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Linear Single Phase Inverter Model for Battery Energy Storage System Evaluation

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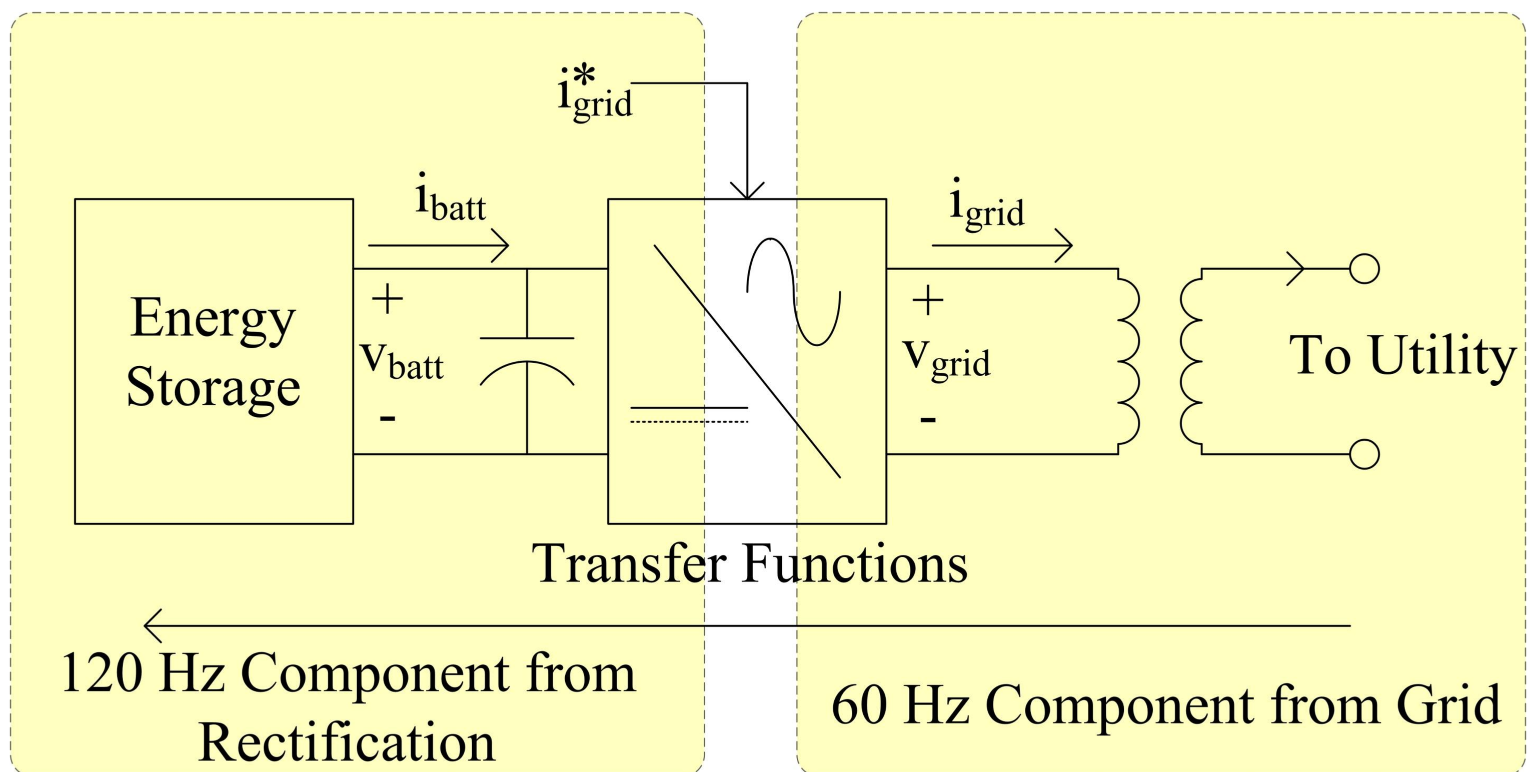
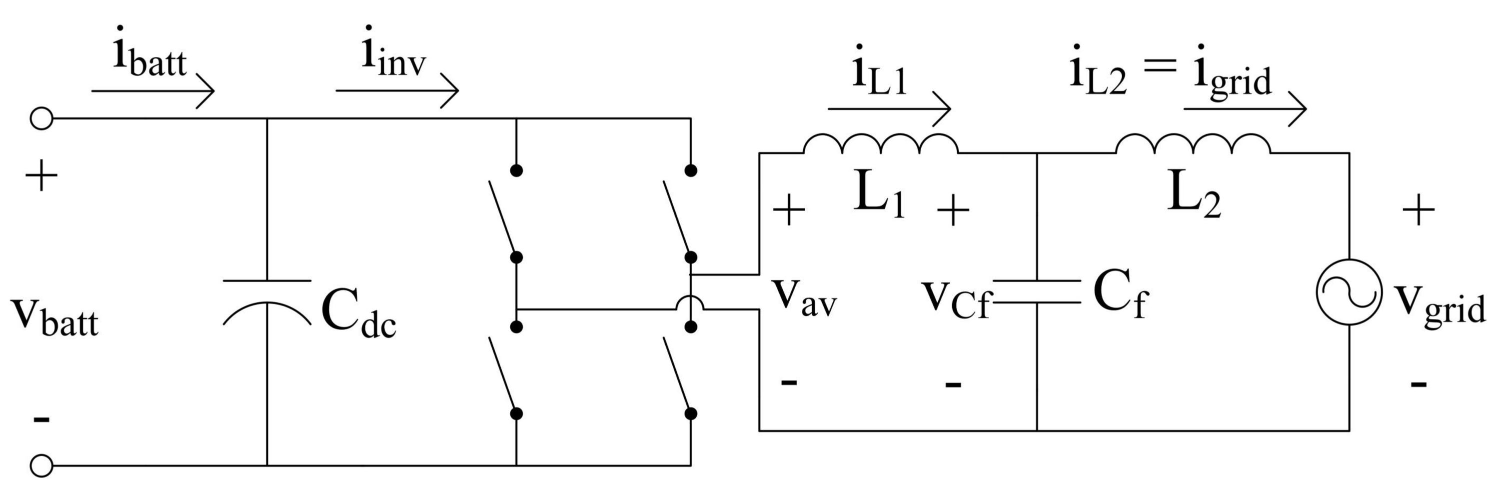
Link to Poster and Transfer Functions
http://jonathankimball.com/mathematics



