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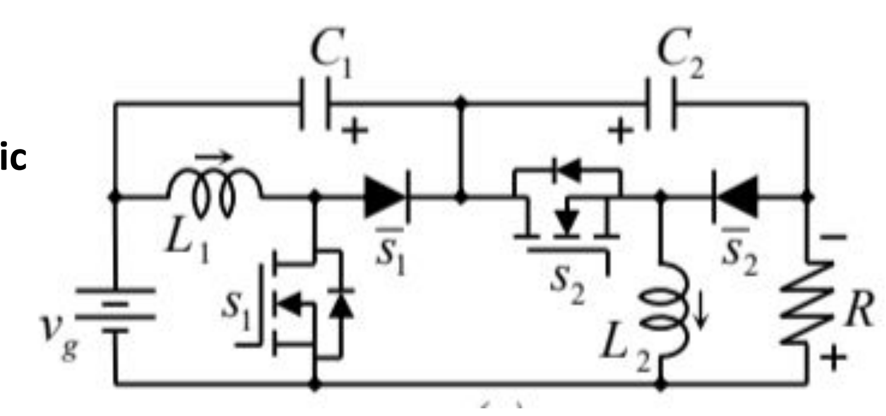
Development of Power Electronic Devices for Renewable Energy Integration

Abstract

The quadratic gain converter can amplify the input voltage by a factor of $D/(1-D)^2$ where D is the duty cycle of the circuit. Additionally, by properly choosing the right values of capacitors, inductors, and pulse width modulation, this converter can also reduce the negative effects caused by the voltage ripple. In this project, I built a quadratic gain converter to run tests on its functionality and to try a new controller for the converter.

Figure 1. Shown here is a schematic of the circuit for the converter.



Introduction

The electricity produced from coal plants, wind turbines, and solar panels is rarely at the necessary voltage and current that is practical for human use and electricity needs which is converters are used. Additionally, these energy sources are not always constant because the amount of available windpower and sunlight changes throughout the day. The electricity being drawn from the load is also variable because our electricity needs are never constant. As a result, there are two variables in this system: the source and the load, also known as the input and the output.

Thus, it is necessary to design converters and controllers that can account for these variables. Converters use capacitors and inductors to store energy, but problems such as voltage ripple arise wasting energy and generating noise. Electrical engineers and physicists have studied many different types of converters that use passive and active components in clever ways to properly handle changing variables and eliminate undesirable effects. One such converter is the quadratic gain converter which uses two capacitors and two inductors to amplify the input voltage by a factor of $D/(1-D)^2$, where D is the duty cycle of the circuit.

