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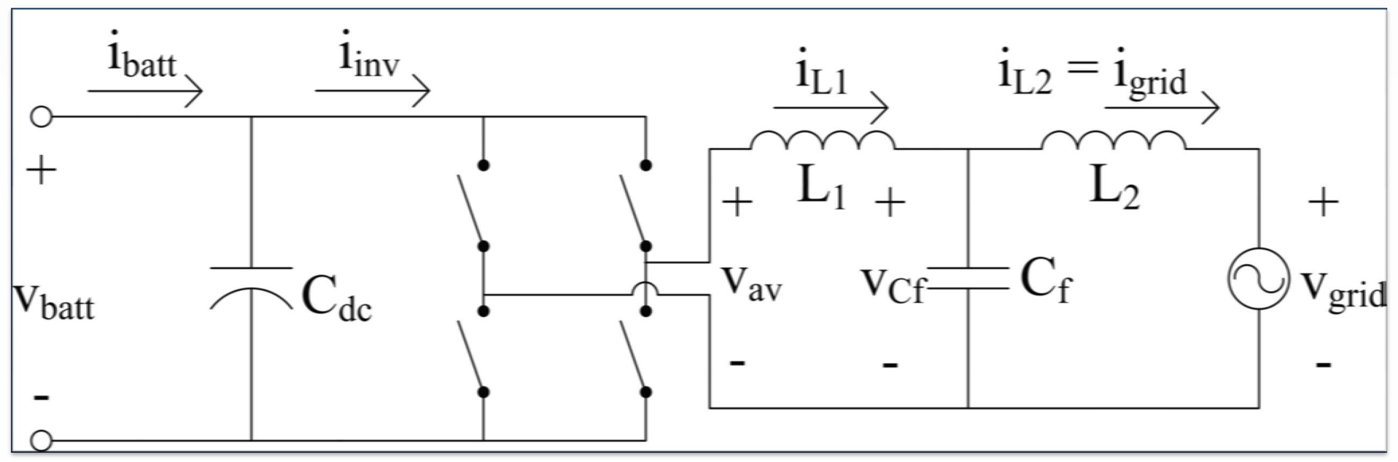
Linear Analysis of Power Electronics for Energy Storage Systems

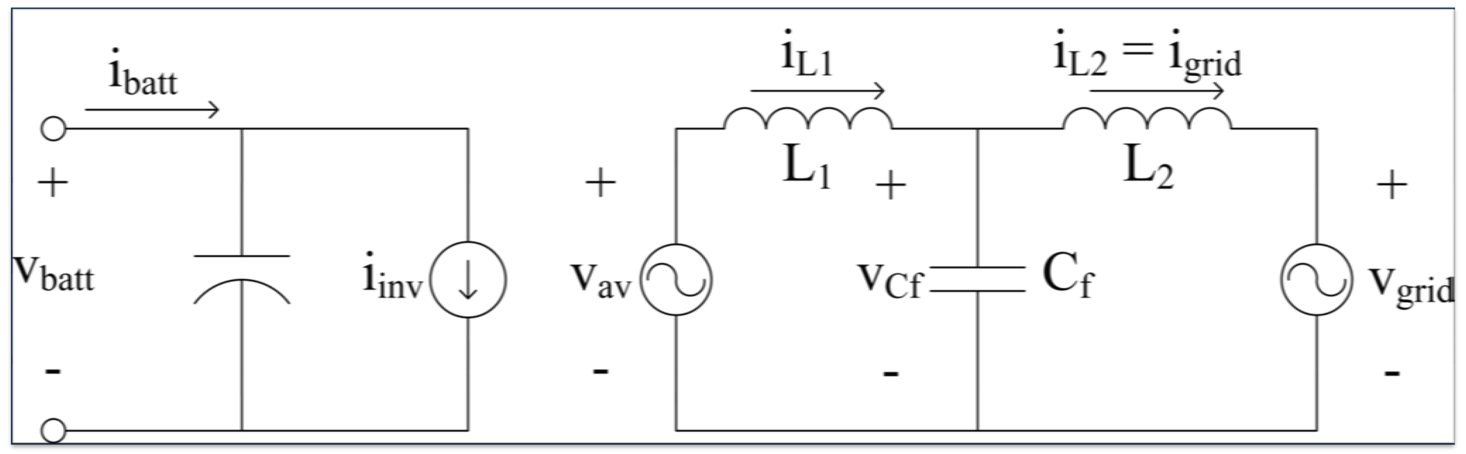
Purpose:

- 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.