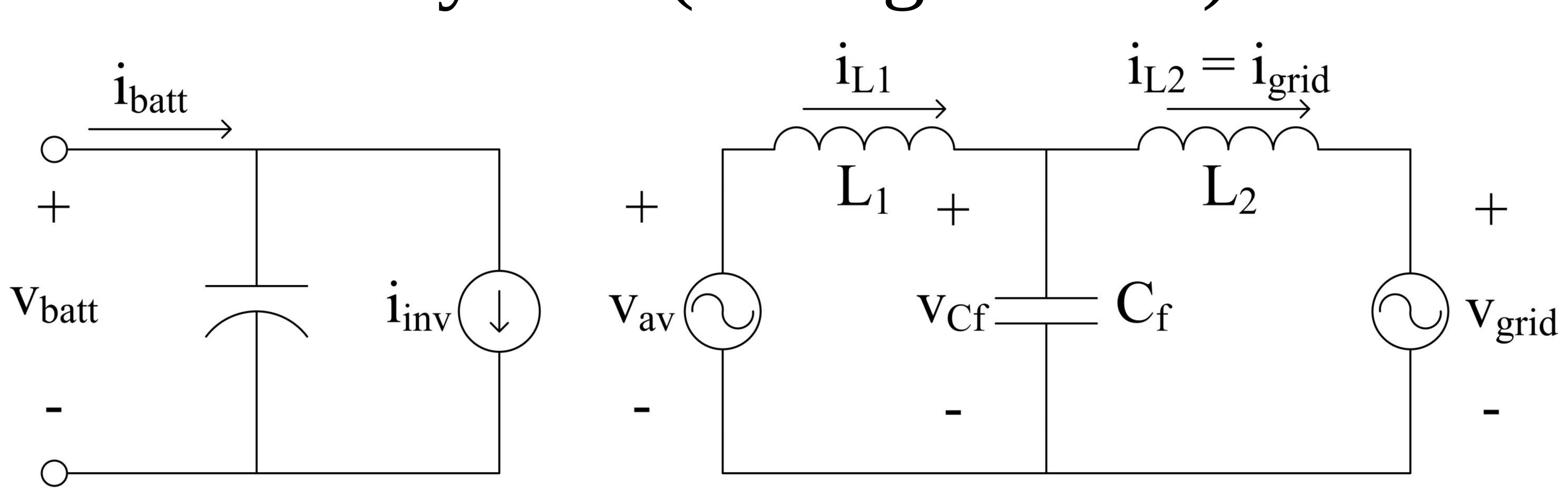
Overview

A method for deriving a set of linear transfer functions for a single phase grid tied system is presented, which can be used to determine how small signal perturbations and transients on the utility side are translated through the inverter to the dc link, as well as assist in controller design. The derived transfer functions have the advantage of not neglecting the double grid frequency component. With this information, battery designers will be able to design a more robust battery specifically tailored for single phase inverter applications.

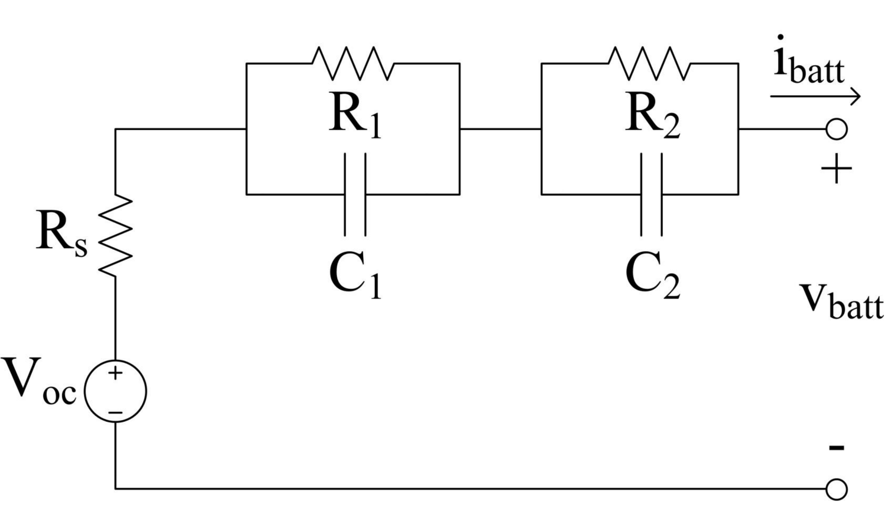
Modeled System (switch model)



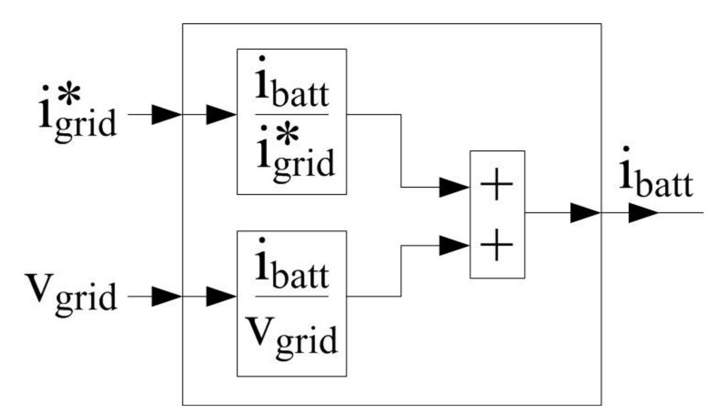
Modeled System (average model)