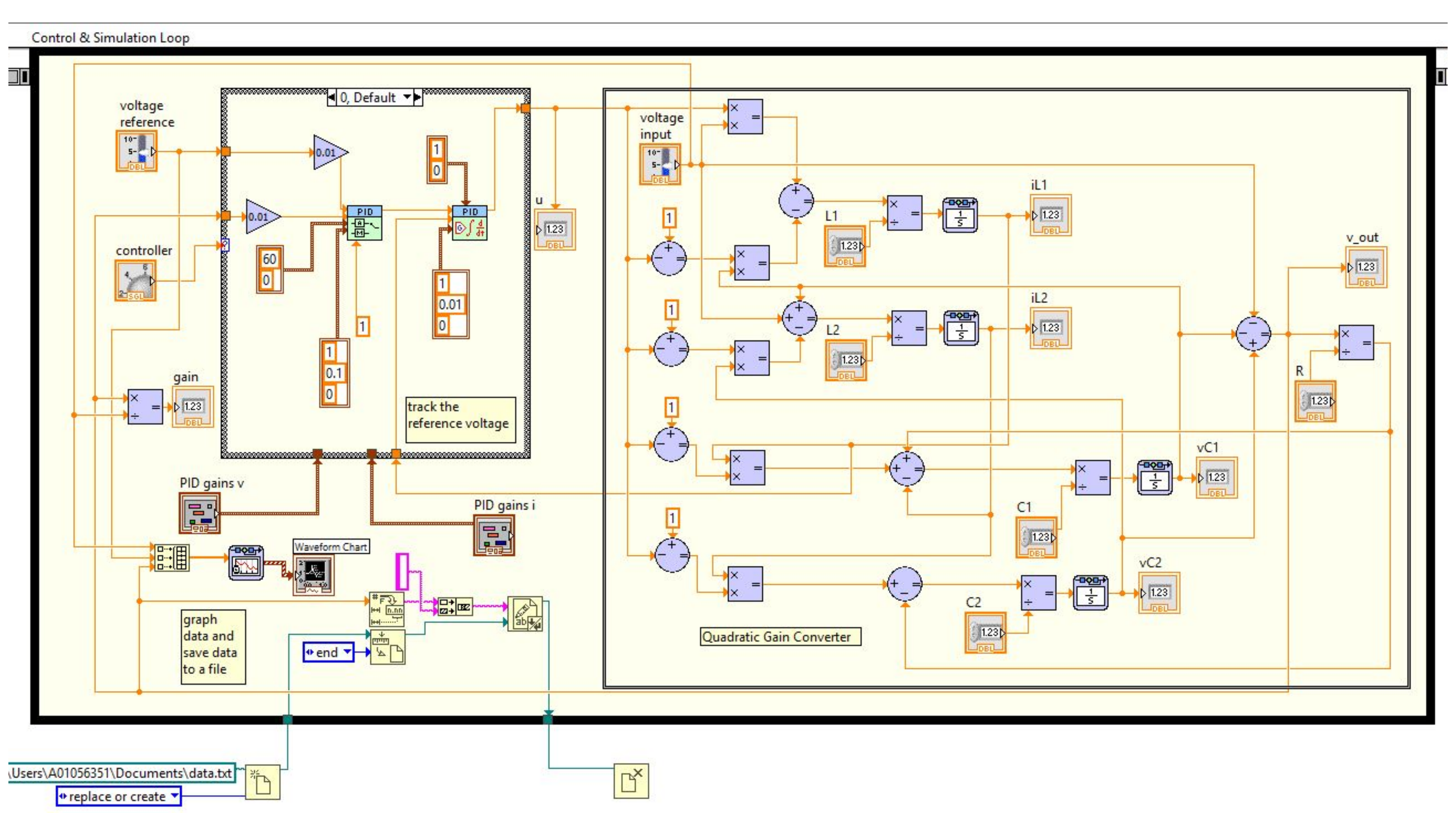


Figure 2. Shown here is the simulation of the circuit on LabVIEW with one of the many controllers that could be used to control the output voltage of the converter.

Results

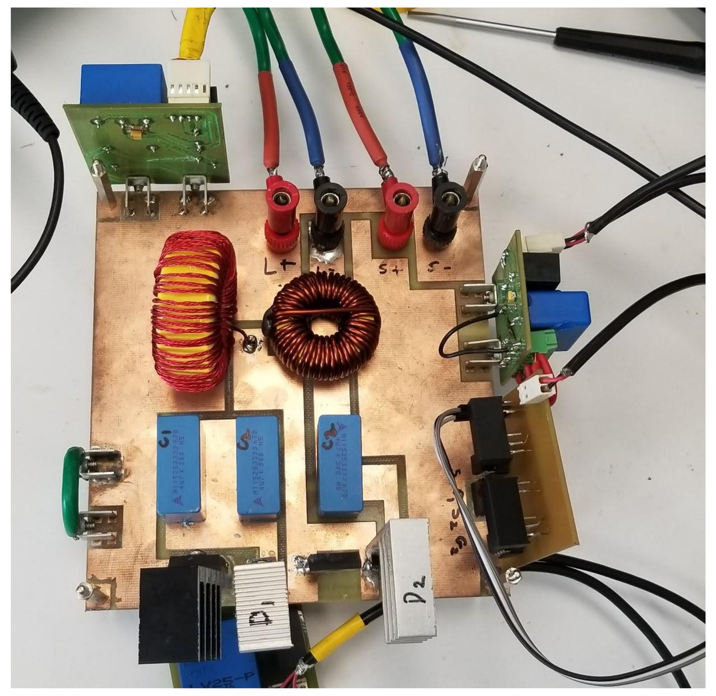


Figure 3. Shown here is the completed circuit of the converter.

