Modeling and Advanced Control Design for DC/DC Converters in Microgrids

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Abstract

Power grids are transforming into smarter ones with the increased integration of distributed renewable energy sources, such as solar and wind. Along with these advancements, microgrids are evolving and are going to dominate the future of energy distribution. In order to accomplish this, their development requires advanced sensors, controls and communications. In this project, we particularly study the advanced control strategy for DC/DC converters used in Microgrids. Modeling and control for both buck converter and boost converter are addressed, respectively. Specifically, after deriving the averaged state-space model for the converter, two control methods are proposed. The first one is simply based on linearization around the equilibrium point and a state feedback control is designed using the standard eigenvalue assignment method. However, the control input, which takes a signal from the duty cycle to the switching device, may be out of range with this design due to the nature of local approximation. To solve this problem, we propose the second solution, which is a new design based on nonlinear control method. We show this control algorithm can stabilize the system while ensuring the duty cycle is in the range of the system. Thorough simulations based on PSpice and Matlab/Simulink are conducted to validate the proposed advanced control methods.

Control Design and Simulation

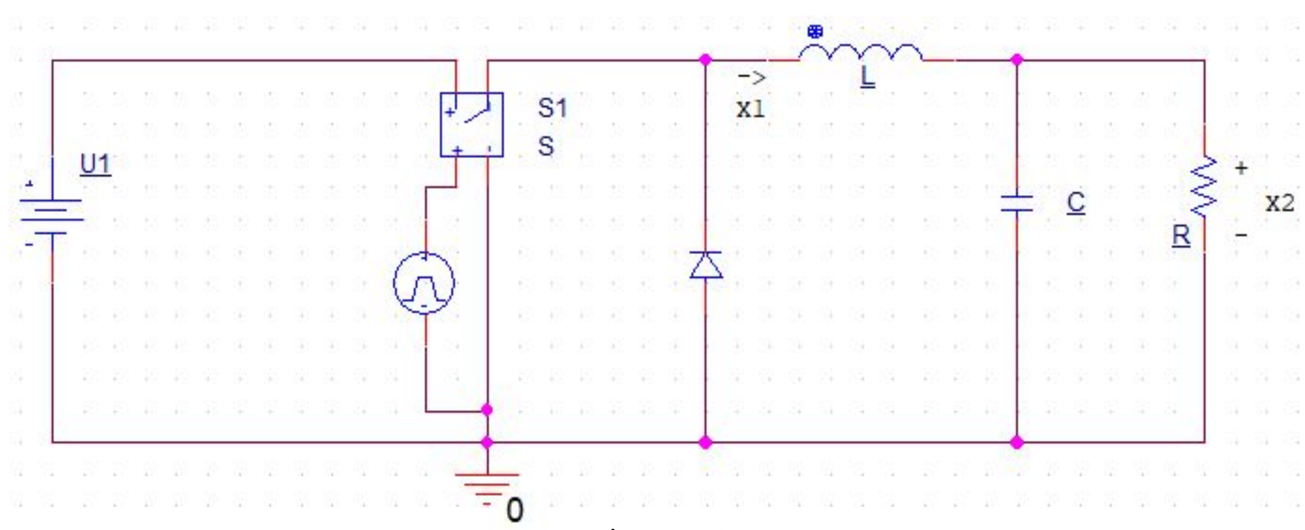

Figure 1, DC/DC Buck Converter

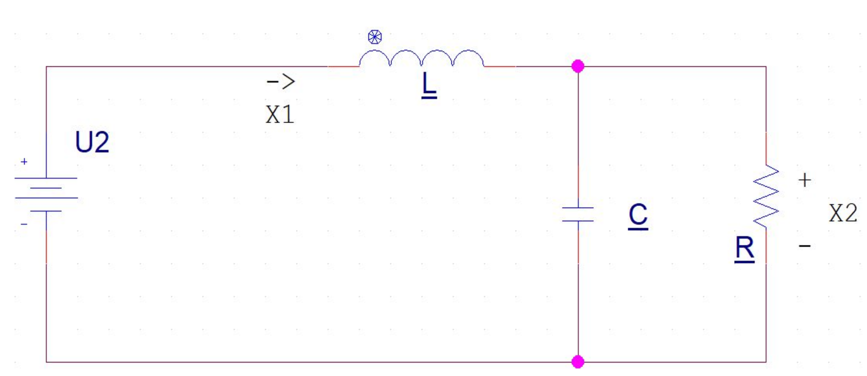

Figure 2, Open Switch Circuit

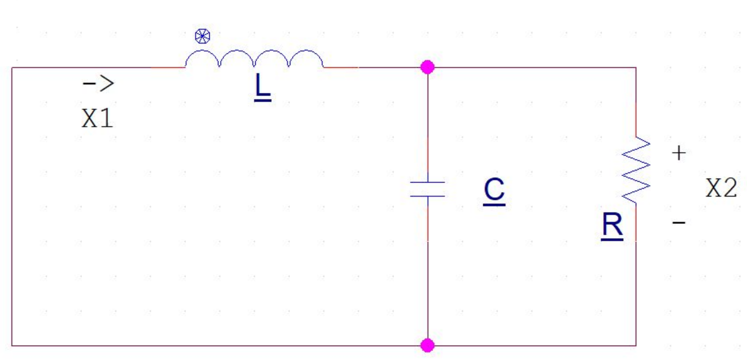

Figure 3, Closed Switch Circuit

- Basic Buck Converter output based on PSpice Model
- DC input signal of 10 [V] with output voltage of approximately 4 [V]

Control Theory Design for Buck Converter

$$\Delta d = -F * \begin{bmatrix} x_1 - x_1^* \\ x_2 - x_2^* \end{bmatrix}$$

$$A_1 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \quad B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$$

$$\Delta d = -\max\{D, 1-D\} * \frac{x_1 - x_1^*}{1 + (x_1 - x_1^*)^2}$$

$$A_2 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \quad B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\bar{A} = dA_1 + (1-d)A_2 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix}$$

$$\bar{B} = dB_1 + (1-d)B_2 = \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix}$$