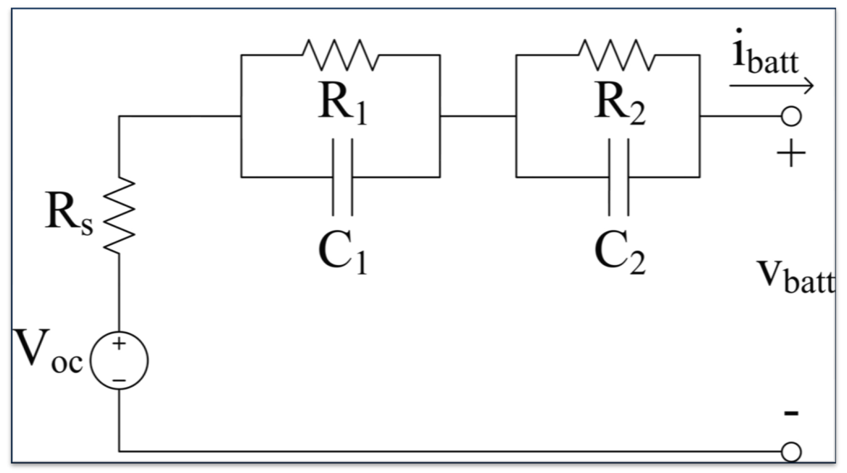
Modeled System (switch model)



Modeled System (average model)



Battery Model



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.

Linearization Issue:

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

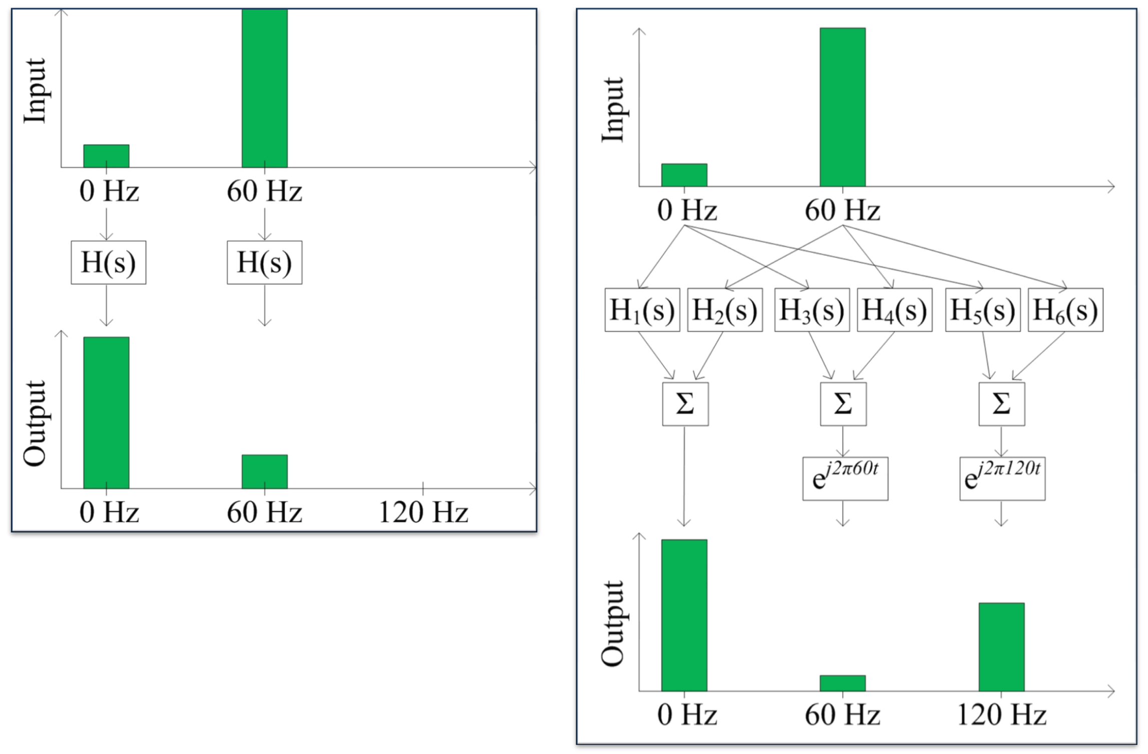
60 Hz input

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

DC + 120 Hz Output

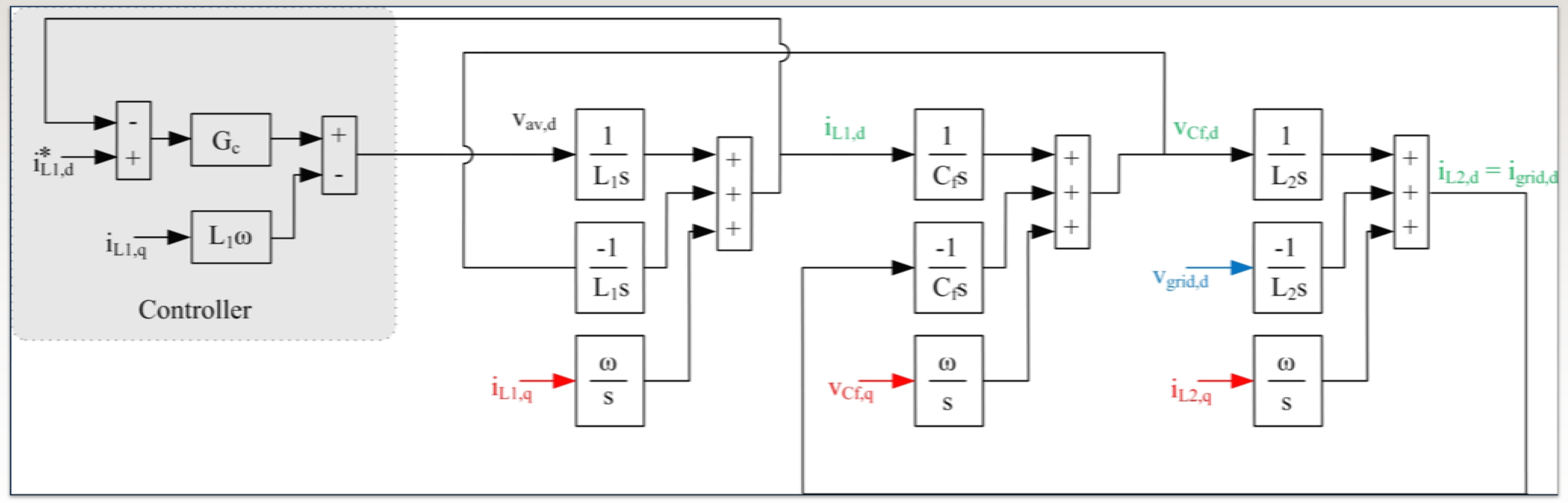
$$i_{inv} = \frac{V_{av} I_{L1}}{2 v_{dc}}[\cos(\phi) - \cos(2\omega t + \phi)]$$

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:

