Uninterruptible Power Supply (UPS)

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Overview

Challenge: The grid can go down leaving unprotected devices without power.

Objective: Make a backup power supply with a 30W load limit with minimal down time.

How: This project is an on-line configuration UPS which supplies the load power by taking the grid voltage, converting it to DC, then back up to AC to feed the load. At the same time charging a battery for when the grid goes down.

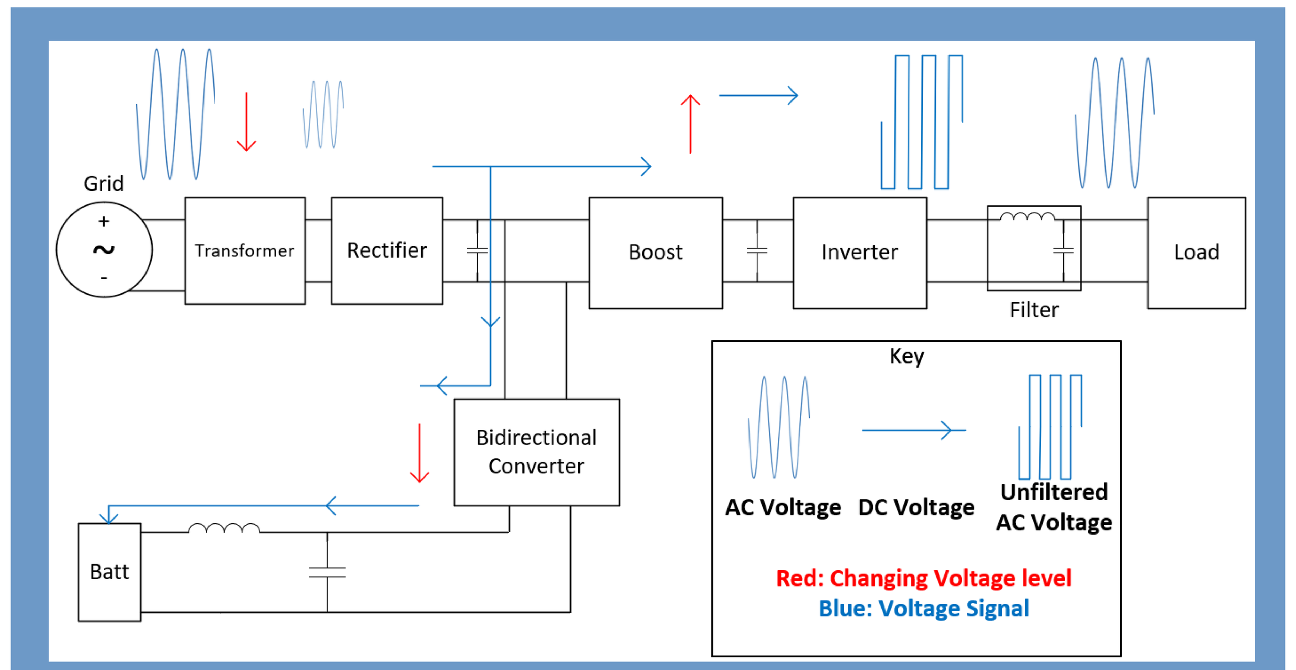

Figure 1: System during normal grid operation

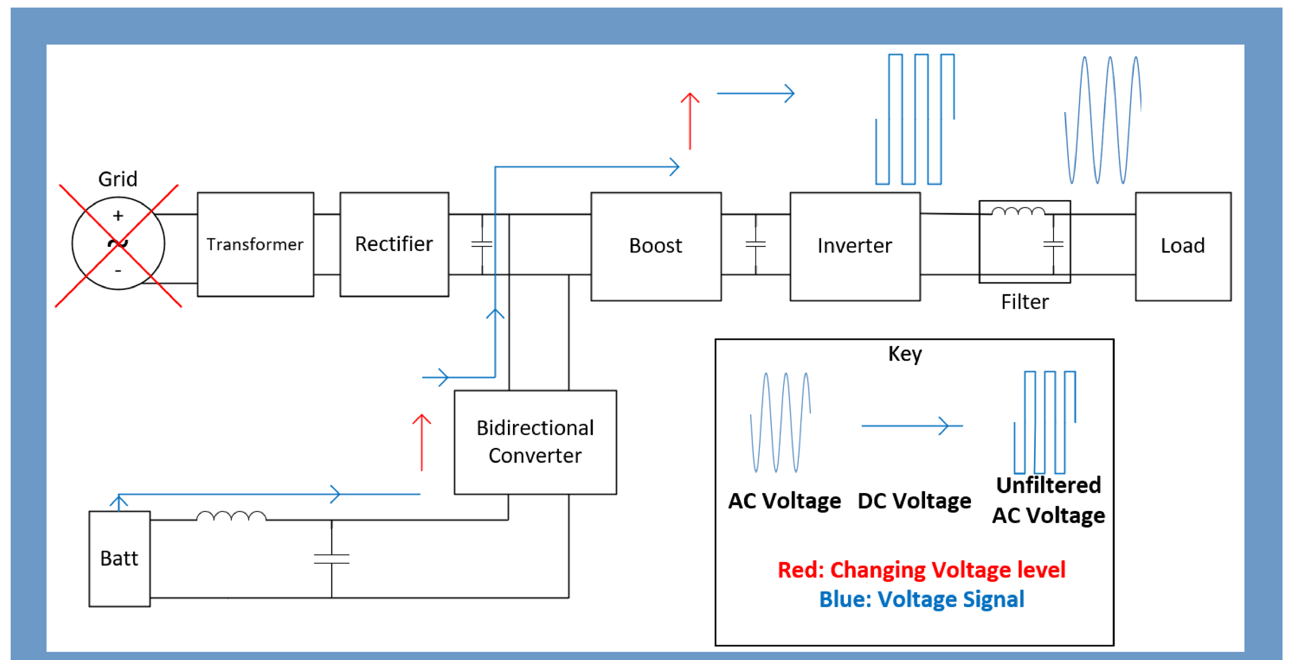

Figure 2: System during grid outage

Rectifier: A transformer steps down the grid voltage then the rectifier converts the AC voltage to DC

Bidirectional Converter: During normal grid operation the converter operates as a buck converter charging the battery. When the grid goes down the converter boosts allowing the battery to supply the load rather than the grid.

Inverter: The DC voltage is boosted to grid level for the inverter to convert it to a 170V 60Hz AC square wave which is filtered into a 120V RMS 60Hz sine wave for the load.

Microcontroller

Arduino Leonardo:

- 7 PWM outputs to control system switching
- 5V input maximum

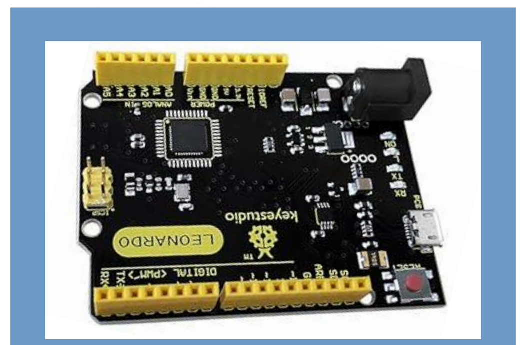

Figure 3: Microcontroller

Methods

Boost Converters:

Capacitor (C) and inductor (L) must be chosen based on the critical equations:

$$L_{Critical} = \frac{(1-D)\times D\times R_L}{2\times F_{sw}}$$

$$C_{Critical} = \frac{D}{2\times F_{sw}\times R_L}$$

D: Duty cycle, $D = 1 - \frac{V_{out}}{V_{in}}$

F_{sw}: Switching frequency

R_L: Load resistance

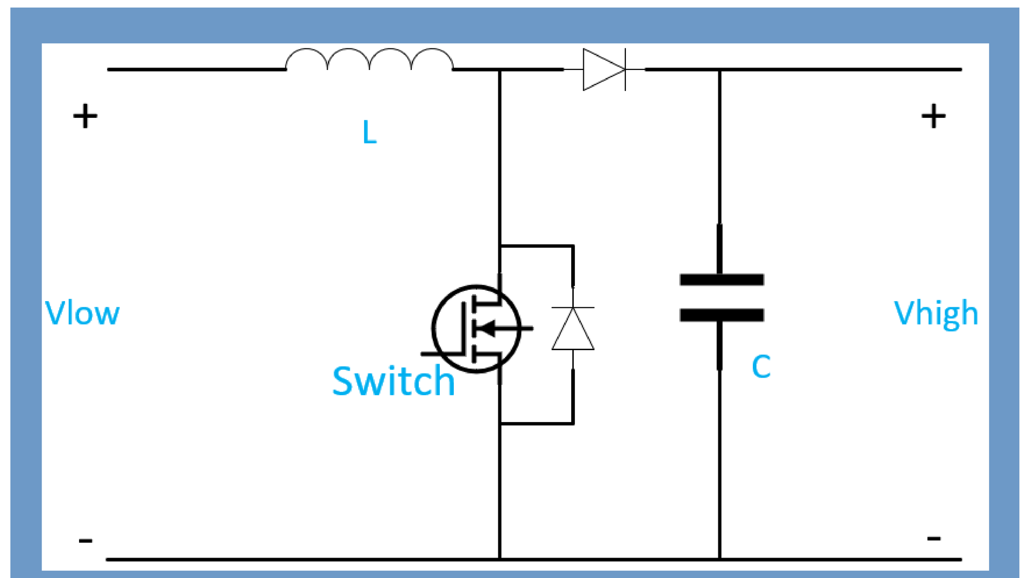

Figure 4: Typical Boost Converter

SIMULINK Initial Testing:

- Initially the system was implemented on SIMULINK to test the viability of the proposed control schemes.

Code Optimization:

- A real time operating system (RTOS) was used to minimize delay between tasks.

Outage Detection:

- Runs as a background task
- When low voltage is measured for 1.2ms an outage is detected
- System reacts to an outage within 16ms of initial detection