Battery Model



Desired Result



Linearization Problem

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

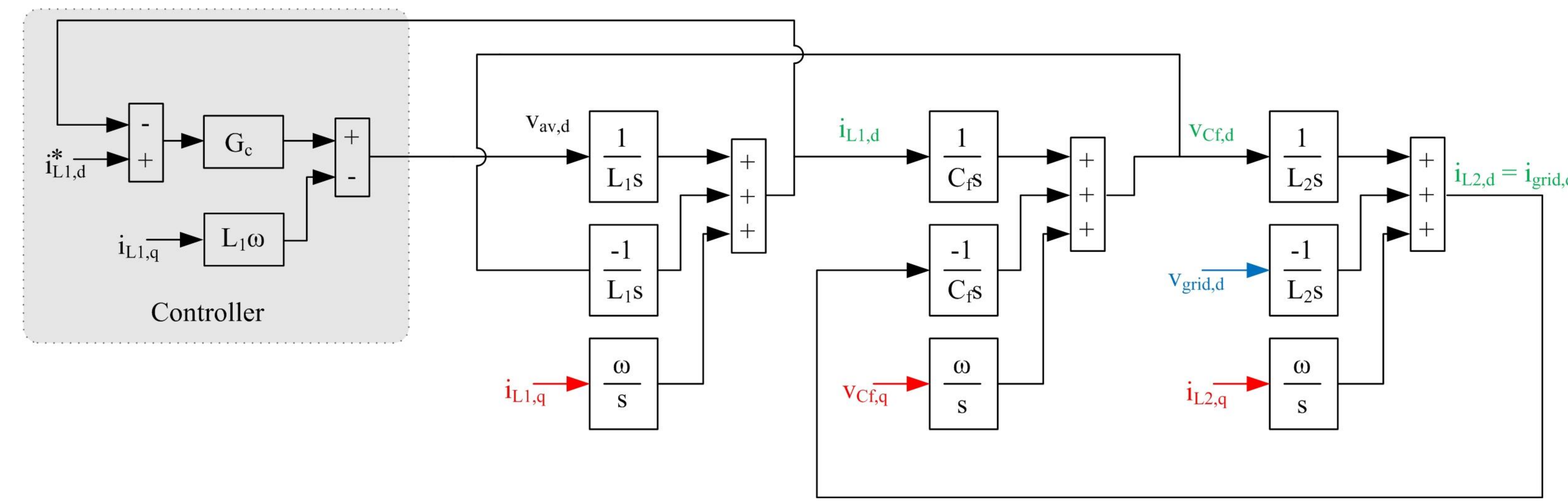
$$i_{inv} = \frac{V_{av}\sin(\omega t) I_{L1}\sin(\omega t + \phi)}{v_{dc}}$$

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

Using two rotating reference frames, one operating at grid frequency and one operating at twice the grid frequency, i_{inv} can be linearized without losing the significant double grid frequency component.

