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Terminal Capacitor Compensation Based Stability Design for DC Microgrids

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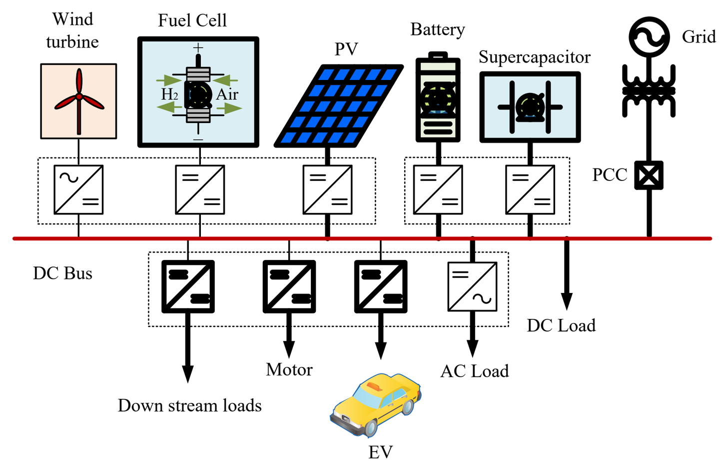
Abstract

This paper investigates the detailed elements of a DC microgrid that might cause instability, and proposes a stabilizing guidance based on the passive stability criterion. For illustration purpose, the terminal output impedance model of a source side power converter under double loop with droop control is built, and its frequency characteristics are analyzed. It is found that the instant high power absorption from the microgrid might make the source side power converter's output to oscillate. The details of how the circuit and control elements in the source side impact the terminal impedance are illustrated. This paper shows that the stability of plug and play performance of DC microgrid can be guaranteed with the proposed stabilization methods. A Matlab/Simulink model is used to validate the analysis.

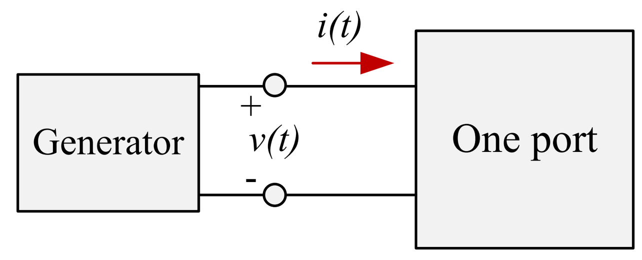


Passive Stability Criterion

A impedance transfer function $Z(\cdot)$ of complex variable s is said to be positive real if

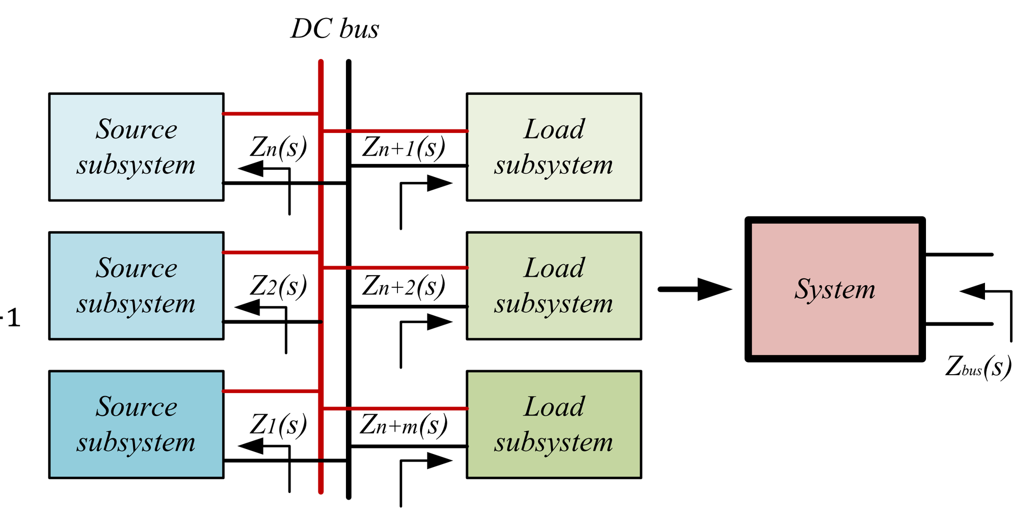
- $Z(\cdot)$ is a rational function of s with real coefficients;
- $Re(s) > 0$ implies $Re[Z(s)] \geq 0$

The second constraint implies $Re[Z(j\omega)] \geq 0$ by continuity for all defined ω. In real power electronic applications, ω could be bounded under switching frequency. If the system total impedance is passive, then the system is always stable based on the passive stability criterion.