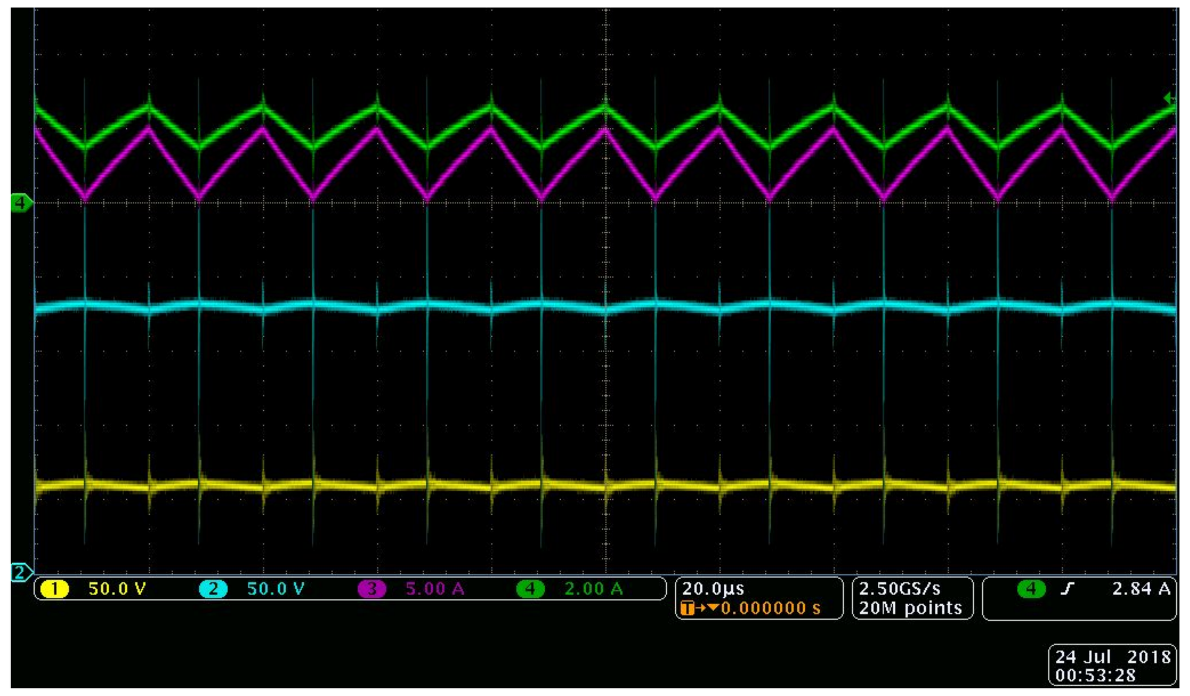


Figure 4. Shown here on the oscilloscope is the voltage through each capacitor and the current through both inductors.