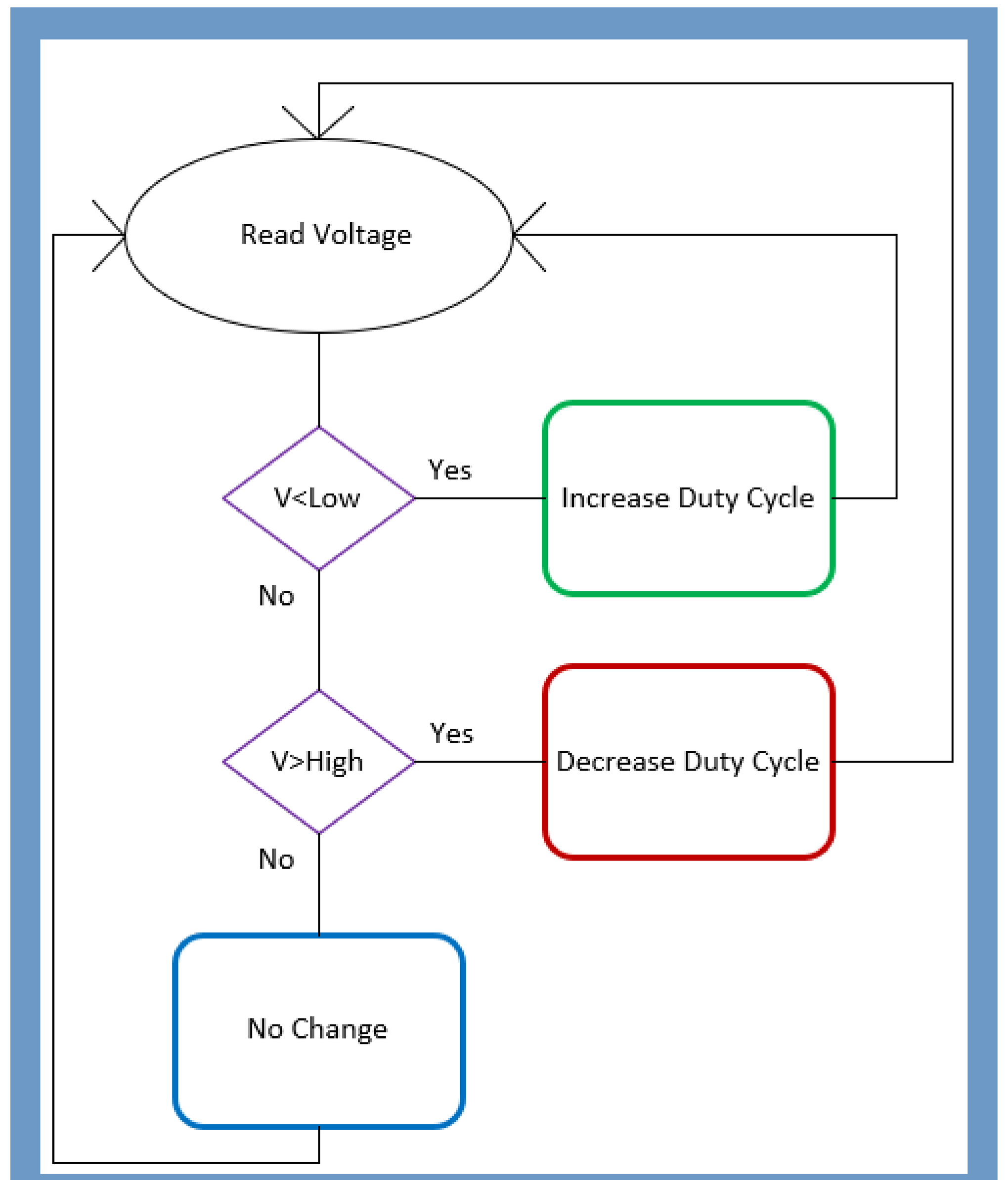

Figure 7: Duty Cycle Decision Tree

Voltage Control:

- Used to determine the output voltage for both the boost converter and boost operation of the bidirectional converter
- Output voltage is proportional to the duty cycle
- Decrease duty cycle as output voltage reaches target voltage

Results

Cascaded Boost Converters

Blue: Targeted Voltage 170V

- Observed Voltage: 172V
- Efficiency: 90%
- Difference in target and observed voltage from hysteresis control

Pink: Targeted Voltage 30V

- Observed Voltage 30.25V
- Efficiency: 90%

Efficiency decreases as load increases for both boost converters down to about 65% at max load.