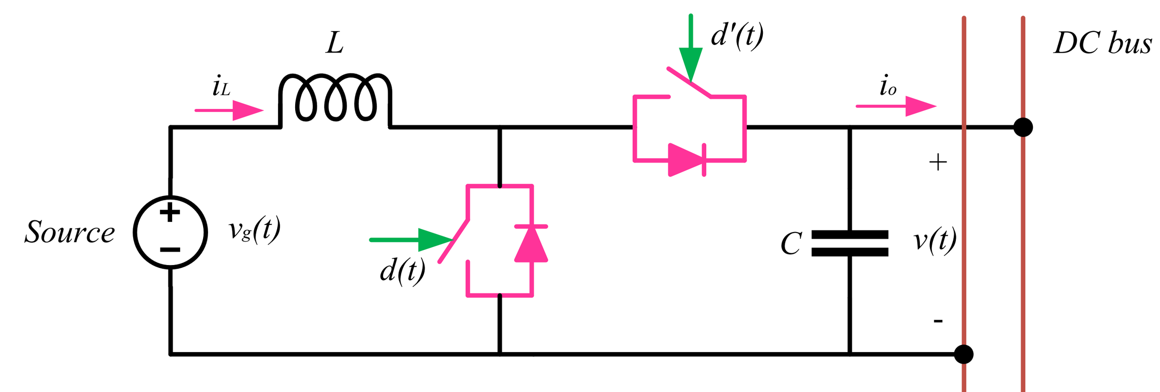


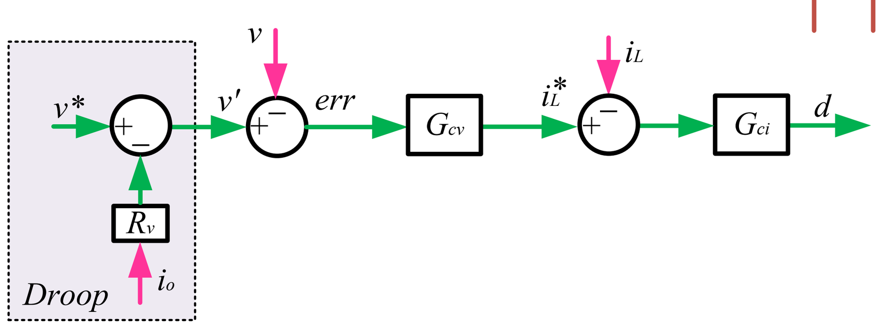
$$Z_o = \frac{\Delta v(s)}{\Delta i_o(s)}$$

$$Z_{bus} = \left(\sum_{i=1}^{n} \frac{1}{Z_i} + \sum_{j=1}^{m} \frac{1}{Z_{n+j}}\right)^{-1}$$