$$\dot{X} = \bar{A}x + \bar{B}u_1$$

Linear Design of Step Down Switching Converter

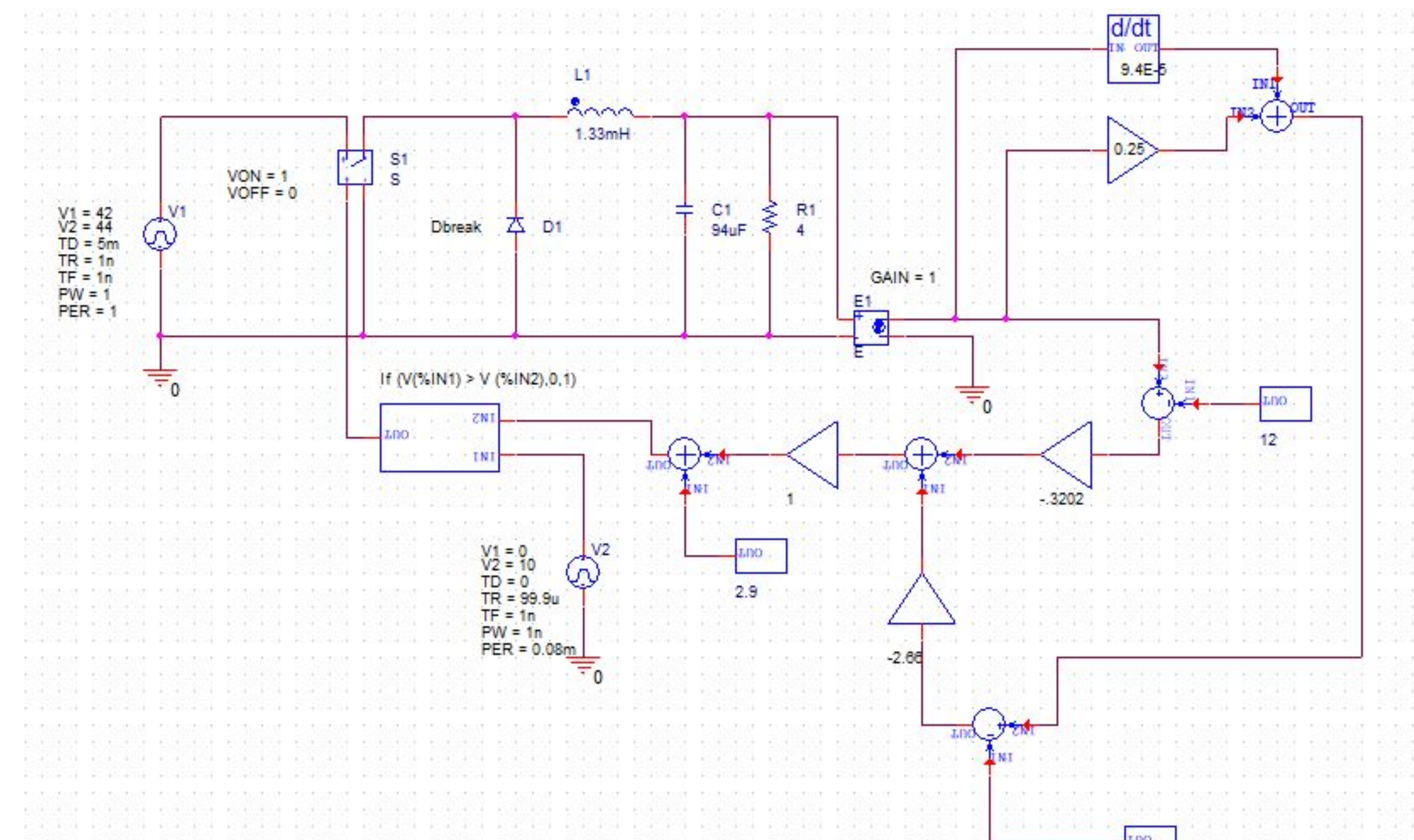
Figure 4, Linear Buck Converter

Experimental Results

