Thermal simulation of supercapacitor

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Abstract

In this work, thermal simulation of the supercapacitor is performed using 1D and 3D simulation tools. The supercapacitor is an energy storage device with characteristics such as high-power density, fast charging and discharging rates, and long cycle life. Supercapacitors are widely used in hybrid electric vehicles, renewable energy systems, trains, etc. It can also be used for the application of agriculture and construction equipment. The life and reliability of the supercapacitor depends on the temperature. Hence, the temperature of the supercapacitor must be maintained within a certain limit. So, the present work simulates the temperature of the supercapacitor at different operating conditions. Further, the temperature behavior of different arrangements of the modules is studied. Also, the effect of forced convection on the surface temperature of the supercapacitor is analyzed. The heat generation of the supercapacitor is obtained using the 1D tool. The 1D supercapacitor model is validated with the experimental results. The heat generation is used as a boundary condition for the 3D thermal simulation of the supercapacitor.

Keywords: Supercapacitor, Thermal analysis, 1D simulation, 3D simulation,

1 Introduction

Supercapacitor is a electrochemical energy storage systems which have high power density. Supercapacitor stores the charge on the material surface. The energy in the form of electrostatic is safe to store as compared to chemical energy. As compared to battery it efficiently releases the high density energy in short duration. It has the cycle life around 10^6 cycles. Also, it gets charged and discharged quickly. So it can be used where the high power density requirement for short duration is a necessity.

In present work the Supercapacitor refers to double layer capacitor. In general supercapacitor's material for different parts are as follows: 1) cell casing and current collector is made up of Aluminum, 2) porous carbon for electrode material, 3) cellulose is used for seperator, 4) Acetonitrile as a electrolyte. During charging and discharging of supercapacitor there is no chemical reacton. The positive and negative ions attracted towards oppositly charged electrodes during charging. So, the charges are stored on the material surfaces. While discharging the positive and negative ions return back to electrolyte.

Supercapacitor has numerous applications in the field of military vehicle and instruments, solar power and wind power plants, power grid and, electric vehicle. Most of the applications such as electric vehicle, the supercapacitors are used as secondary power source. The primary power source may be conventional engine or the Lithium-Ion (LI) batteries. So in every application supercapacitor stores and discipate high power density for short duration as compared with the LI batteries. This short duration operation increases the temperature of supercapacitor.

The supercapacitor performance affected by operating temperature[1]. Organic electrolyte inside supercapacitor evaporates above 20°C [2]. Also, the lifetime of supercapacitors decreases by half every 10°C increase in temperature of the supercapacitor above 25°C [3]. Ideally, to utilize the full lifespan of the module, the temperature must be below 5°C [4]. In practical, to utilize the maximum lifespan of supercapacitor the cooling system is required when the operating temperature of the supercapacitor exceeds 65°C [5]. Supercapacitors can perform better upto – 40 °C, so there is no heating requirement of supercapacitor at low temperature operating conditon [6]. So it is necessary to simulate the temperature over the surface of the supercapacitor.

The present work simulates the temperature of the supercapacitor at different operating conditions. Further, the temperature behavior of different arrangements of the modules is studied. Also, the effect of forced convection on the surface temperature of the supercapacitor is analyzed. The heat generation of the supercapacitor is obtained using the 1D tool. The 1D supercapacitor model is validated with the experimental results. The heat generation is used as a boundary condition for the 3D thermal simulation of the supercapacitor.

2 Model description

There are two models used in this work 1) 1D simulation model and 2) 3D simulation model. 1D simulation model has the 1D electrical circuit of the supercapacitor module. 1D circuit gives the value of the heat generated with respect to time for perticular current input cycle. 3D simulation model has two different arrangement of the supercapacitor module. It simulates the temperature change over the surface of the supercapacitor.

