Supercapacitor System Efficiency Test

Brief Description of the System and Test Results

The schematic of the facility where the tests are performed is shown in Fig. 1. It consists of two incomer transformers each rated at 11 kV/400 V, two isolation transformers each rated at 400 V/400 V, two inverters and three DC/DC converters, and a variety of energy storage assets. The following tests focus in controlling power flows between the grid and the supercapacitor bank rated at 90 kW, 2 kWh, 43.3 F & 650 V. In the existing set-up the maximum power of the DC/DC power converters is limited at 60 kW, however their rated power is 90kW. The AC voltage at the input and output side of the isolation transformer is 400 V and the voltage at the DC bus varies in the range of 650 V - 700 V.

The tests presented in this document aim to capture the efficiency of the supercapacitor bank and associated power converters. For this purpose of understanding power flows in these tests, a simplified layout of the grid-connected supercapacitor system in isolation is shown in Fig. 2. The corresponding powers at the terminals of each device and Supercapacitor bank state of charge (SoC) are reported by the system and used in the plots below. In this efficiency test, the real power at the supercapacitor bank terminals is varied in steps of 25% at every time-step of 20 s, as shown in Fig. 3.

Some useful discussions regarding Supercapacitor modelling and SoC evaluation can be found in the references [1], [2].

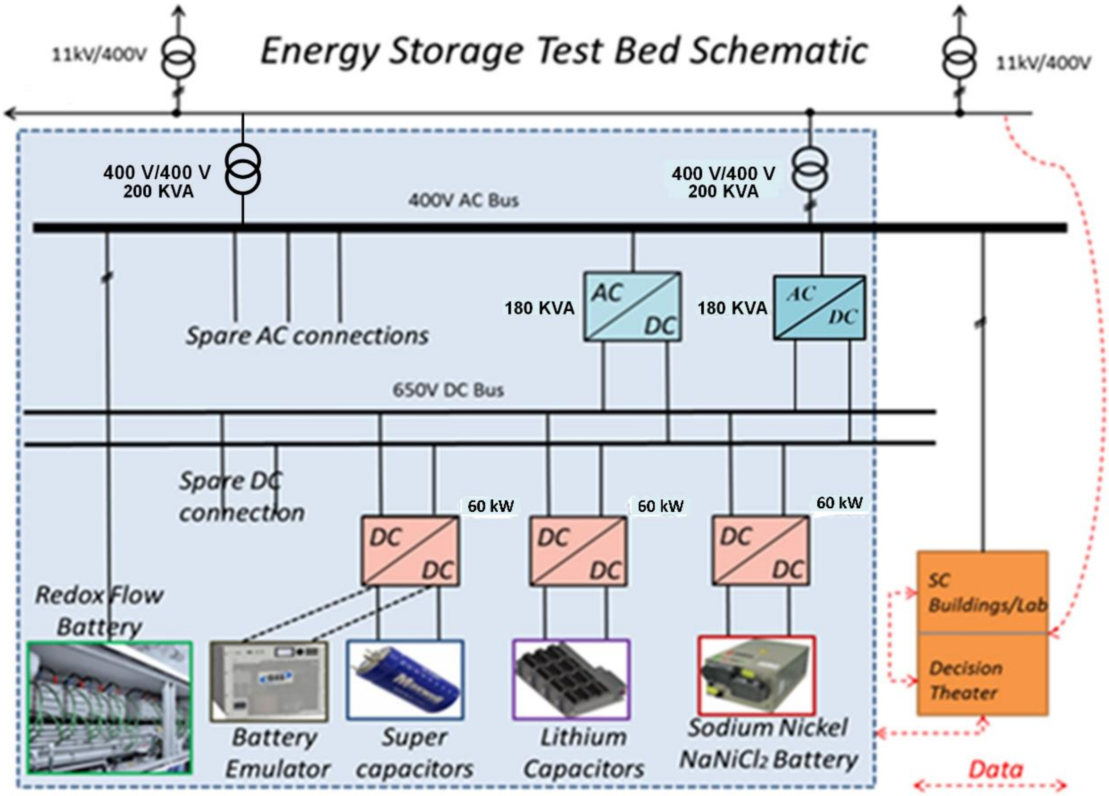

Fig. 1: Schematic of the facility

1. Calculation of Efficiencies

1) Efficiency of Supercapacitor system over time-step = Energy Stored in ESS/Energy taken from the grid (During Charging) or Energy supplied to the grid/Energy Discharged from ESS (During Discharging)

where,

Energy taken/supplied from/to the grid = Supercapacitor Power * Time Duration

Energy Stored/Discharged in/from Supercapacitor = 0.5 × C × $(V_2^2 - V_1^2)$ Joule