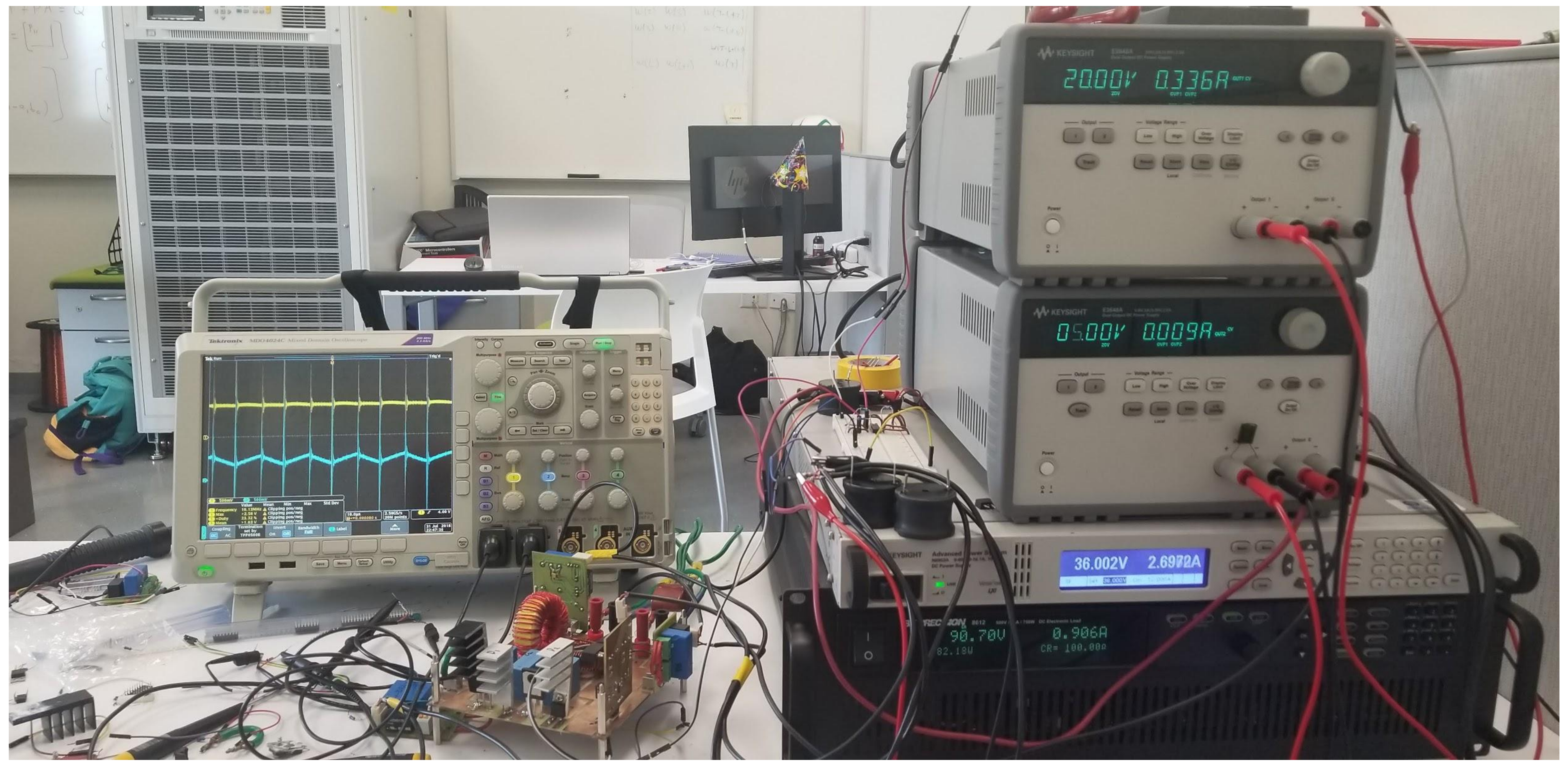


Figure 5. Shown here is the completed converter connected to a variable power source and to a variable load. The converter is also connected to a variable PWM signal and to the CompactRIO which reads signals. The oscilloscope shows the output current and voltage of the converter which both have ripples due to the duty cycle of the circuit.

Output Voltage and Power of Load at Different Duty Cycles

duty cycle	V source (V)	I source (A)	V load (V)	I load (A)	P source (W)	P load (W)	efficiency	voltage gain
0.56	36.00	2.89	94.57	0.95	104.04	89.37	0.86	2.63
0.58	36.00	3.14	98.21	0.98	113.04	96.34	0.85	2.73
0.62	36.00	3.57	104.50	1.04	128.52	108.68	0.85	2.90

Table 1. The data of the output voltage and power is close to the expected values based on the steady state relationship of the converter. The data was taken at various duty cycles with the input at a constant voltage of 36V.

Materials and Methods

- I first used LabVIEW to simulate the circuit so that I could create a PID controller for the converter.
- Next, I designed circuits for the converter, driver, and sensors using KiCad.
- Once the PCBs were printed, I assembled, searched for, and soldered the necessary components which included capacitors, inductors, MOSFETs, diodes, and heat sinks.
- Finally, I put together a breadboard circuit to generate a variable PWM signal to control the output of the converter using a TL494 integrated circuit.

Conclusions

The completed circuit of the quadratic gain converter worked as expected, and the measured gains matched almost exactly the expected gains of the converter, $D/(1-D)^2$. The minor differences in the data were most likely due to small energy losses from some of the components of the circuit. We were able to test the circuit with various values of capacitors, inductors, and duty cycles which will be helpful to figure out how to reduce the voltage ripple.

In the future, this model of the converter can also be used to test various controllers. The development of novel controllers with innovative strategies has the potential to create new ways to convert energy with less energy loss and better grid management. I was not able to run tests with controllers using LabVIEW because the CompactRIO can't record samples at a high enough frequency, but more work should be done to find a device that fits the required parameters.

References

P. M. Garcia-Vite, J. E. Valdez-Resendiz, J. C. Mayo-Maldonado, J. C. Rosas-Caro, M. del Rosario Rivera-Espinosa and A. Valderrabano-Gonzalez, "Quadratic gain converter with output voltage ripple mitigation," *2017 IEEE Energy Conversion Congress and Exposition (ECCE)*, Cincinnati, OH, 2017, pp. 2253-2259.

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