2.1 1D- supercapacitor model

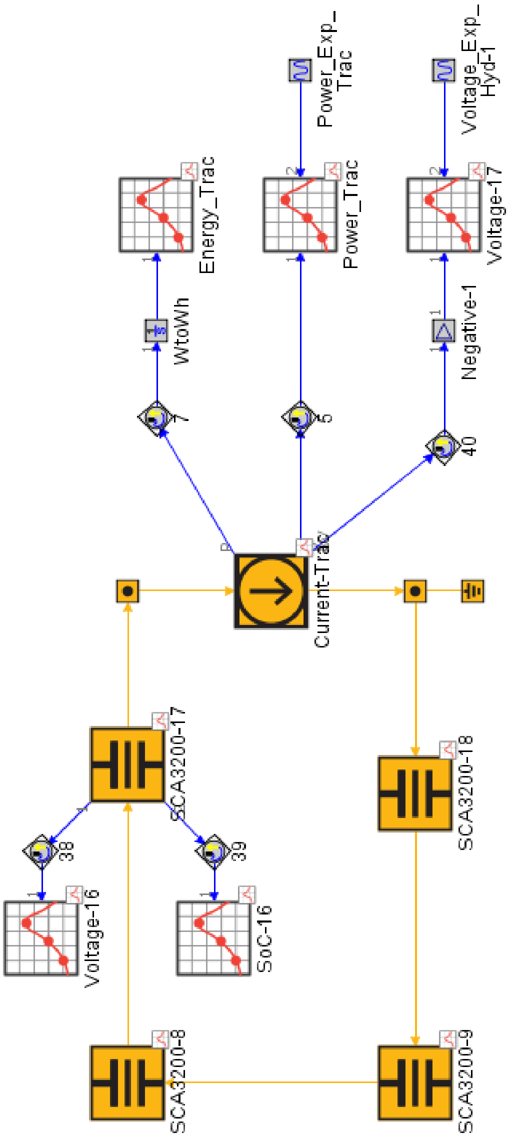

Figure 1. 1D electrical circuit of supercapacitor

Figure 1 shows the 1D electrical circuit of the supercapacitor. It consists of 4 supercapacitor modules connected in series. It produces the output of power, voltage, heat generated and state of charge of supercapacitor. The change in heat generated by supercapacitor will be used as input in the 3D thermal simulation model as heat boundary condition over surface of the supercapacitor module.

Following are inputs required for 1D model simulation:

- Supercapacitor datasheet.
- State of charge versus voltage property of the supercapacitor.
- Number of cells and their connection (series or Parallel) in each module.
- Number of modules and their connection (series or Parallel).
- Equivalent series resistance value.

2.2 3D- Simulation model

Figure 2 and 3 show the 3D model with boudary condition and mesh for supercapacitor module arrangement-1. In this arrangement modules are arranged on single horizontal level. These modules are enclosed in the rectangular box. Here, one of the longer length side of the box has the velocity inlet with circular opening and remaining side has pressure outlet with rectangular slit opening.

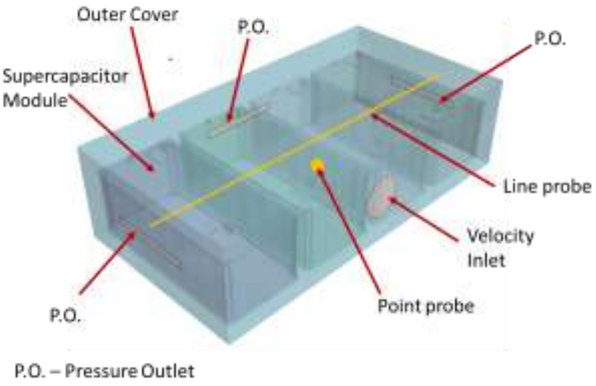

Figure 2. Supercapacitor arrangement # 1

The mesh representation of the arrangement-1 is shown in the figure 3. The trimmed type mesh is used for lesser time of simulation.

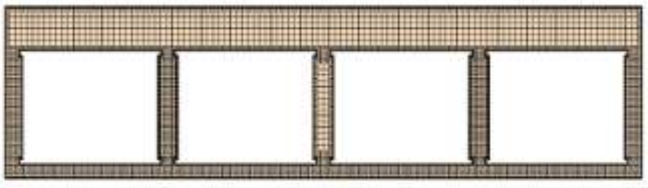

Figure 3. Mesh representation of arrangement # 1

Figure 4 and 5 shows the 3D model with boudary condition and mesh for supercapacitor module arrangement-2. In this arrangement two modules are kept side by side and other two models are kept above these modules. These modules are enclosed in the rectangular box. Here, one of the side of the box has the velocity inlet with circular opening and remaining side has pressure outlet with rectangular slit opening.