C (Capacitor) = 43.3 F (From Technical Specifications)

V_1 & V_2 are voltages across the Supercapacitor at two consecutive time instants

2) DC/DC Converter Efficiency = Converter Output Power/Converter Input Power (During both Charging & Discharging)

3) Inverter Efficiency = Inverter Output Power/Inverter Input Power (During both Charging & Discharging)

4) Transformer Efficiency = Transformer output Power/Transformer Input Power (During both Charging & Discharging)

5) Overall System Efficiency = Efficiency of Supercapacitor over time-step × Converter Efficiency × Inverter Efficiency × Transformer Efficiency

Fig. 2: Simplified Layout of Supercapacitor System

2. Experimental Results

A) Following are the plots of Powers, SoC, Voltage & Efficiencies at initial SoC of 0%.

(Similar plots can be obtained for other initial SoC values from the .csv data files)

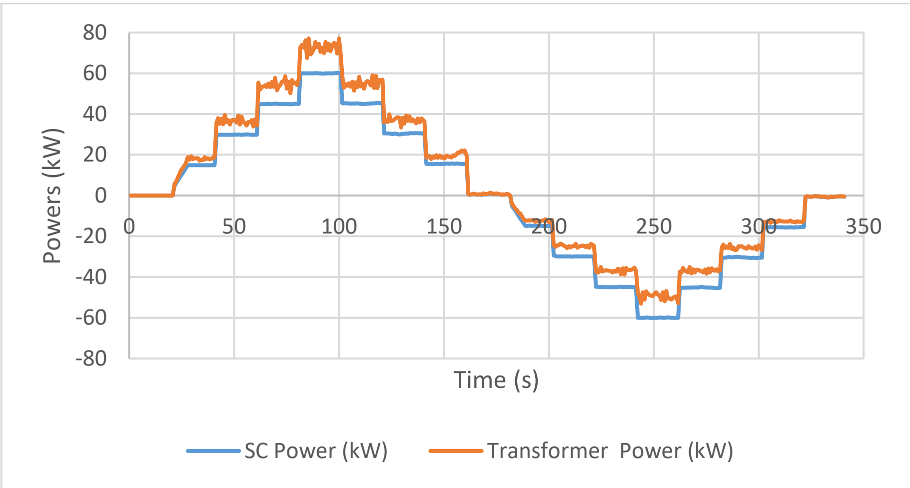

