An Intelligent, Grid Connected, PV Charging Station for Plug-in Electric Vehicles

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Outline

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  - Block diagrams of system
- Hardware Topologies
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- Control Strategies
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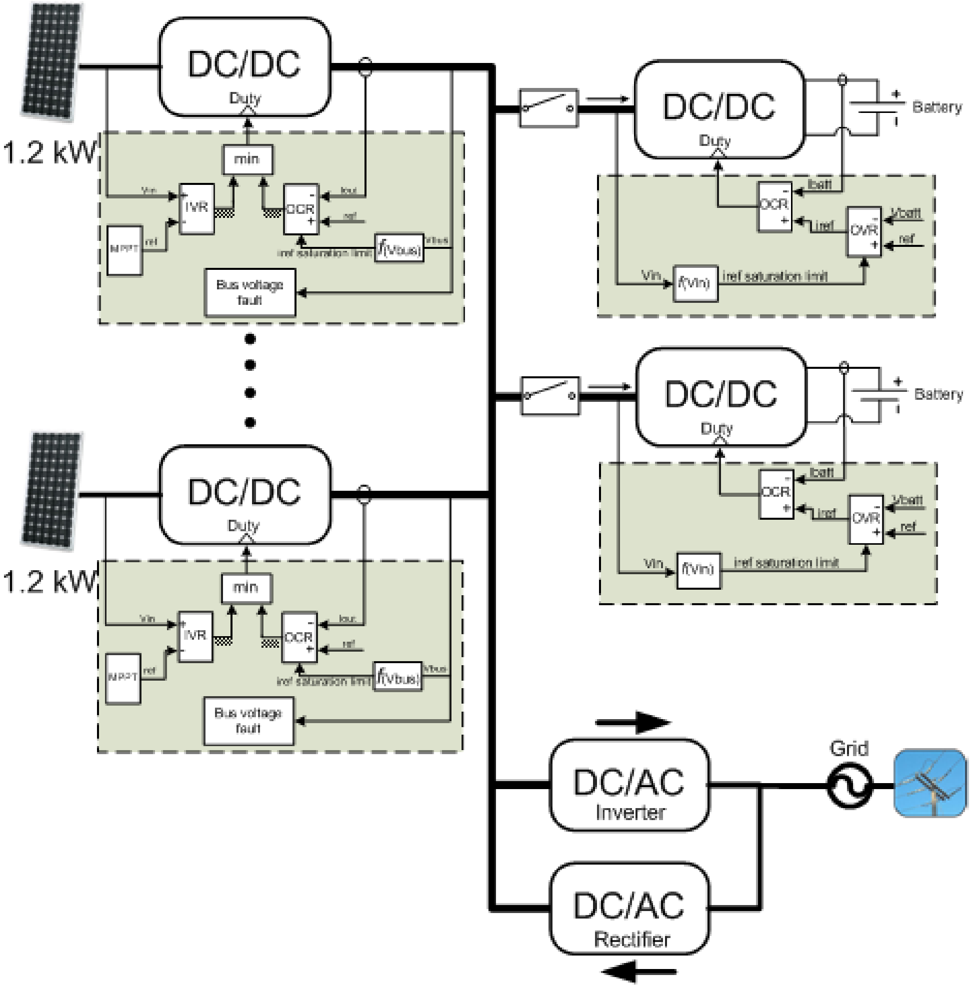
Introduction

- Current technology exists for charging electric vehicles (EV's) from photo voltaics (PV)
- This technology requires many conversion stages yielding lower power conversion efficiency
  - PV is connected to grid using MPPT enabled grid-tie inverters
  - EV is charged from the grid using an AC/DC converter
- Providing a direct DC/DC conversion process increases efficiency of system

Introduction

- Goals
  - Preserve modularity of existing PV->Grid->EV technology
  - Improve overall efficiency of charging EV from solar power
  - Provide safety for user when charging car batteries with proper fault protection

