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Sandia National Laboratories

Linear Analysis of Power Electronics for Energy Storage Systems

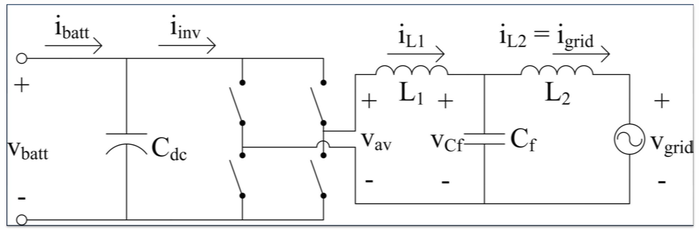
Purpose:

- To gain a better understanding of the frequency content of the battery when perturbations occurs at the utility during normal power conversion system operation like voltage and frequency support and renewable firming.
- A set of transfer functions have been developed to predict the frequency content of the battery.

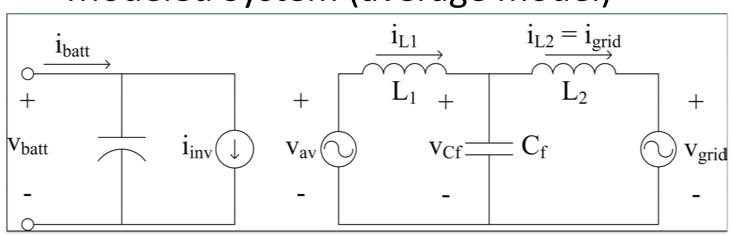
Impact on DOE OE Energy Storage Mission:

- Gives battery manufacturers an additional tool to optimize and develop a more reliable battery for single phase grid-tied systems.
- Unlike current frequency analysis methods, this method is not computationally expensive.
- This is a step towards analyzing battery performance in the frequency domain, where there is much potential for growth.

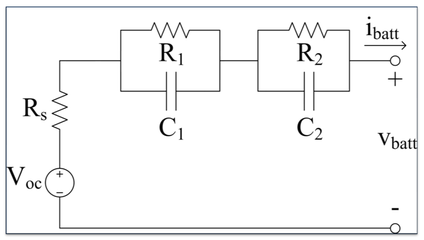
Modeled System (switch model)



Modeled System (average model)



Battery Model



Linearization Issue:

$$i_{inv} = \frac{v_{av} i_{L1}}{v_{dc}}$$

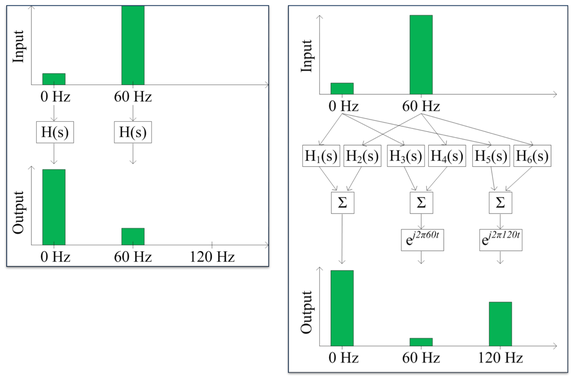
60 Hz input

$$i_{inv} = \frac{V_{av}\sin(\omega t) I_{L1}\sin(\omega t + \phi)}{v_{dc}}$$

DC + 120 Hz Output

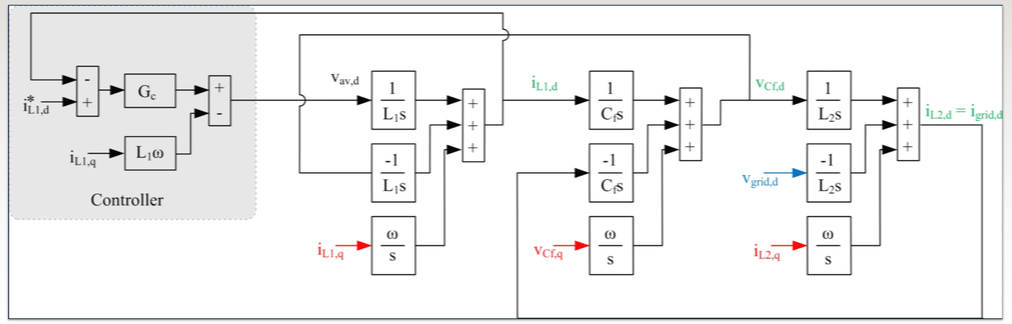
$$i_{inv} = \frac{V_{av} I_{L1}}{2 v_{dc}}[\cos(\phi) - \cos(2\omega t + \phi)]$$