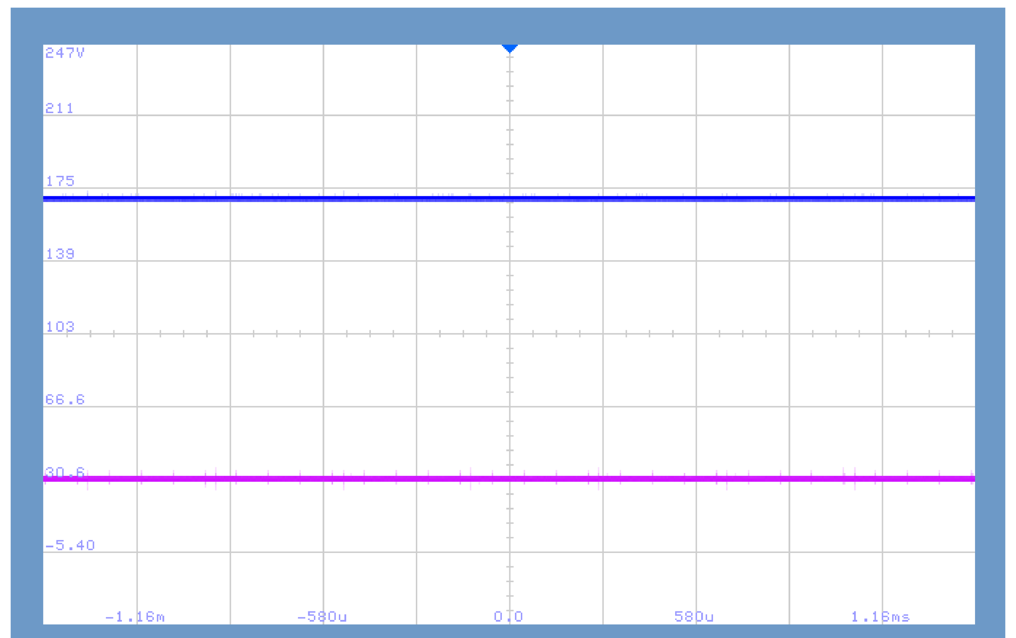

Figure 5: Cascaded Boost Converters Output

Inverter:

AC Square Wave: Targeted voltage 30V, 60Hz

- Observed voltage: 30V, 62Hz
- The black line is 0V for reference
- Efficiency: 95%
- There is a small spike of voltage at the start of each cycle

Grid outage delay: Targeted 16ms

- Observed: 5-18ms

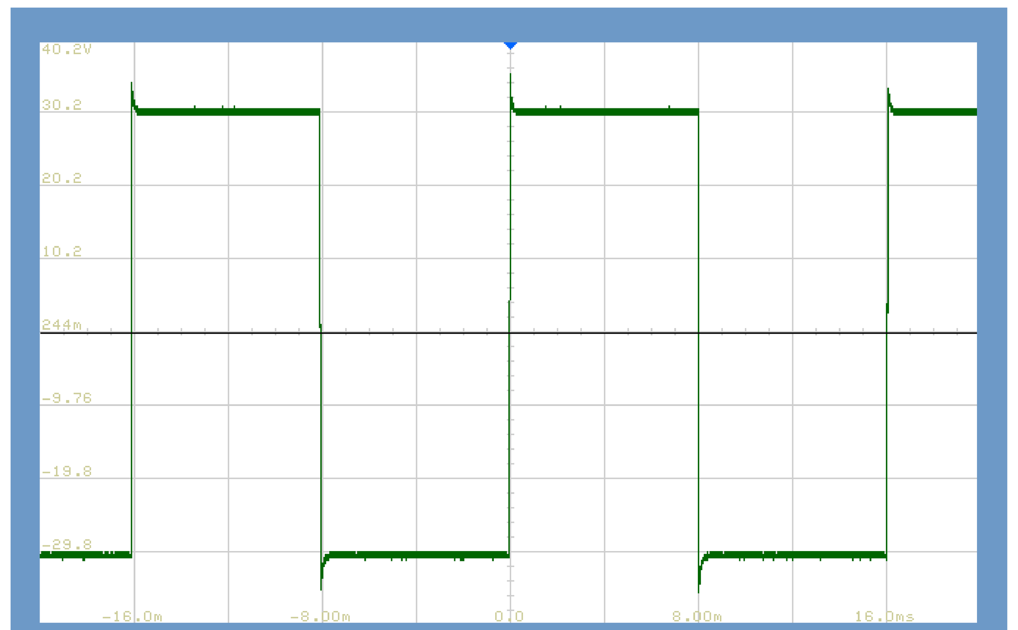

Figure 6: Inverter Output

Future Work

- Implement a battery charger
- Introduce advanced control schemes
- Improve outage detection response time
- Improve the efficiency of the system at max load
- Introduce SPWM and filtering to the inverter system to output a sinusoidal voltage
- Combine inverter control program with voltage control on one microcontroller

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