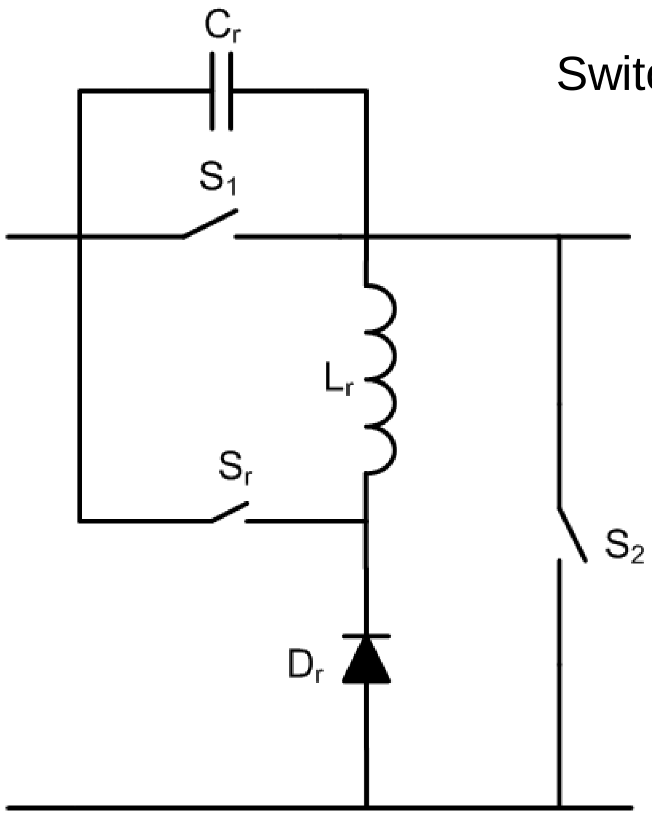
Introduction



Hardware Topology

- Zero-Voltage-Transition (ZVT) Buck Converter with synchronous switching
- Solar Specifications;
  - Vin: 300VDC – 450VDC
  - Vout: 200VDC – 270VDC
  - Iout: Up to 6 A
  - $Power_{max}$ = 1.2 kW
- Charger Specifications
  - Vin: 200VDC – 270VDC
  - Vout: 24,48 or 72VDC (based on battery)
  - Iout: Up to 56 A
  - $Power_{max}$ = 4 kW