Modelling & Solution

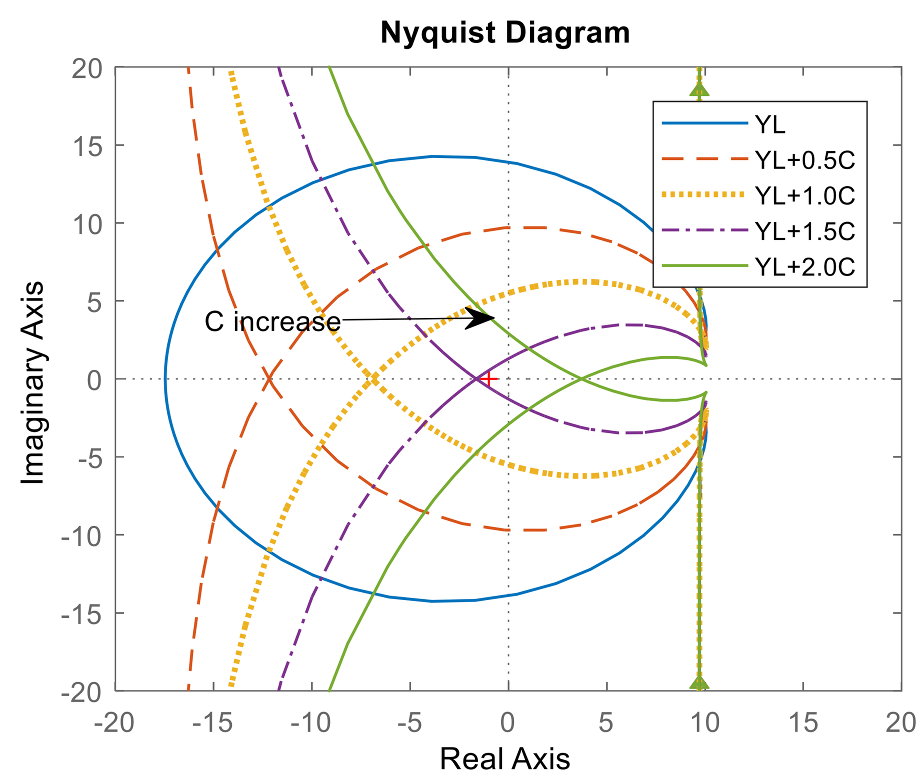




A bidirectional Boost converter is used as an example to discuss the terminal output impedance of interface converter.

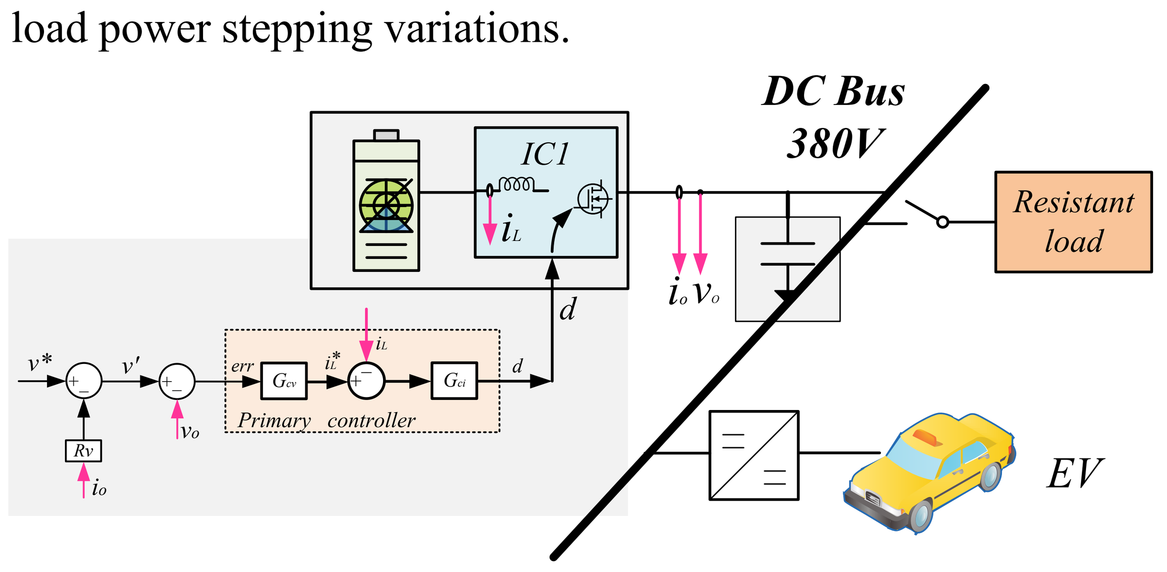
$$\begin{cases} L\dfrac{di_L(t)}{dt} = v_g(t) - d'(t)v(t) \\ C\dfrac{dv(t)}{dt} = d'(t)i_L(t) - i_o(t) \end{cases}$$

$$Y_o = -\frac{\Delta i_o(s)}{\Delta v(s)}$$
$$= \frac{-G_{cv}G_{ci}I_L sL + D'G_{cv}G_{ci}V + D'^2 + G_{ci}I_L D'}{(G_{ci}V + sL) - (sL)R_v G_{cv}G_{ci}I_L + D'R_v G_{cv}G_{ci}V}$$
$$+ \frac{sC(G_{ci}V + sL)}{(G_{ci}V + sL) - (sL)R_v G_{cv}G_{ci}I_L + D'R_v G_{cv}G_{ci}V}$$



