Verification of Safety Margins of Battery Banks Capacity of Class 1E DC System in a Nuclear Power Plant

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Introduction

❖ The Fukushima event of 2011 illustrated how station blackout (SBO) and restoration of the AC power can be significantly affected by external events and can take a longer time to recover than was previously postulated.

❖ DC power system batteries play an important role during SBO conditions since they are required to power a minimum set of critical:

- ✓ Equipment/components important to safety.
- ✓ Instrumentation for monitoring of plant parameters.
- ✓ Emergency lighting.

❖ Prior to these event in Fukushima most batteries are designed with coping capability of four hours.

❖ The accident showed the need for the coping capability to be increased to at least eight hours.

❖ This research is to verify the safety capacity margin of battery banks of class 1E DC system and test the response to SBO using the load profile of a Korean design nuclear power plant (NPP).

DC power supply system in NPPs

❖ DC Power system in NPPs comprises four channels batteries and chargers.

❖ Categorized into Class 1E and non-Class 1E. The Class 1E categories are electrical equipment and systems essential for :

- ✓ emergency reactor shutdown.
- ✓ containment isolation, reactor core cooling.
- ✓ containment and reactor heat removal in order to prevent significant release of radioactive material to the environment.

❖ Satisfy single failure criteria

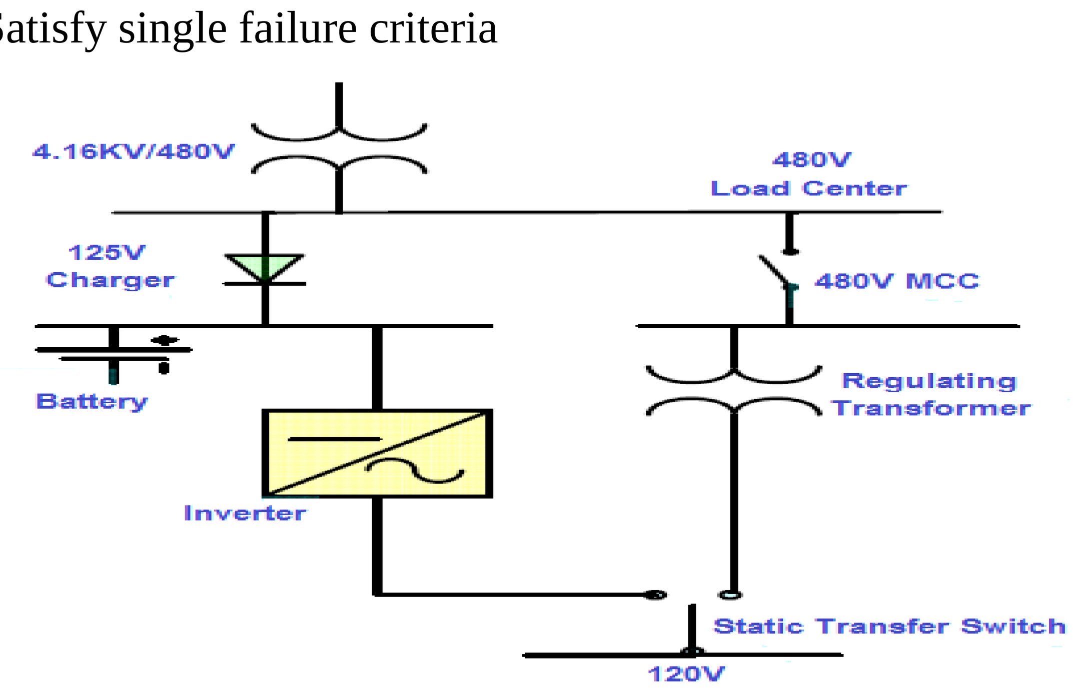

Fig.1. One of the trains of DC system of a nuclear power plant

Verification of Capacity Margin

❖ Estimation of capacity rating factor (Kt) at a giving period of time using curve fitting (Origin Pro) See Figure 2 and 3.

$$K_t = 1.15433 + 0.021817T - \left(1.8458\times10^{-5}\right)T^2 + \left(1.09623\times10^{-8}\right)T^3 \quad (1)$$

❖ Analysis of the load profile and sketching of the battery duty cycle for both two and eight hours. (see Figure 4 and 5).

