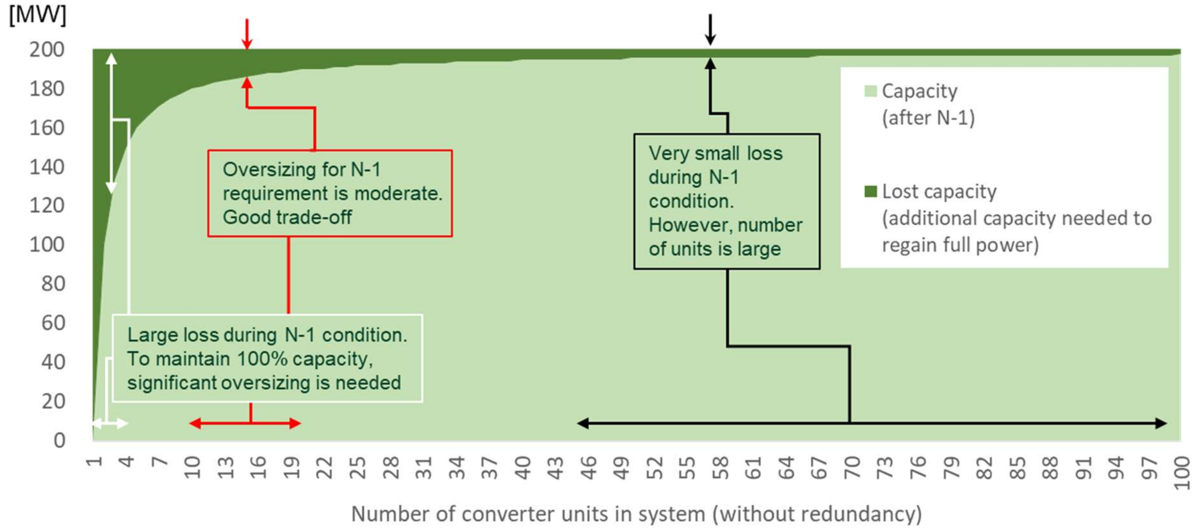

Figure 2 : Relationship between capacity loss in fault case and converter number in system

In conclusion, both high and low DC voltage rating systems have technical or operational challenges as shown above. The PE-based ancillary service with the middle range DC voltage rating can provide the advantage shown below.

- For a medium-voltage converter, the development required for supercapacitor and protection equipment is not a huge challenge
- Total footprint can be saved by applying 10 ~ 20 MW class converter which is proven technology
- Unit level redundancy is guaranteed by adding small ratio of capacity against total one

Considering from the recent supercapacitor module rating, several kV (e.g. 3 kV) DC voltage rating can offer a good balance between benefit and technical challenge difficulty.