$$i_{inv2q} = \frac{i_{L1d} v_{avq} + i_{L1q} v_{avd}}{2v_{dc}} \quad i_{invdc} = \frac{i_{L1d} v_{avd} + i_{L1q} v_{avq}}{2v_{dc}} \quad i_{inv2d} = \frac{i_{L1d} v_{avd} - i_{L1q} v_{avq}}{2v_{dc}}$$

Filter and Inverter block diagram



Controller Design Equations

Control to output transfer function when controlling i_{grid}

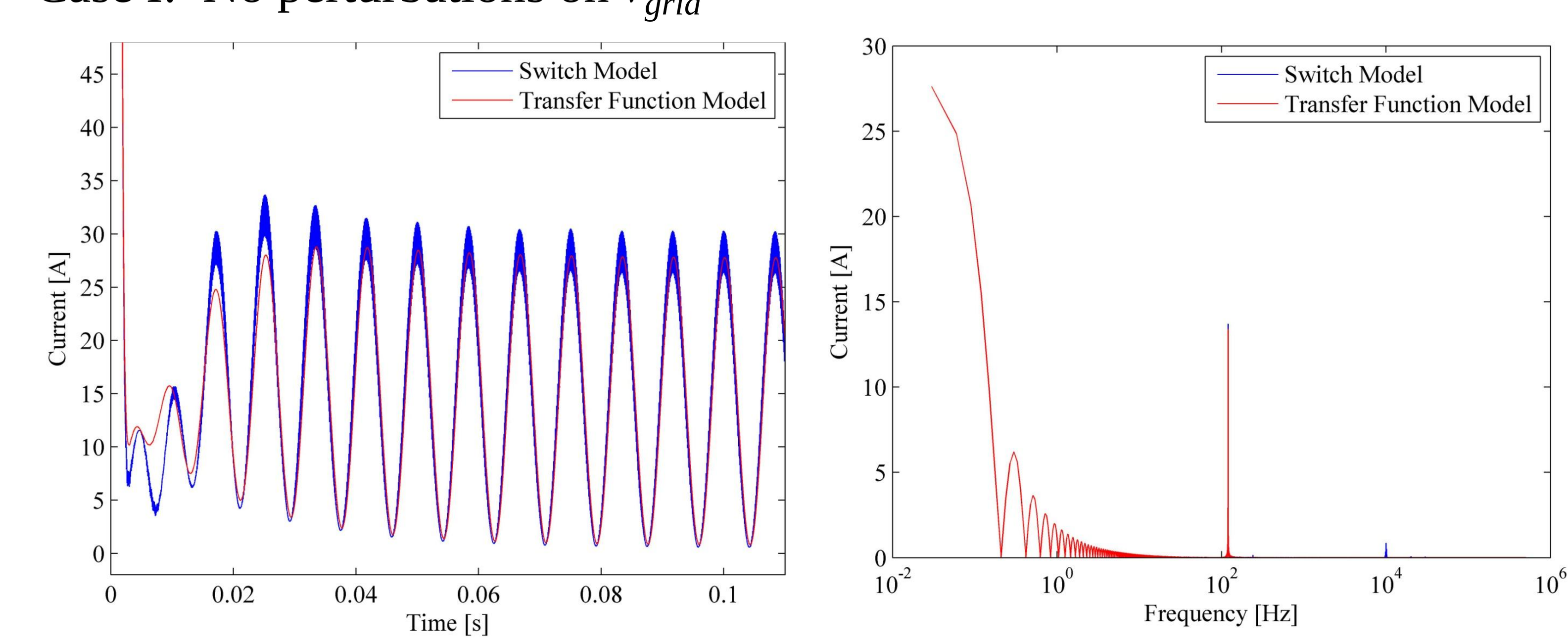
$$\frac{i_{gridd}}{v_{av}} = \frac{1}{C_f L_1 L_2 s^3 + (-C_f L_1 L_2 \omega^2 + L_1 + L_2)s} \quad \text{Assuming } G_c \times \frac{i_{gridd}}{v_{av}} >> 1$$