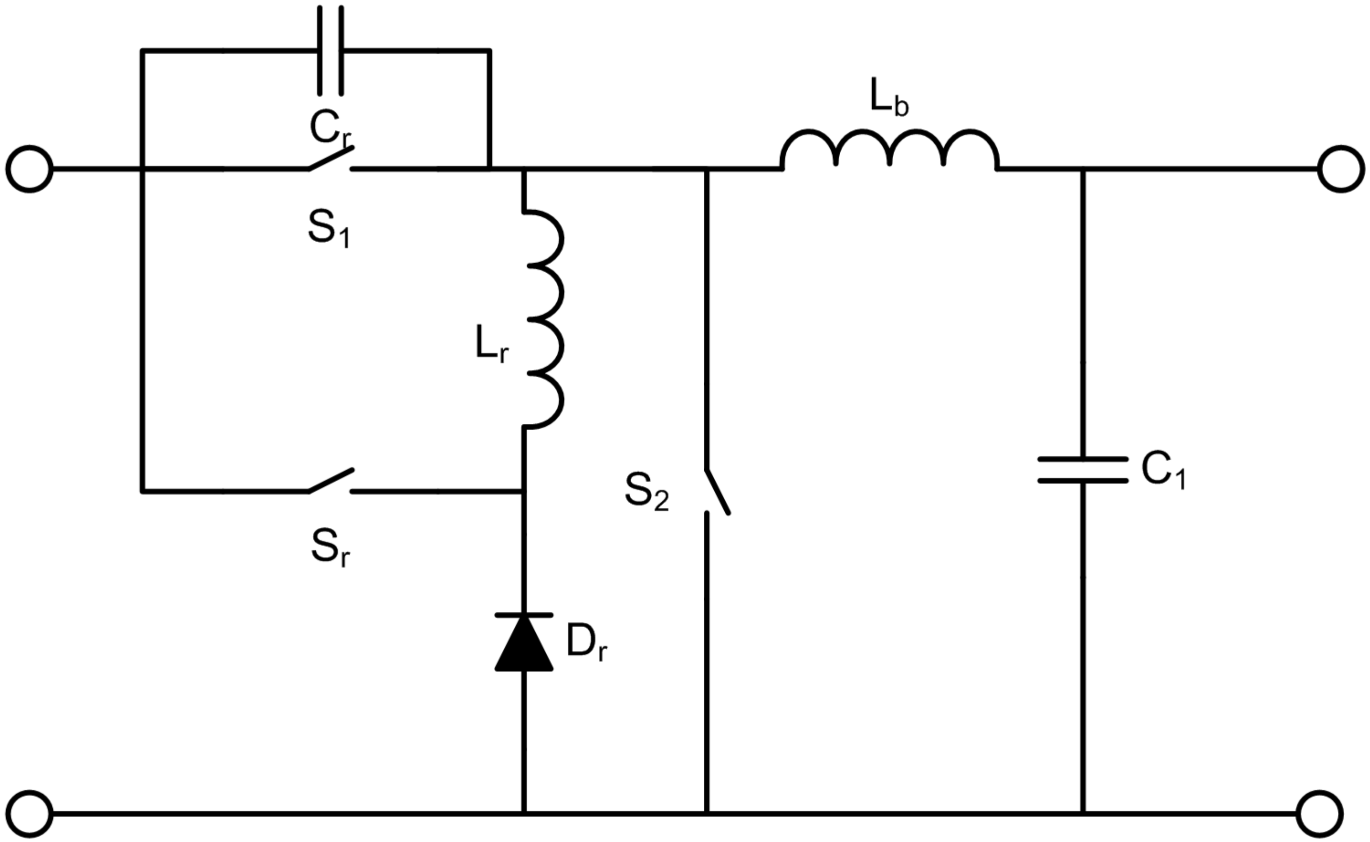
Hardware Topology



Switching Cell for the Buck Converters

Lr and Cr are used so that a resonance occurs between them. The main switch, S1, is turned on after Cr has been discharged to zero volts during the resonance stage