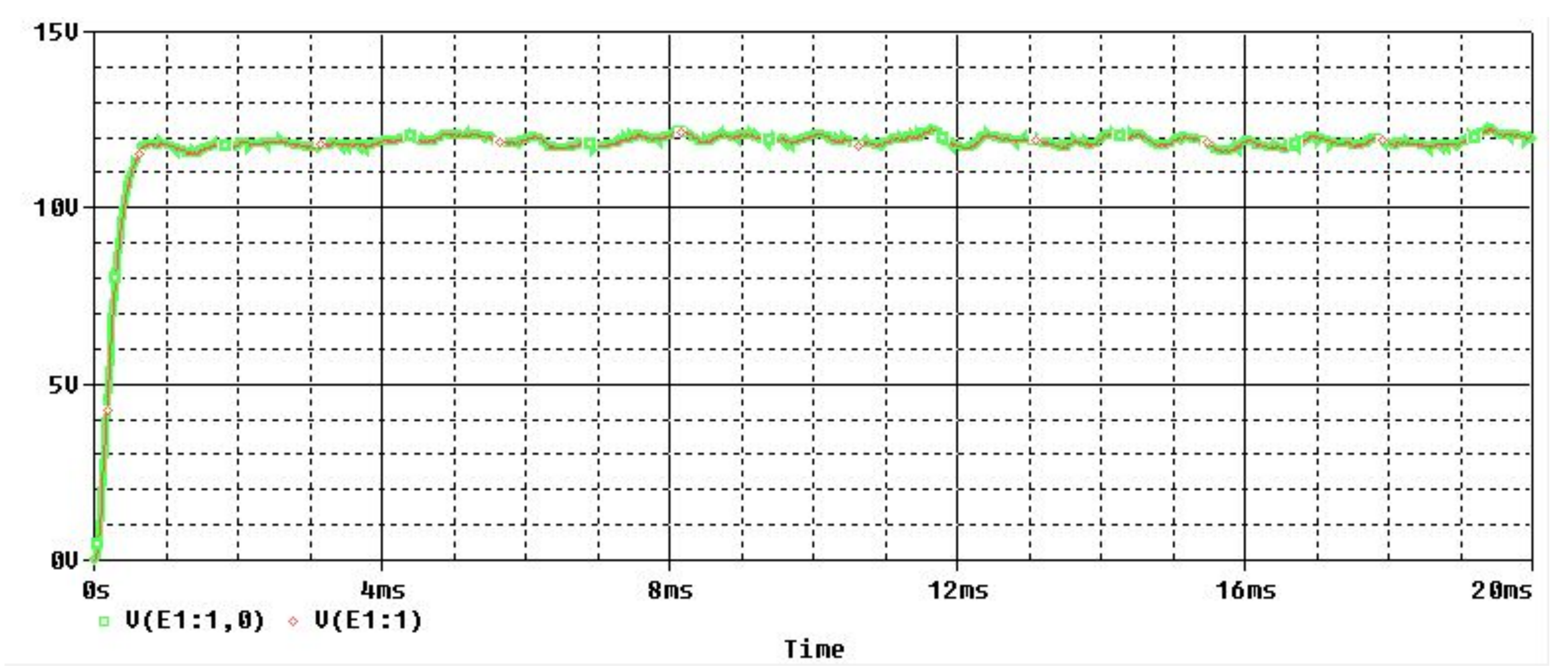

Figure 5, Linear Design Output

- Output of linear buck converter shown in Figure 4
- 42 [V] Input to ~12 [V] steady state output