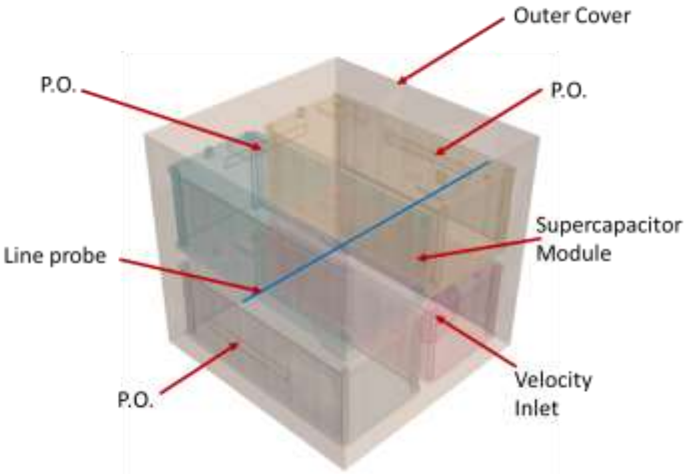

Figure 4. Supercapacitor arrangement # 2

The mesh representation of the arrangement-2 is shown in the figure 5. The trimmed type mesh similar to arrangement-1 is used for lesser time of simulation.

For both the arrangement single fluid region is specified and all surfaces are kept as wall except velocity inlet and pressure outlet. The change in heat with respect to time is specified over the surface of the supercapacitor module.

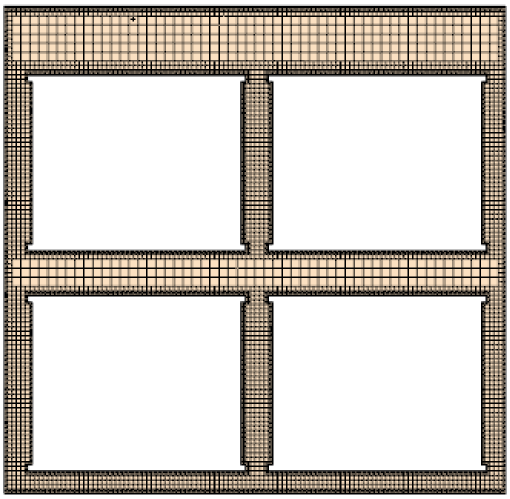

Figure 5. Mesh representation of arrangement # 2

3 Validation and Grid independency

The validation of the 1D circuit results is carried out by comparing the power and voltage output with respect to the experimental results. The figure 6 shows that the normalized power variation with respect to time is approximataly same for experimental and simulation values. Similarly, the change in normalized voltage values with respect to time is comparable for experimental and simulation values (Figure 7).

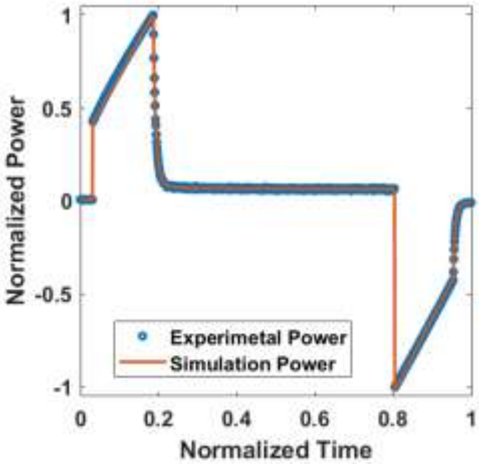

Figure 6. The comparison of normalized experimental and simulation power

Further, the change in normalized heat with respect to time is plotted in figure 8. This is used as heat source over the surface of supercapacitor. Figure 9 shows the change in the state of charge of the supercapacitor with respect to time. The variation of state of charge (SOC) of the supercapacitor with respet to time is shown in figure 9.