Fig. 3: Real Power Outputs

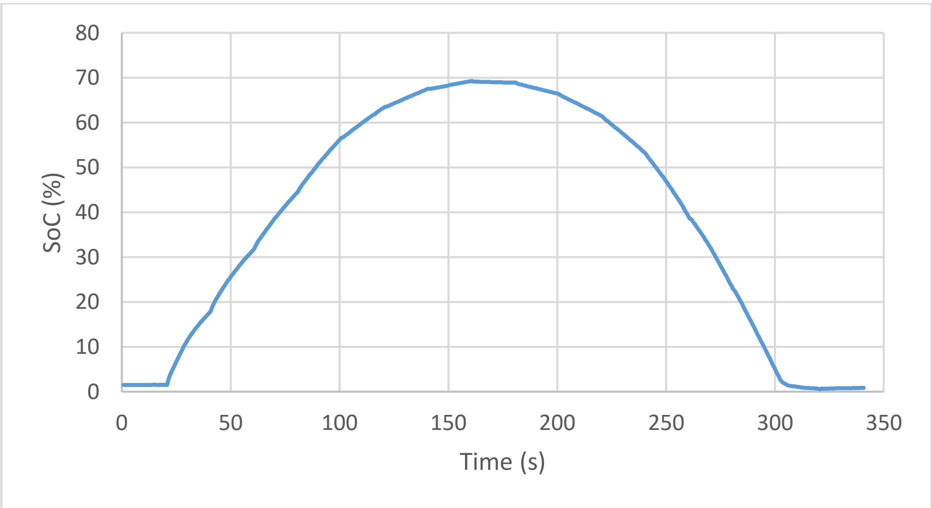

Fig. 4: SoC of Supercapacitor

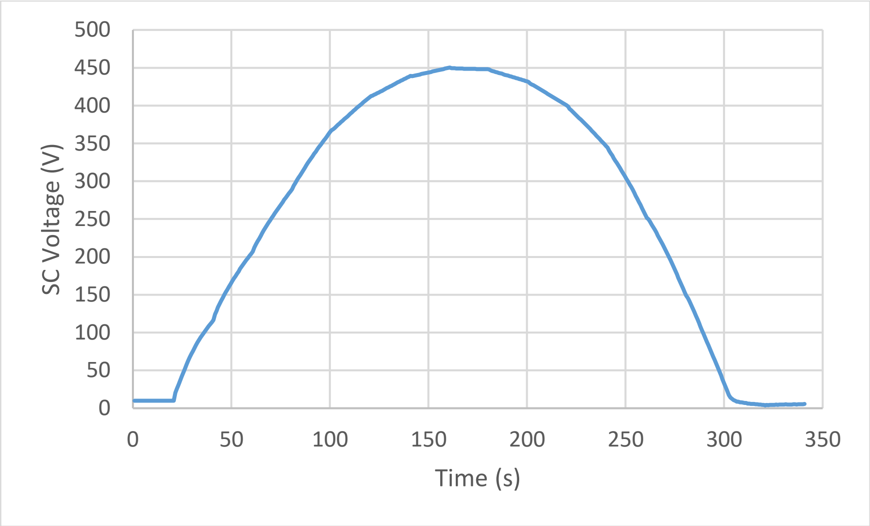

Fig. 5: Voltage Output of Supercapacitor

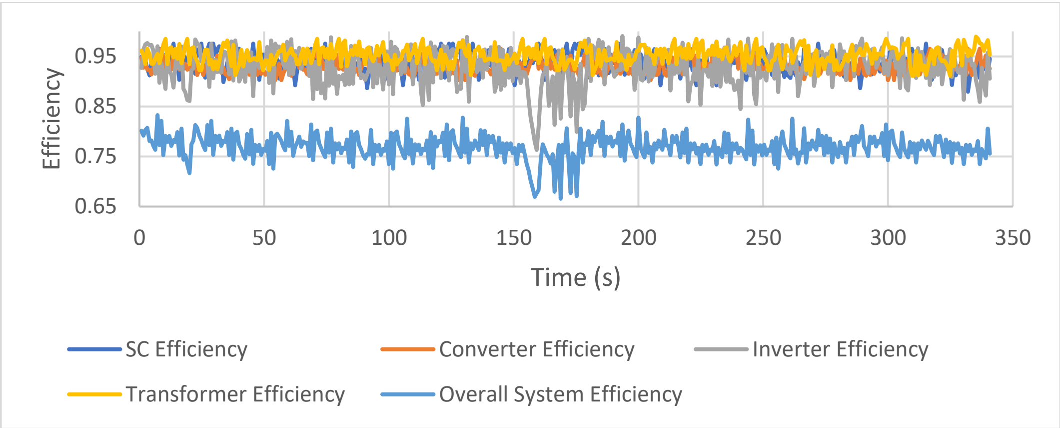

Fig. 6: Variation of Efficiencies of Supercapacitor & Converters

B) Comparison of Efficiencies at Different Initial SoC Values

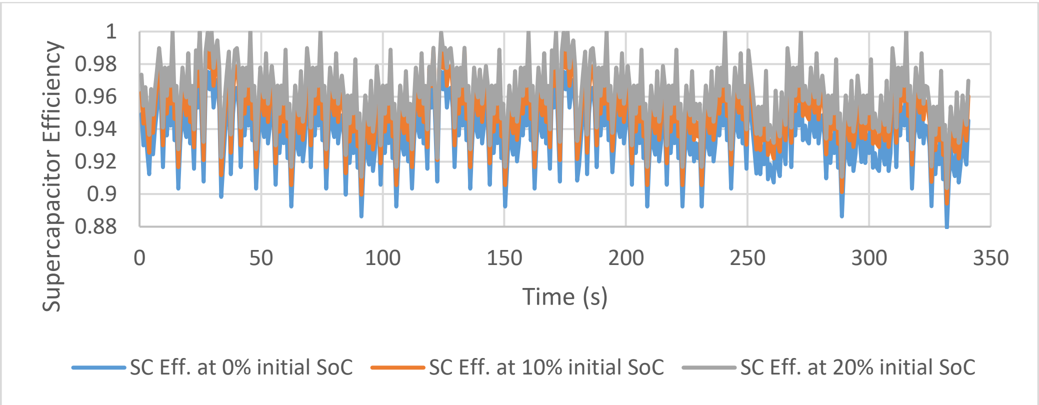

Fig. 7: Supercapacitor Efficiency

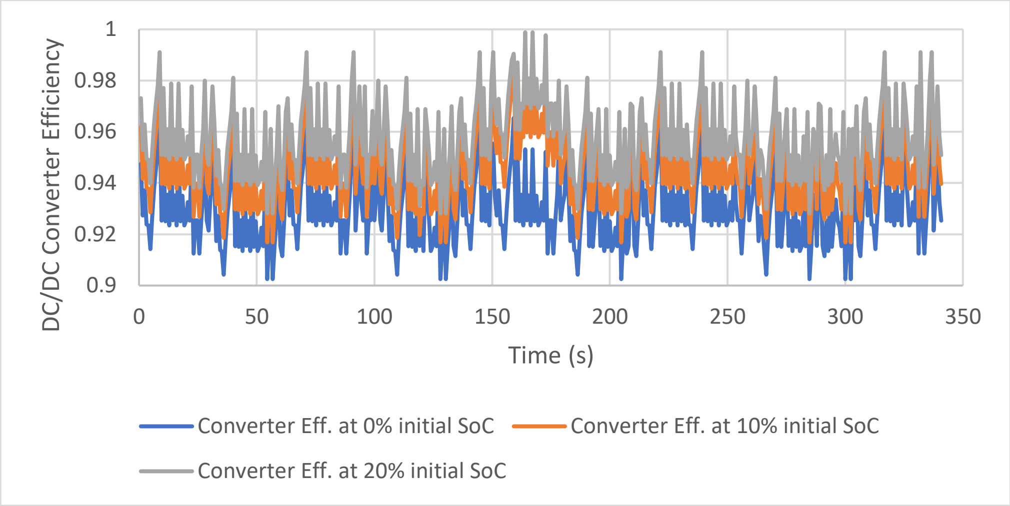

Fig. 8: DC/DC Converter Efficiency

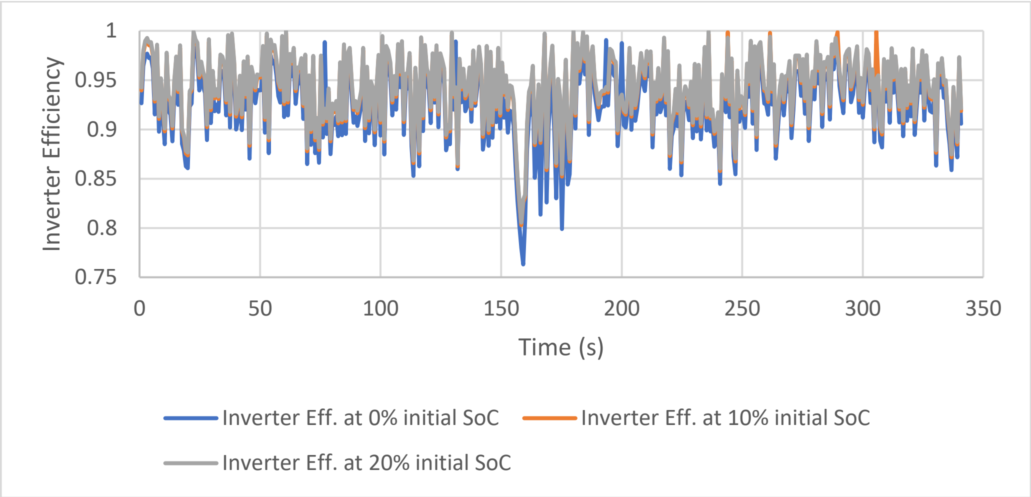

Fig. 9: Inverter Efficiency

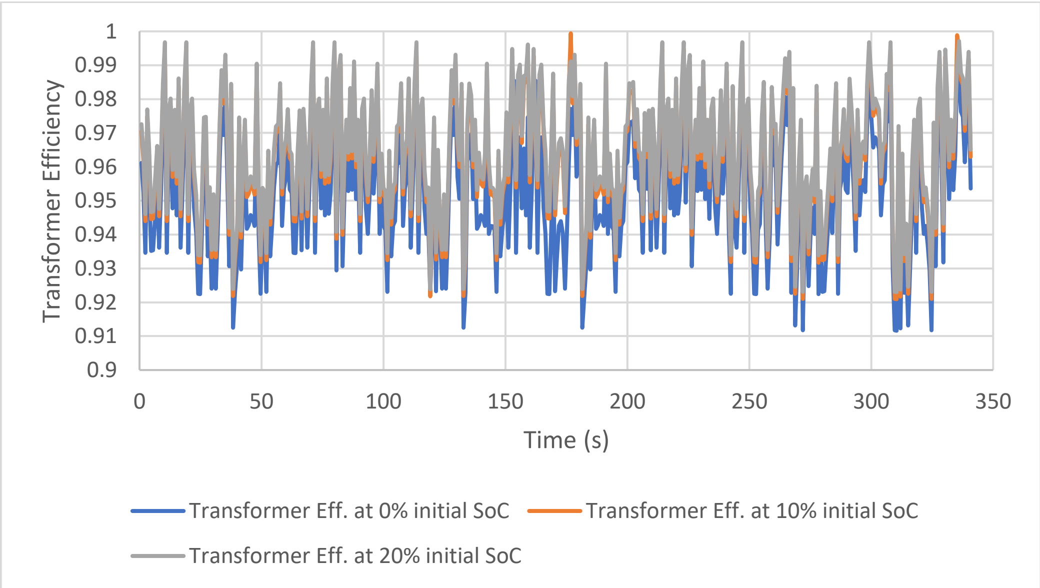

Fig. 10: Transformer Efficiency

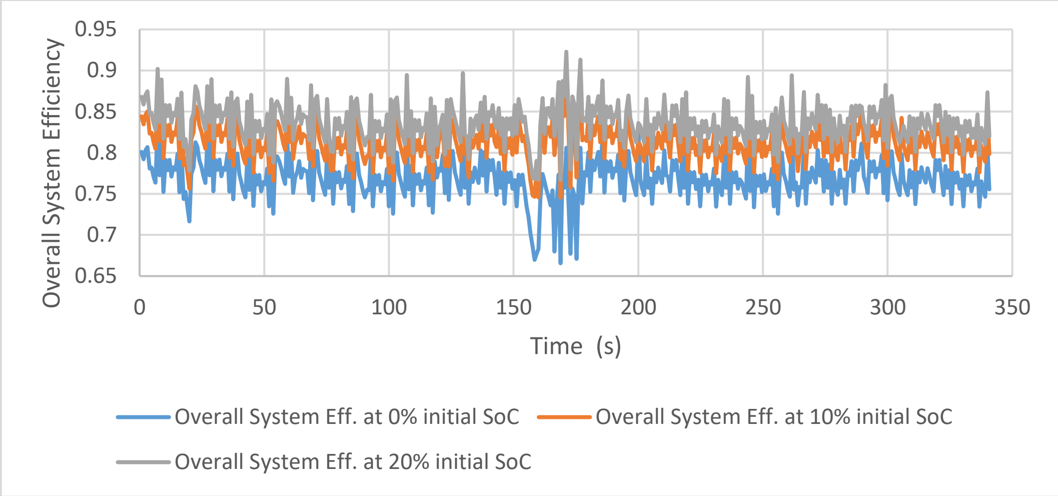

Fig. 11: Overall System Efficiency

From the above graphs, it can be observed that the efficiencies of supercapacitor, converters & transformer increase slightly with the increase in the initial SoC values.