❖ Calculating required capacity using iterations process and worksheet in accordance to IEEE Std. 485-2010.

$$F = \max_{s=1}^{N} F_S = \max_{s=1}^{N} \sum_{p=1}^{N} \left[A_p - A_{(p-1)}\right] K_t \quad (2)$$

❖ Comparison of the calculated value with that of the NPP considered.

❖ Determination of the capacity safety margin of each battery.

❖ The K_t value is very critical due to it variance for different cell voltage, temperature, and duration of time.

Result and Discussion

❖ The curve fitting from figure 2 and 3 to generate Kt values shows collective data from the battery is best represented by third order polynomial using origin pro 2015 software from available data. (see equation 1)

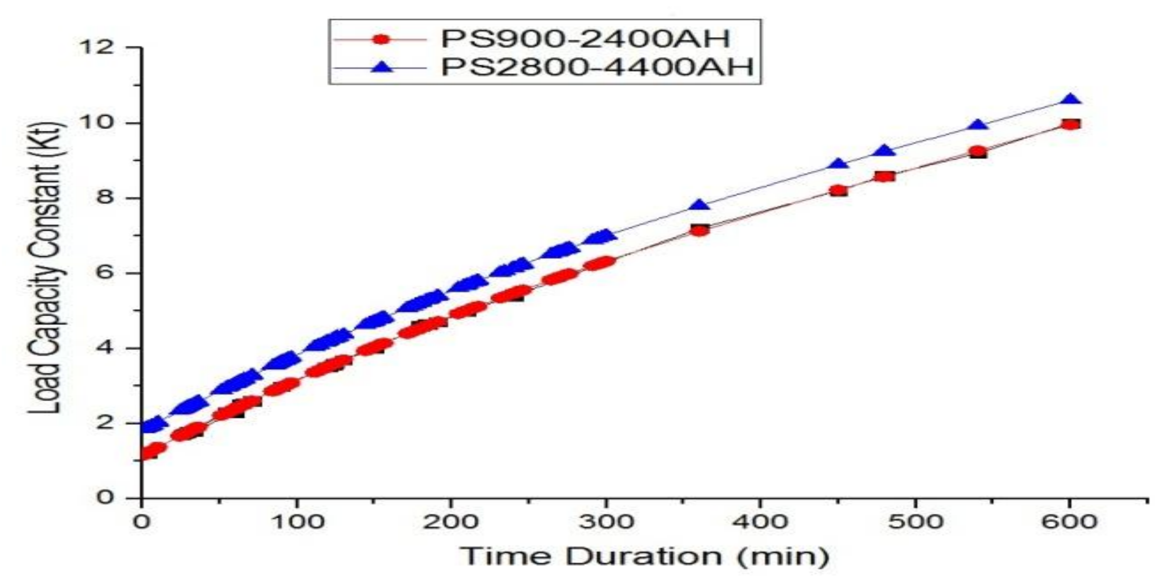

Fig.2. Discharge rate linear curve to generate the K_t value based on eight hour.