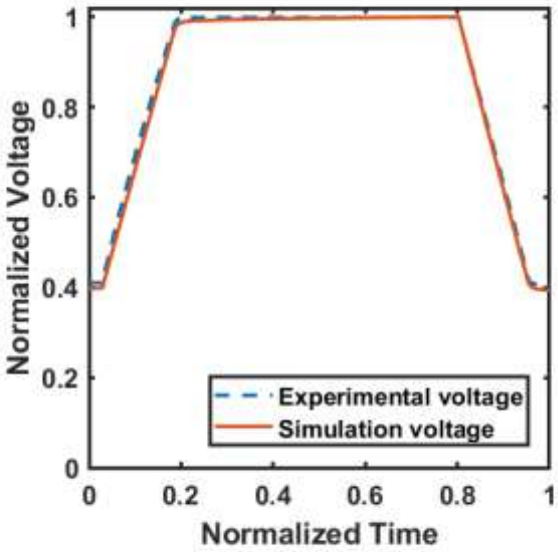

Figure 7. The comparison of normalized experimental and simulation voltage

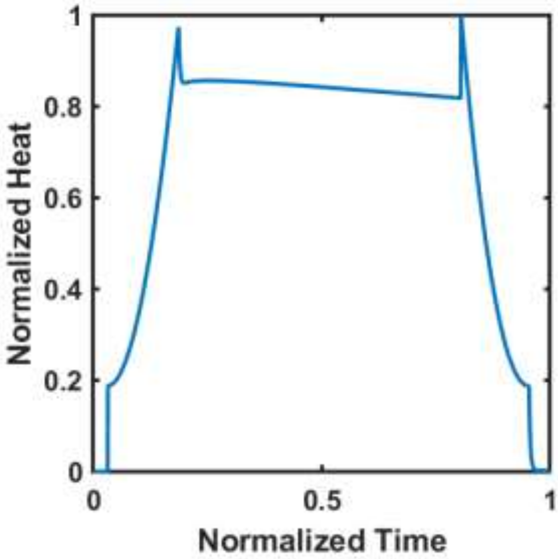

Figure 8. The normalized heat generated by supercapacitor

Table 1 shows the grid independency study for arrangement-1. The temperature values are considered at the probe shown in the figure 2. This table indicates that for grid-3 onwards the % error of the temperature is decreases less than 10%. So the solution is grid independent from grid-3 onward.

All values in plots and table are normalized with respect to maximum value.

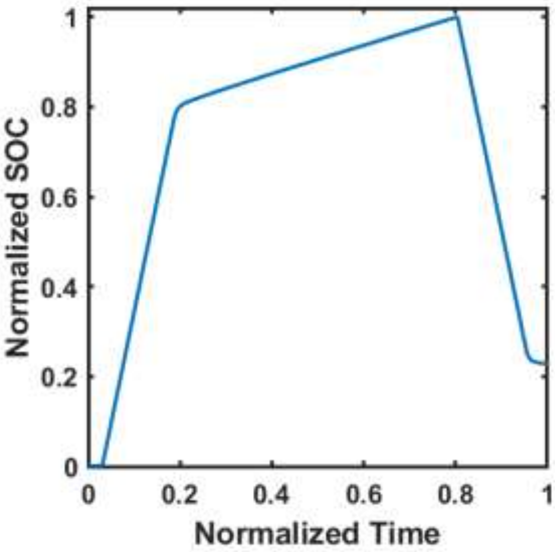

Figure 9. The normalized SOC of the supercapacitor

Table 1 Grid independency check

Grid number	Cell count	% Error temperature at Point probe
Grid-1	429579	-
Grid-2	1003999	10.4
Grid-3	2666305	5.98
Grid-4	7590276	0.3

4 Result and discussion

4.1 Results of Arrangement #1

Figure 10 shows the variation of temperature at different inlet speed for arrangement-1 along the line probe shown in the figure 2. At low speed the temperature variation is higher than at the medium and high speed. It indicates that the low speed is not sufficient to reduce the temperature. Figures 11,12 and 13 show the temperature contour over the module surface at low, medium and high speed respectively. Hot spots at the low is observed more as compared to medium and high speed. So, high speed is sufficient to maintain constant temperature of supercapacitor surface.