Simulation Results

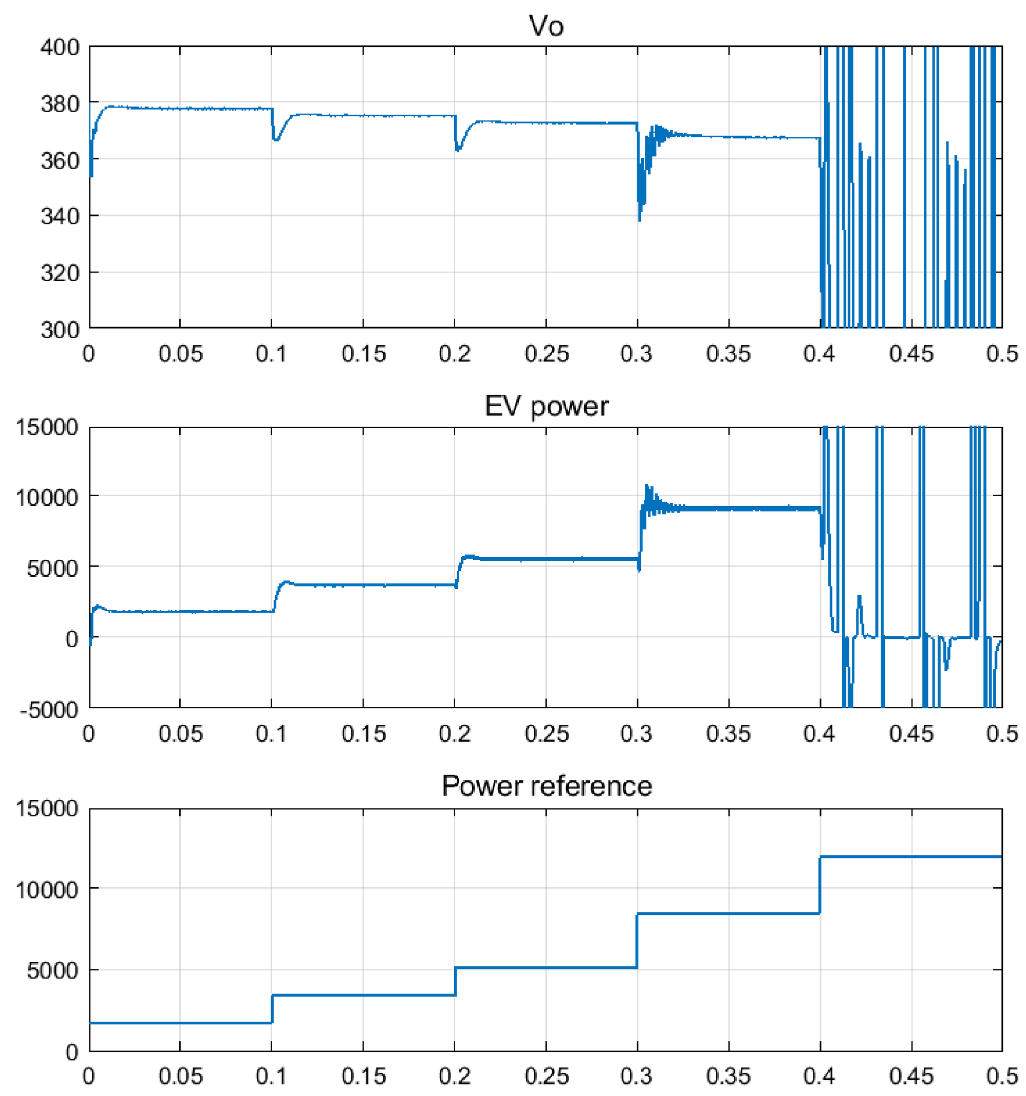
A simulation model is used for validating above analysis. It contains a droop controlled bidirectional Boost converter, an EV load, and a resistant load. The converter in the EV load is same as the sources converter while only the inner current loop is applied for load power stepping variations.