Harmonic Transfer Functions:



Standard transfer functions (left) can only map each frequency onto itself. As a result, any nonlinear relationships in a system are lost. Using standard TF's to analyze a battery's frequency content yields inaccurate results. Harmonic transfer functions (right) preserve nonlinear relationships and allow the system to be modeled in a linear fashion. The system can then be analyzed using well established techniques.

Filter and Inverter Block Diagram:

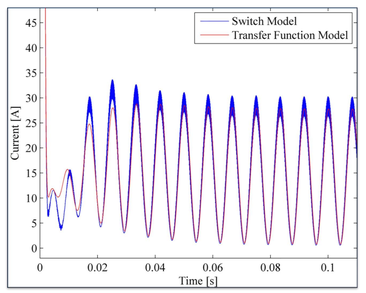


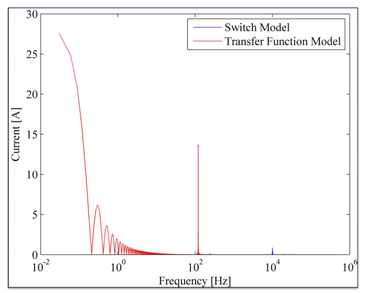
Control to Output Transfer Functions:

$$\frac{i_{gridd}}{v_{av}} = \frac{1}{C_f L_1 L_2 s^3 + (-C_f L_1 L_2 \omega^2 + L_1 + L_2)s}$$

$$\frac{i_{L1d}}{v_{av}} = \frac{C_f^2 L_2^2 s^4 + 2C_f L_2 (C_f L_2 \omega^2 + 1)s^2 + (C_f L_2 \omega^2 - 1)^2}{C_f^2 L_1 L_2^2 s^5 + C_f L_2 (2L_1 (C_f L_2 \omega^2 + 1) + L_2)s^3 + (L_1 (C_f L_2 \omega^2 - 1)^2 + C_f L_2^2 \omega^2 + L_2)s}$$

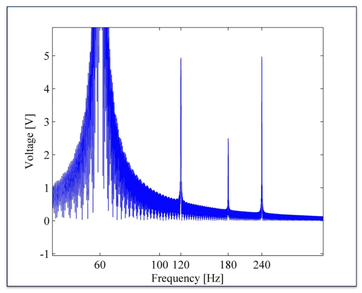
Simulation Results:

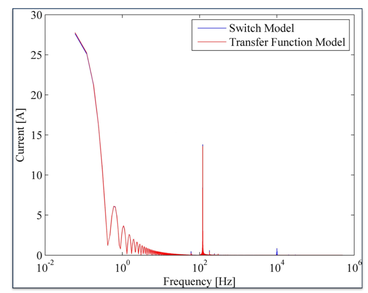


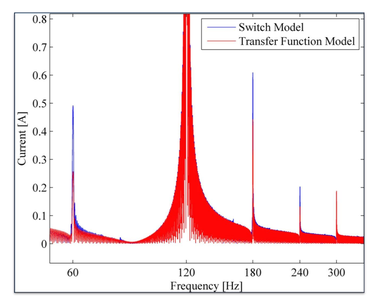


Time domain and frequency domain simulation results are shown for the switch level model vs. the proposed model with an ideal 60 Hz input (Left) .

Harmonics are then added to the input of system, to further test the proposed model's accuracy (Below).







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