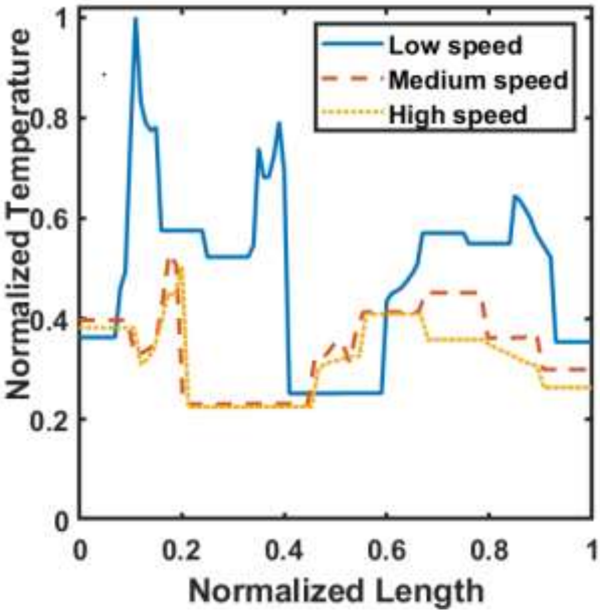

Figure 10. Temperature variation along the line probe as shown in figure 2

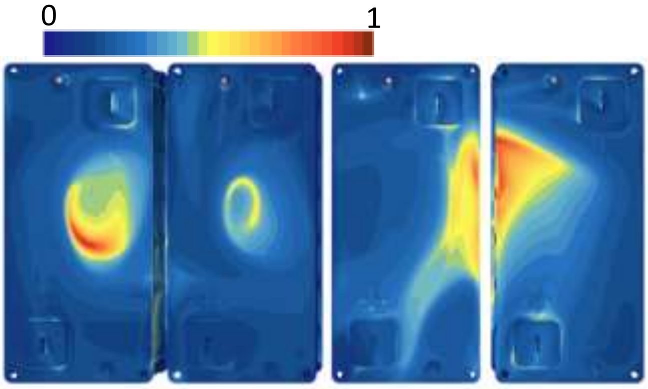

Figure 11. Temperature contour on the module surface at low speed

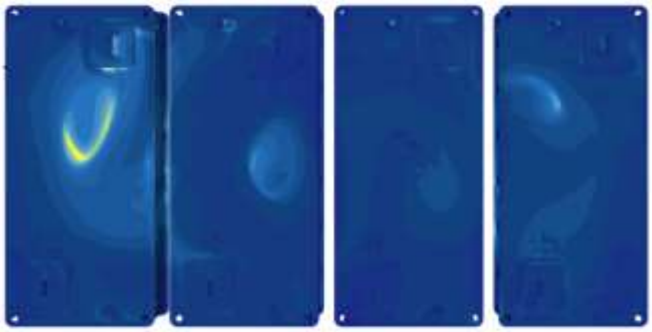

Figure 12. Temperature contour on the module surface at medium speed

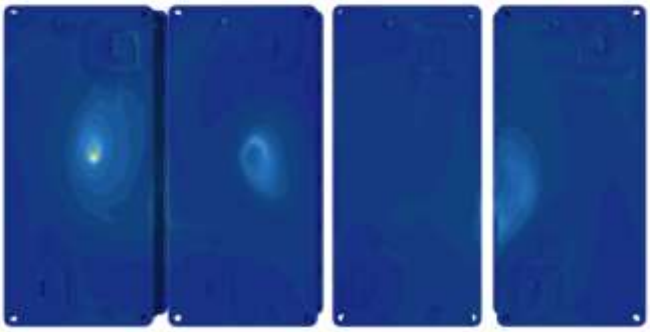

Figure 13. Temperature contour on the module surface at high speed

4.2 Results of Arrangement #2

Figure 14 shows the variation of temperature at different inlet speed for arrangement-2 along the line probe shown in the figure-4. At low speed the temperature variation is higher than at the medium and high speed. It indicates that the low speed is not sufficient to keep the constant temperature. Figures 15,16 and 17 shows the temperature contour over the module surface at low, medium and high speed respectively. Hot spots at the low are observed more as compared to medium and high speed. So, medium and high speed is sufficient to maintain constant temperature of supercapacitor surface

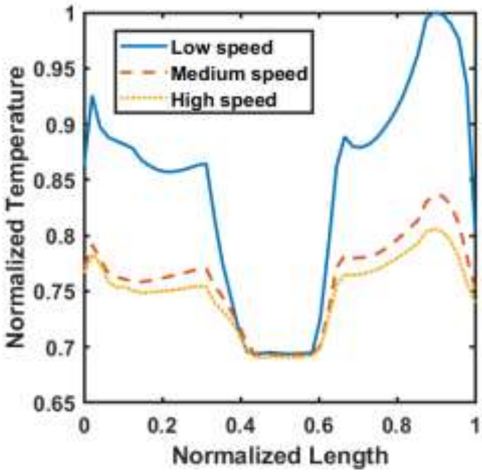

Figure 14. Temperature variation along the line probe as shown in figure 2

Figure 15. Temperature contour on the module surface at low speed

Figure 16. Temperature contour on the module surface at medium speed

Figure 17. Temperature contour on the module surface at high speed

5 Conclusion

The thermal simulation of the supercapacitor is performed. The 1D model is validated with the experimental results. Forced convection at high speed shows better cooling for both arrangements. In the second arrangement there are no hot spots observed in the temperature contour of medium and high speed. Need further simulation with different arrangements of the supercapacitor. Also, there is a need for experimental results to validate the 3D thermal model.

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Amitkumar S. Gawas completed Ph.D.. He is expert in heat convection domain. Libera Natalia La Face completed Ph.D.. She is CFD expert.

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