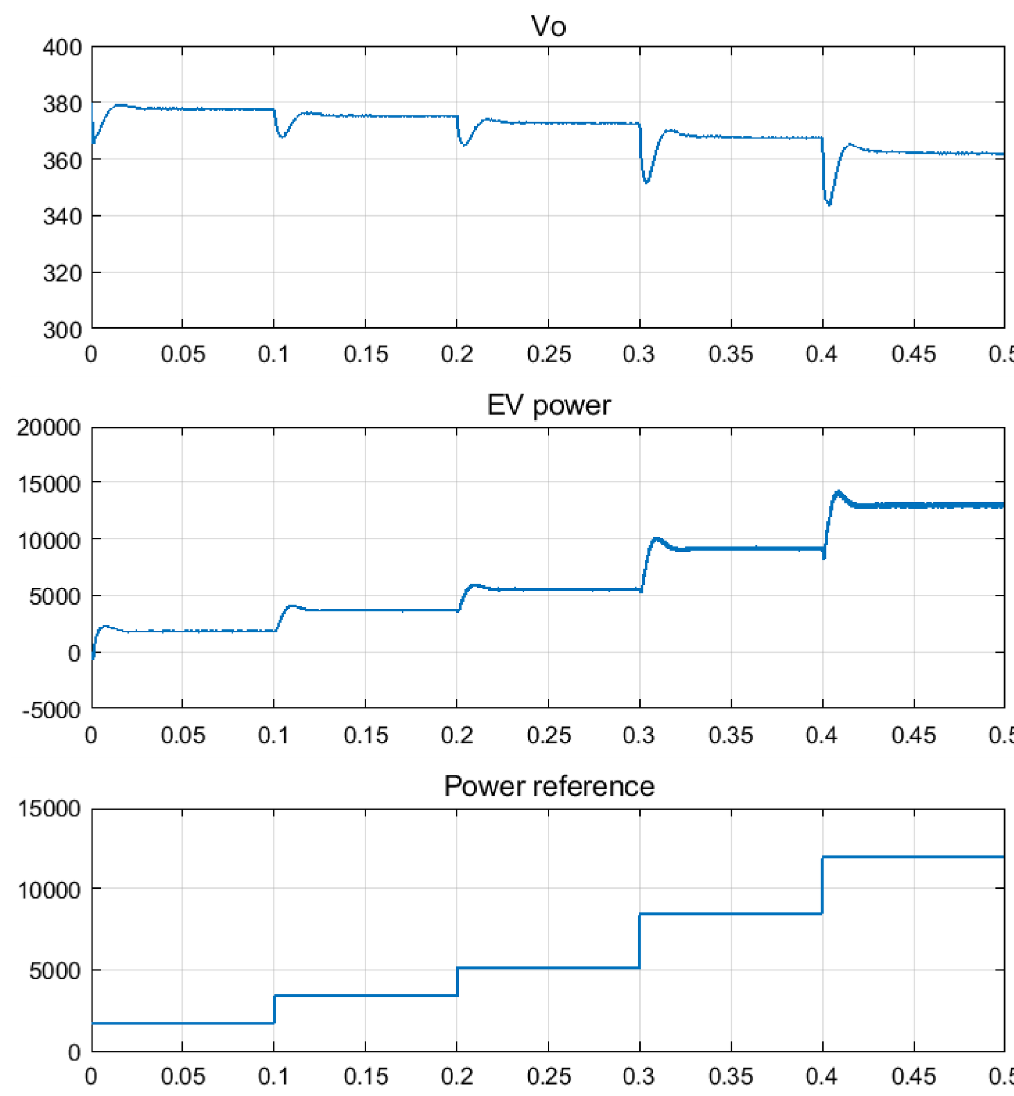
First of all, when the terminal capacitor is 470uF without additional capacitor compensation, the simulation results of EV charging power stepping are shown in left figure.

Adding the terminal compensating capacitor with additional 470uF based on above analysis, the same simulation process is conducted, the result is shown in right figure.

It can be concluded that adding the terminal capacitor compensation can make the EV fast charging more stable.



Oscillation occurs when the EV charging power steps up.



Terminal capacitor compensation to stabilize the system.

Summary

This paper uses passive stability criterion to analyze the EV fast charging scenario in DC microgrids. The admittance model of bidirectional Boost converter is built for the analysis. The analysis results show that the high frequency negative admittance is directly related to the load power and the terminal capacitor can compensate the negative value. When the system supplies the instant heavy load, additional capacitor compensation is required.

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