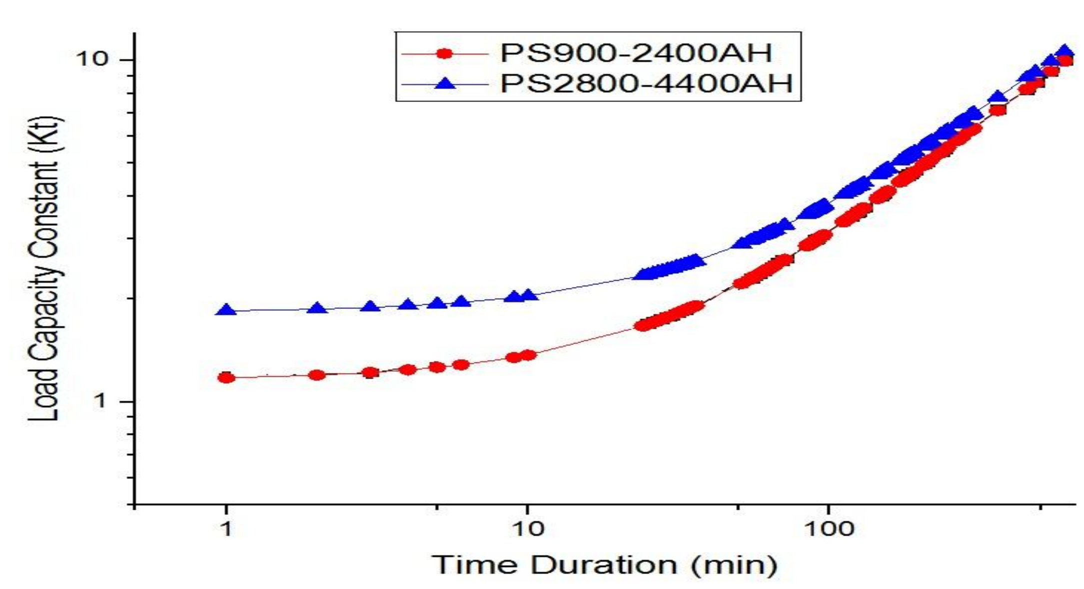

Fig.3. Log-Log curve to generate the K_t value based on eight hour.

❖ The load profile of each channel used of the batteries are described in figure 4 and 5.

❖ Red, Green, yellow and blue represents channels A, B, C and D respectively.

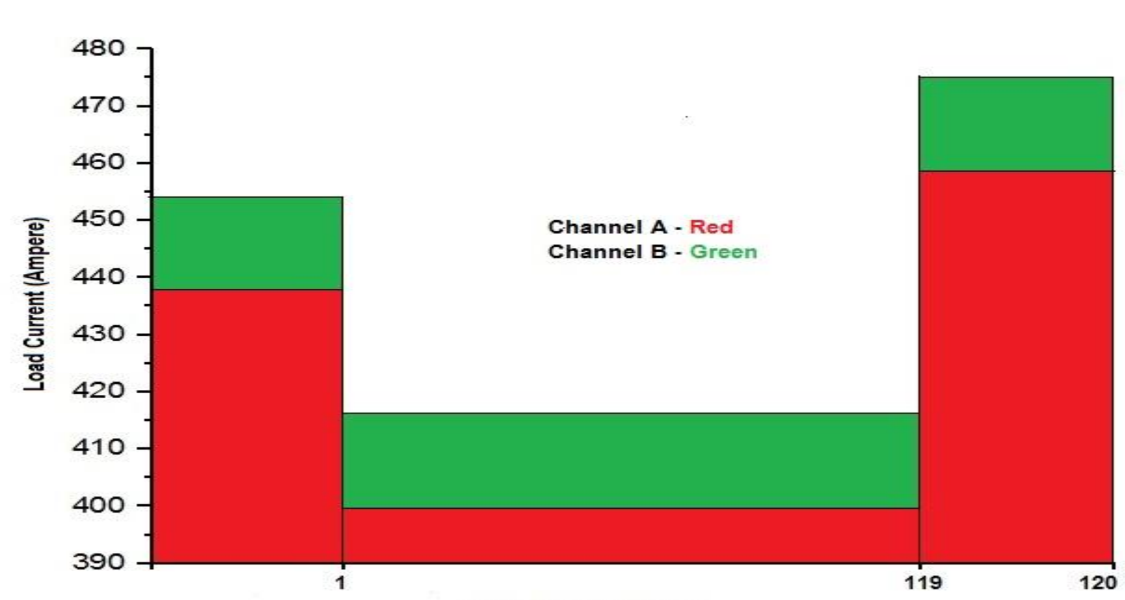

Fig.4. Duty cycle of load profile on channel A and B battery of the NPP considered

❖ In calculate the capacity of the batteries and determine the safety margin of the capacity the aging factor, design margin and temperature correction factor of 1.25, 1.01 and 1.08 respectively are used.