C) Calculation of Round-Trip & Average Efficiencies at Different Initial SoC Values

Round-trip efficiency of the supercapacitor bank at different values of intial SoCs can be calculated from the SoC graphs using the formula below:

Round-trip Efficiency of the Supercapacitor = ΔSoC (charge)/ΔSoC (discharge)

where:

ΔSoC is the difference between starting and ending SoC for each operation i.e. charge and discharge, in this experiment

Thus, the round-trip efficiency of the Supercapacitor at

(i) 0% initial SoC is 97.7 % (=66.5/68)

(ii) 10% initial SoC is 98.01 %

(iii) 20% initial SoC is 98.52%

The average efficiencies of the supercapacitor, converters, transformer & overall system over the given time duration are also calculated from the .csv data file and tabulated as shown below in Table 1.

Table 1: Average Efficiencies of USB components

Average Efficiency of	At initial SoC = 0%	At initial SoC = 10%	At initial SoC = 20%
(i) Supercapacitor	93.69%	95.06%	96.11%
(ii) DC/DC Converter	93.03%	94.58%	95.71%
(iii) Inverter	92.71%	94.08%	94.33%
(iv) Transformer	95.23%	96.24%	96.45%
(v) Overall System	76.90%	81.36%	83.62%

From the above efficiency calculations, it can be concluded that the round-trip & average efficiencies of the supercapacitor are close to each other. Moreover, it can also be inferred from the above table that the average efficiencies of supercapacitor, converter, inverter, transformer and overall system increase slightly with increase in initial SoCs.

References

[1] M. Ceraolo, G. Lutzemberger, and D. Poli, "State-of-charge evaluation of supercapacitors," Journal of Energy Storage, vol. 11, pp. 211 – 218, 2017.

[2] A. Bostrom, A. V. Jouanne, T. K. A. Brekken, and A. Yokochi, "Supercapacitor energy storage systems for voltage and power flow stabilization," 1st IEEE Conference on Technologies for Sustainability, pp. 230 – 237, 2013.