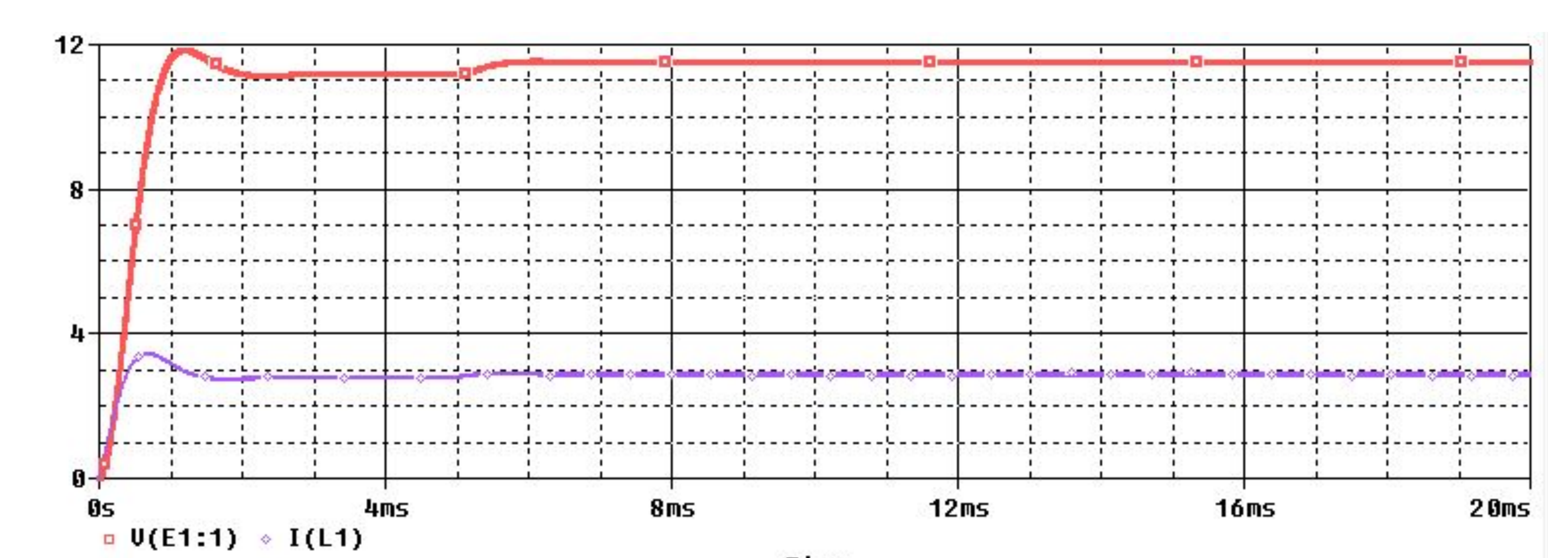

Figure 6, Nonlinear Design Output

- Output of nonlinear buck converter shown in Figure 7
- 42 [V] Input to ~12 [V] steady state output
- Steady state inductor current was obtained by using a smaller period for V2

Background

The growth of renewable energy sources, namely within the photovoltaic sector, has been growing at an impressive rate within the past decade and this growth can continue with the development of more efficient and cost effective methods for energy production. Our project aims to improve power efficiency in microgrids by introducing the advanced control strategy for the DC/DC converters used in the system. This helps prevent power loss through the stabilization of the desired output in the presence of disturbances. Better power efficiency makes implementing solar microgrids much more desirable than fossil fuel generator alternatives.

Project Objectives

- Study modeling of PWM based DC/DC converters
- Design linear state feedback controller based on the linearized average state space model
- Design nonlinear controller based on Lypunov's method to deal with ESRs
- Conduct simulations to validate the proposed new design