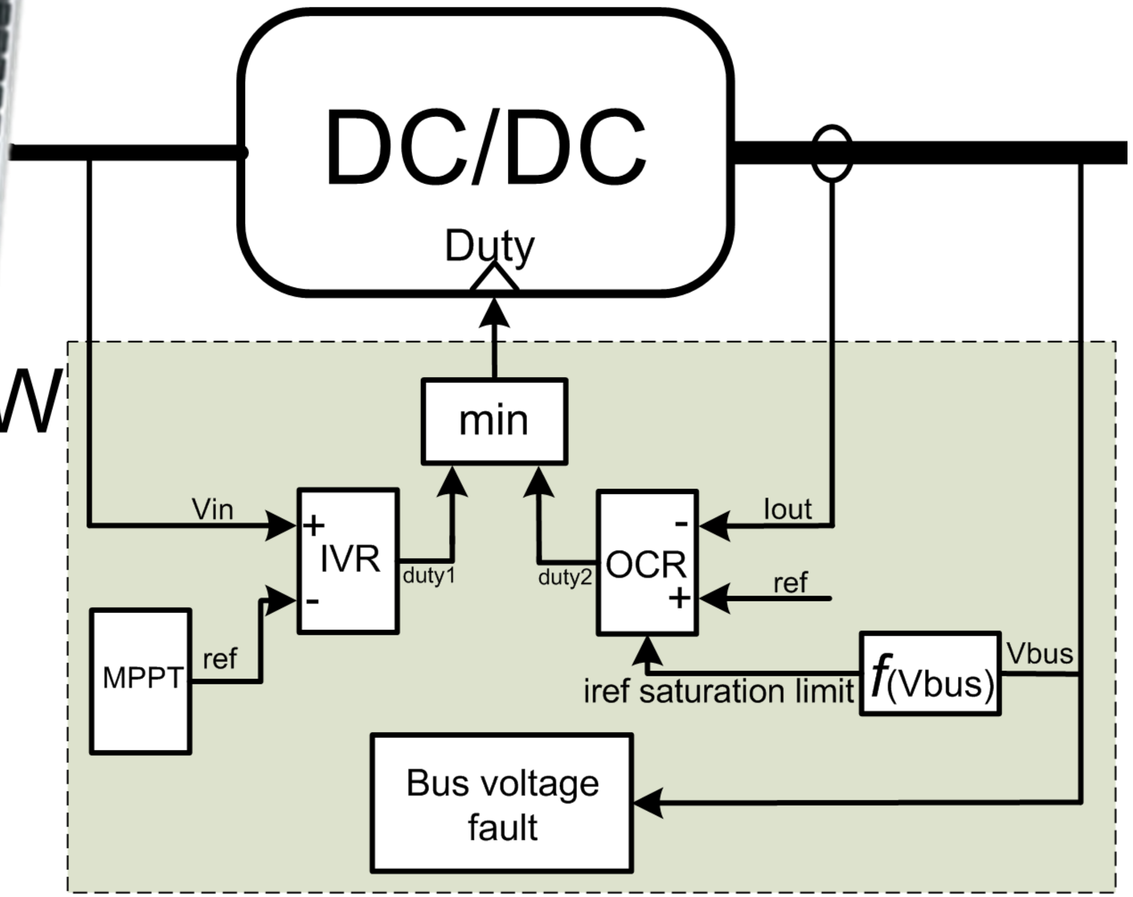
Hardware Topology



Control Strategy

- Solar Converter

1.2 kW



Control Strategy

- Solar Converter
  - Maximum Power Point Tracking (MPPT)
    - Used in wind and solar applications to optimize the loading on the source so that maximum power is transferred to the load
    - MPPT is always used on the solar converters as long as the bus voltage is not too high
    - MPPT is disabled whenever the bus voltage comes up a safe threshold

Control Strategy

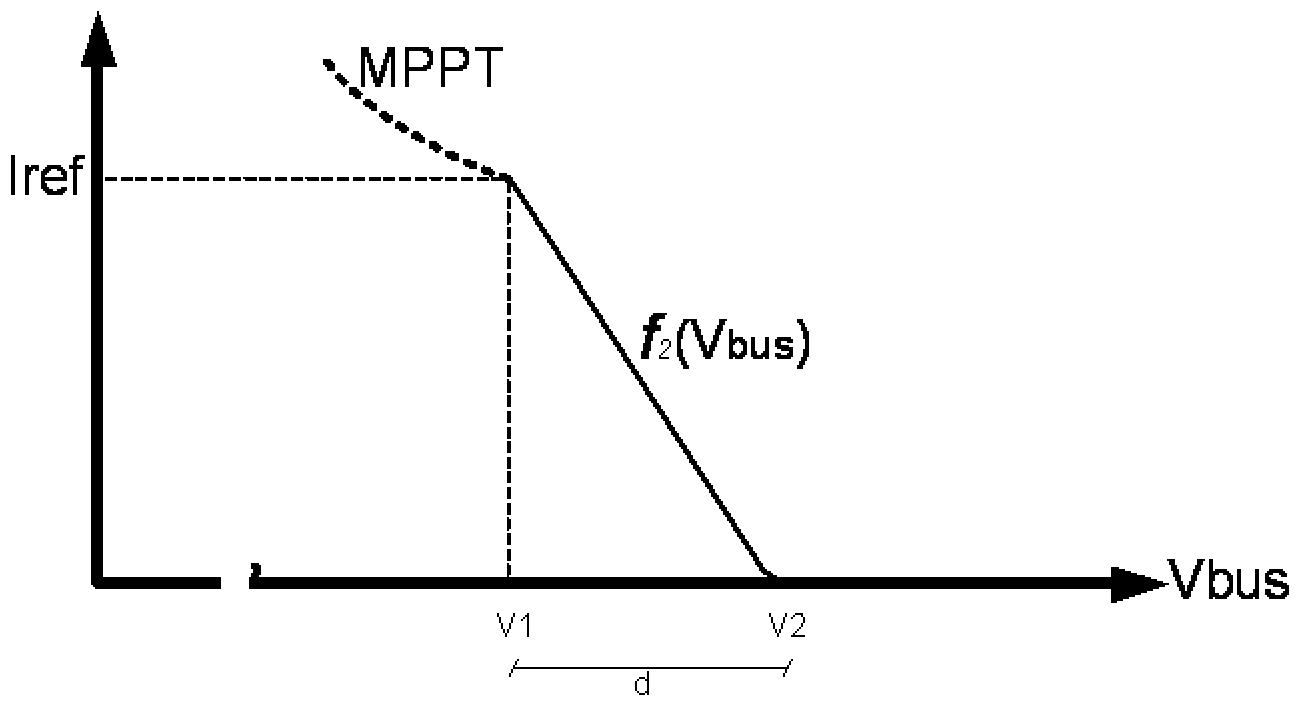
- Solar Converter
  - Voltage and Current Regulation
    - MPPT controls the reference for the IVR
    - IVR competes with OCR
    - OCR is limited by the droop function