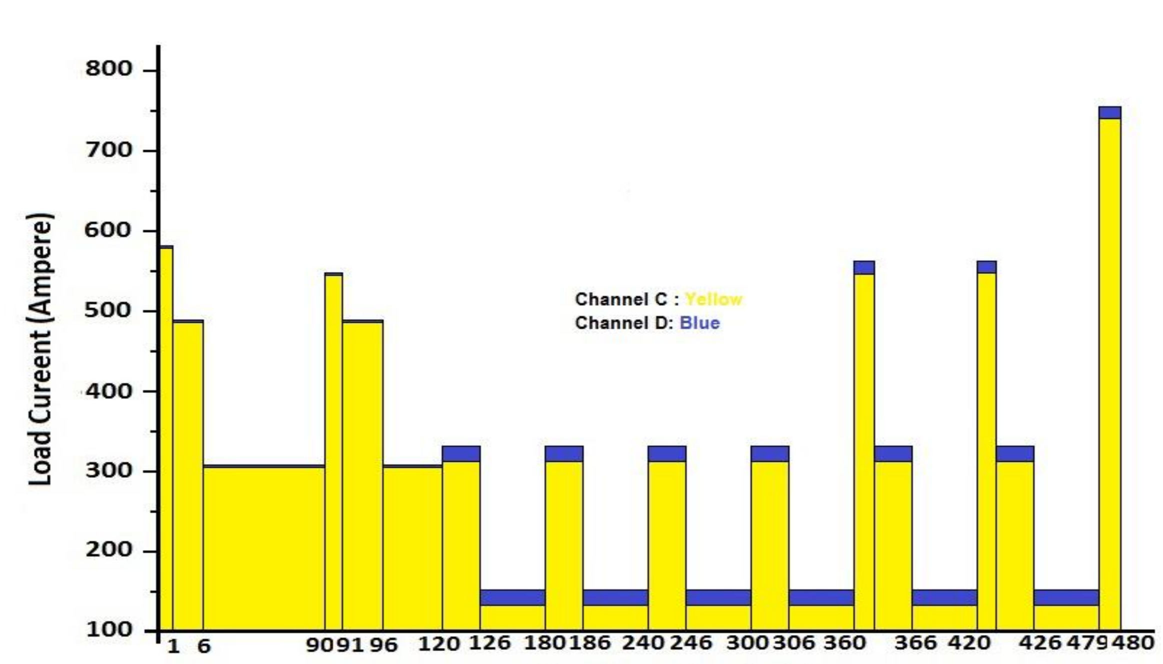

Fig.5. Duty cycle of load profile on channel C and D battery of the NPP considered

❖ The corresponding NPP batteries installed capacity, the calculated value, standard cell size selected, safety margin and percentage of the margins (See Table 1).

Result and Discussion

❖ The cell size is selected based on available standard battery size. When the cell calculated is greater than standard cell size, the next larger cell is required.

❖ The capacity calculated indicated that the capacity margin between the calculated value and that installed for the DC power system of the nuclear power plant considered are 200 AH, 400 AH and 200AH for channels A and B, C and D respectively.

❖ The percentage of the capacity margin for channel A and B, C, and D are 7%, 9%, and 5% respectively.

❖ The evaluation of the verified capacity for the designed and installed batteries in the NPP of consideration shows that the safety margin for each battery is reasonable.

Table 1: Comparison between calculated values to design value in FSAR of the plant

Battery Channels	Calculated value (AH)	Standard cell size selected (AH)	Plant designed value (AH)	Safety margin (AH)	% margin
Channel A	2206.59	2600	2800	200	7
Channel B	2272.35	2600	2800	200	7
Channel C	3975.91	4000	4400	400	9
Channel D	4015.75	4200	4400	200	5

Conclusion

❖ The capacity margins of class 1E batteries of DC power system batteries in a nuclear power plant were determined using the load profile of the plant.

❖ If appropriate manufacturer K_t data are not available, the accuracy of the battery capacity might not be accurately Verify.

❖ The estimated missing data of the K_t by mathematical curve fit method were selected in a conservative manner.

❖ The batteries shows a reasonable margin for each battery with coping capability of two hours for channel A and B, and eight hours for channel C and D. system.

Future Work

❖ The study covered load profile for the range of eight hour. Though, this study showed a reasonable safety margin for the battery considered. In future, it is intended to verify the response of the battery capacity in design extension condition beyond eight hour.

❖ Improve on the regulatory safety requirement for a robust DC power systems of NPPs.

References

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