Nonlinear Control of Step Down Switching Converter

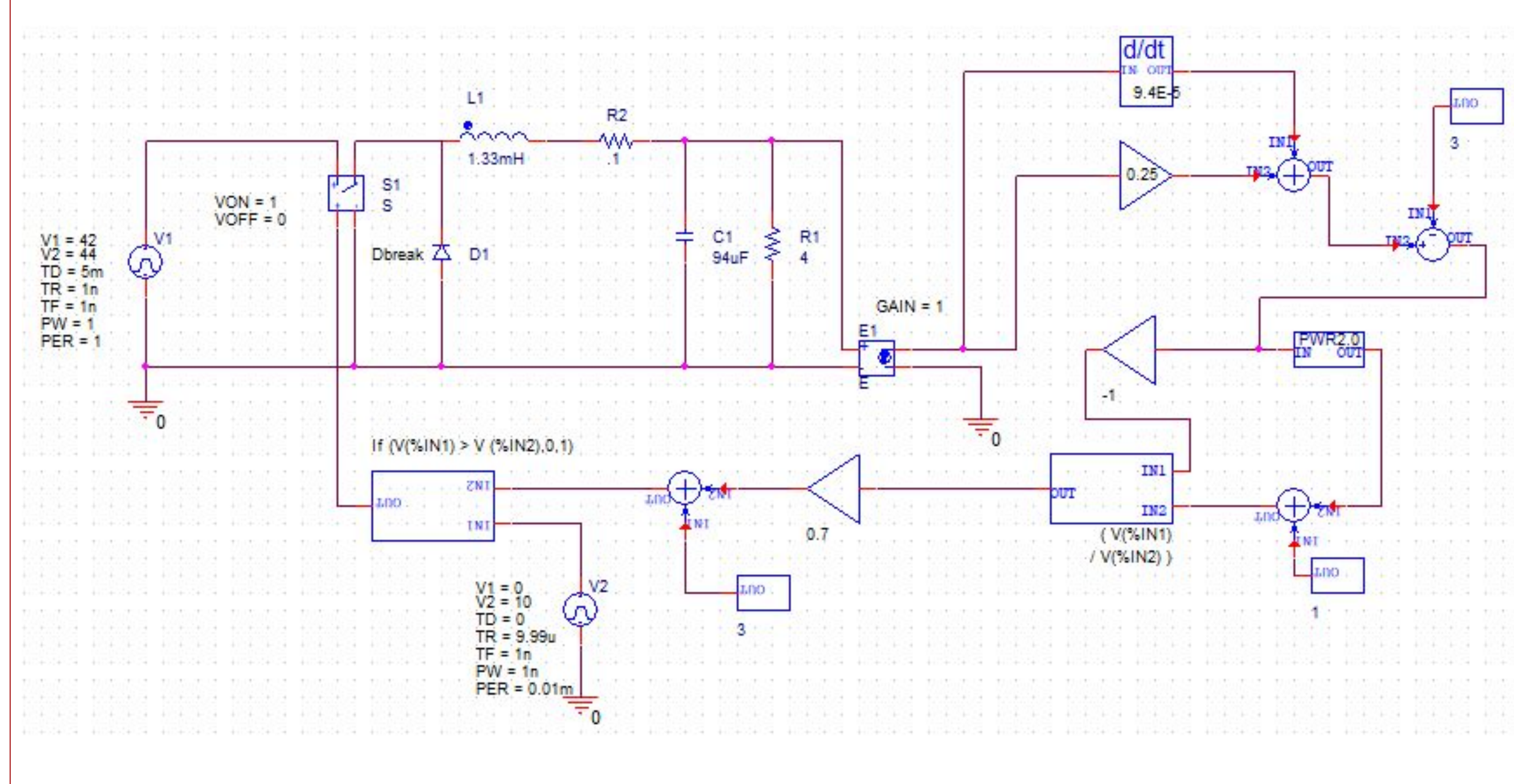
Figure 7, Nonlinear Buck Converter

Conclusion

Due to the environmental impact of finite fossil fuels on our atmosphere, it is imperative that we take the necessary steps towards sustainable energy sources such as solar power. This project thoroughly studied the control techniques and strategies for DC/DC converters, namely strategies for linear and nonlinear control of buck and boost converters. The simulation results which were obtained verify the effectiveness of the proposed converter design. Once implemented, our system will be able to improve power efficiency within microgrids due to it's precise variable input tracking.

Future Work

After creating and implementing an efficient control technique for the DC to DC converters used within the system, the next step is to fully integrate this converter into a microgrid with the assistance of an inverter, and this may be accomplished via the usage of a C2000 Piccolo microcontroller. Further experimentation can also be done with types of photovoltaic cells in order to obtain maximum efficiency of the system.

References

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[3] Texas Instruments, "Digitally controlled solar micro inverter design using C2000 Piccolo microcontroller," TIDU405B datasheet, Oct.2014 [Revised June 2017].