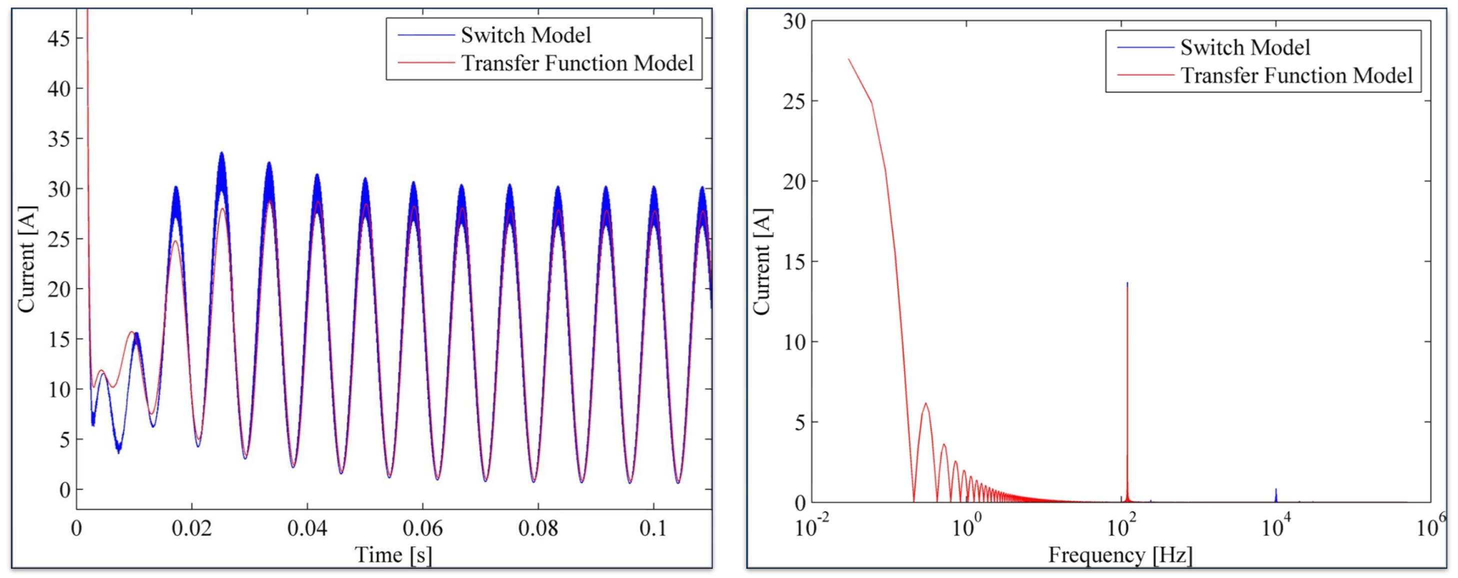


Control to Output Transfer Functions:

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

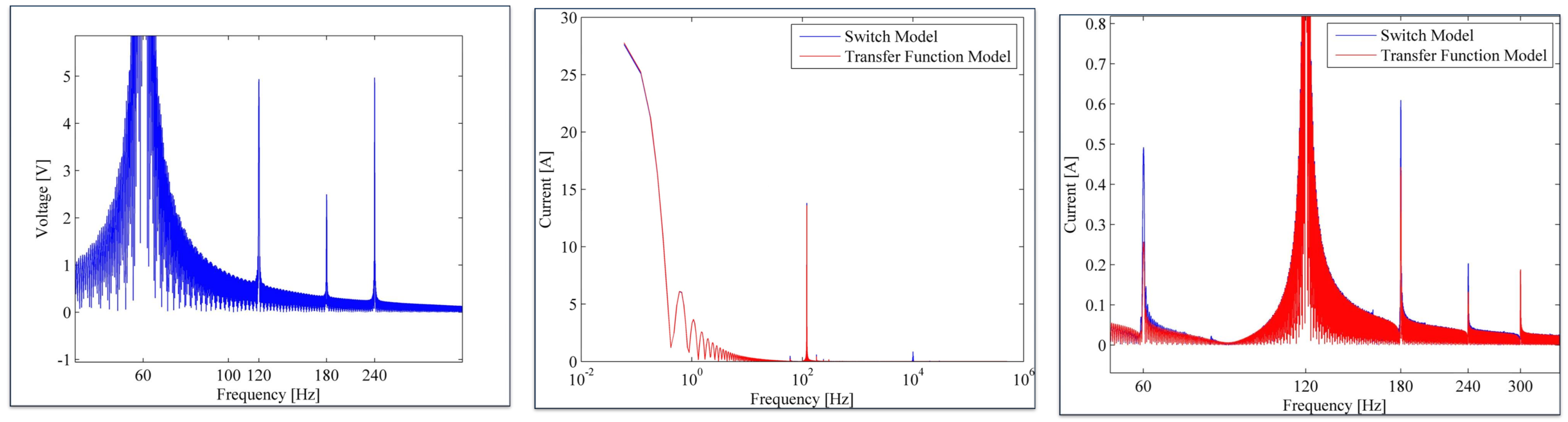
$$\frac{i_{L1d}}{v_{av}} = \frac{C_f^2 L_2^2 s^4 + 2C_f L_2 (C_f L_2 \omega^2 + 1)s^2 + (C_f L_2 \omega^2 - 1)^2}{C_f^2 L_1 L_2^2 s^5 + C_f L_2 (2L_1 (C_f L_2 \omega^2 + 1) + L_2)s^3 + (L_1 (C_f L_2 \omega^2 - 1)^2 + C_f L_2^2 \omega^2 + L_2)s}$$

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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