Control to output transfer function when controlling i_{L1}

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

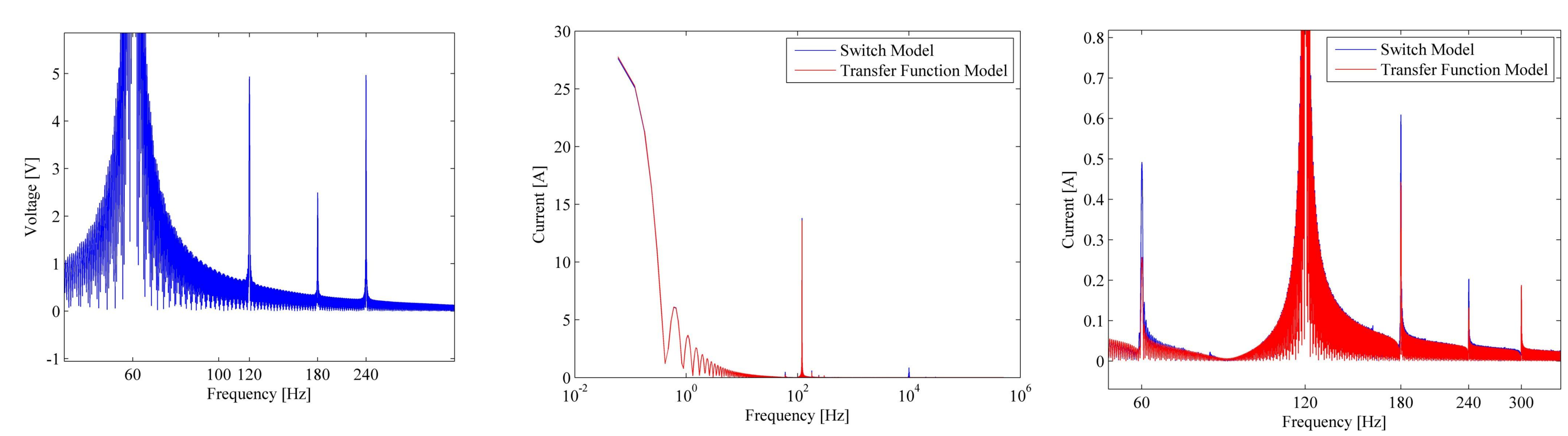
Simulation Verification of Transfer Functions

Case I: No perturbations on v_{grid}



The transfer function derived are too lengthy to gain any intuitive value from them, without further simplification. The derived functions can be found in a Simulink file format at http://jonathankimball.com/mathematics

Case II: Perturbations Added to v_{grid}



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