Control Strategy

- Solar Converter
  - Droop Behavior
    - The droop behavior exists to preserve the modularity of the charging station
    - It will begin to limit the output of OCR if the bus voltage becomes too high
    - Bus voltage will rise if not enough loading is present on the bus and the solar is still charging the bus

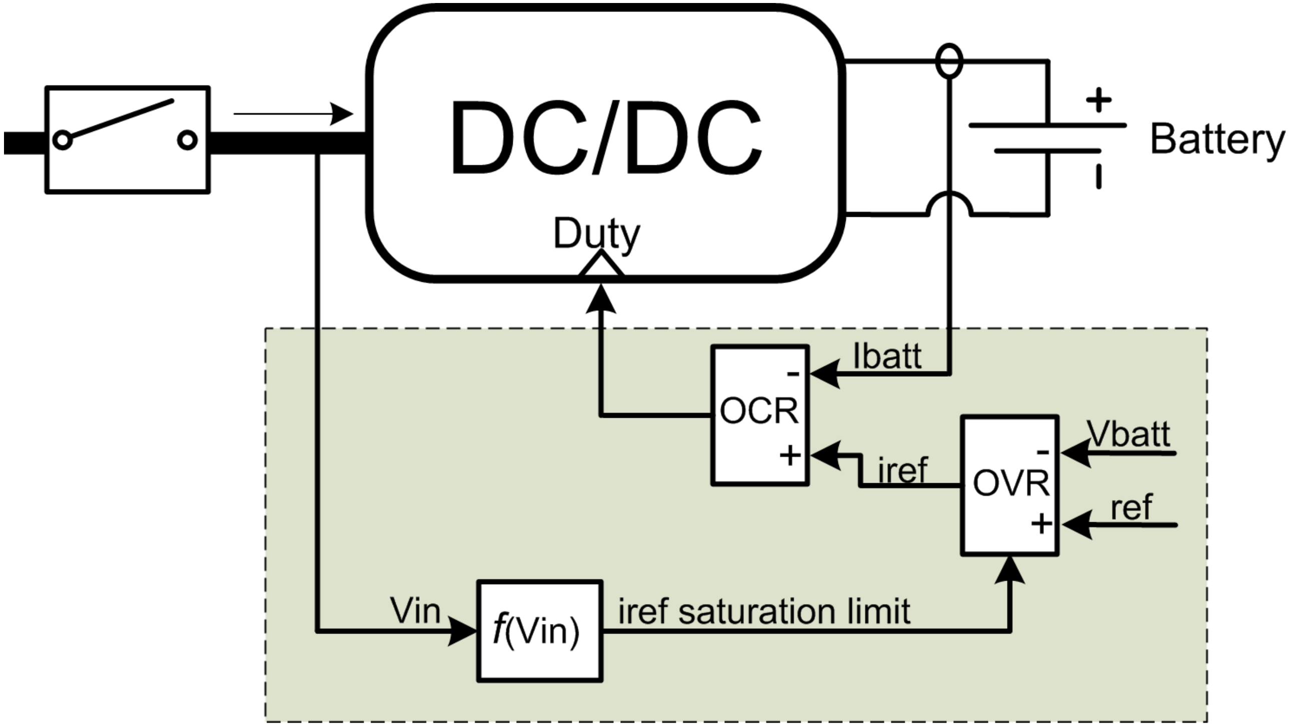
Control Strategy

- Solar Converter
  - Droop Behavior



Control Strategy

- Battery Charger



Control Strategy

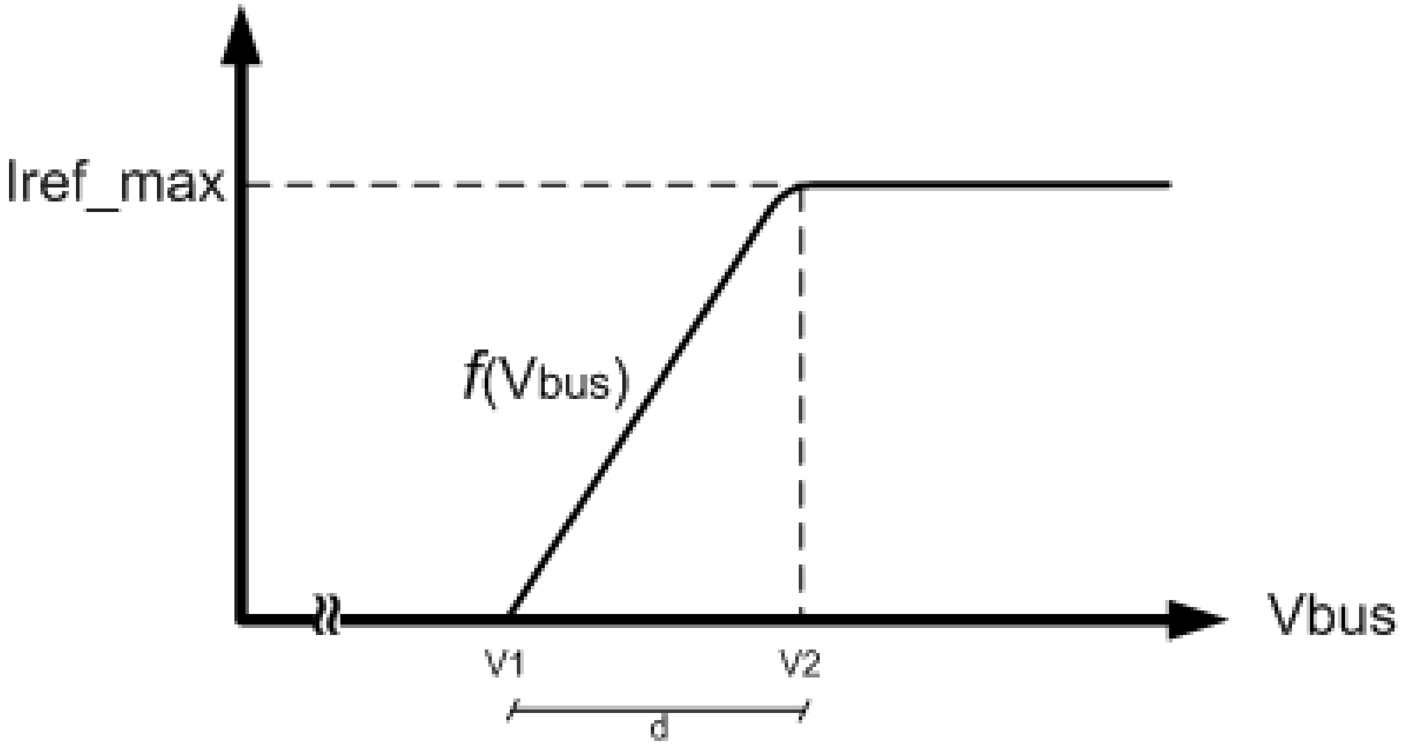
- Battery Charger
  - Voltage and Current Regulation
    - The outer control loop, OVR, controls the inner loop, OCR
    - A droop behavior exists and limits the OVR controller

Control Strategy

- Battery Charger
  - Droop behavior
    - As mentioned, the droop behavior limits the OVR controller
    - As the bus voltage falls due to excessive loading and not enough energy from the source(s), the OVR loop will be limited to allow the bus voltage to rise

Control Strategy

- Battery Charger
  - Droop behavior



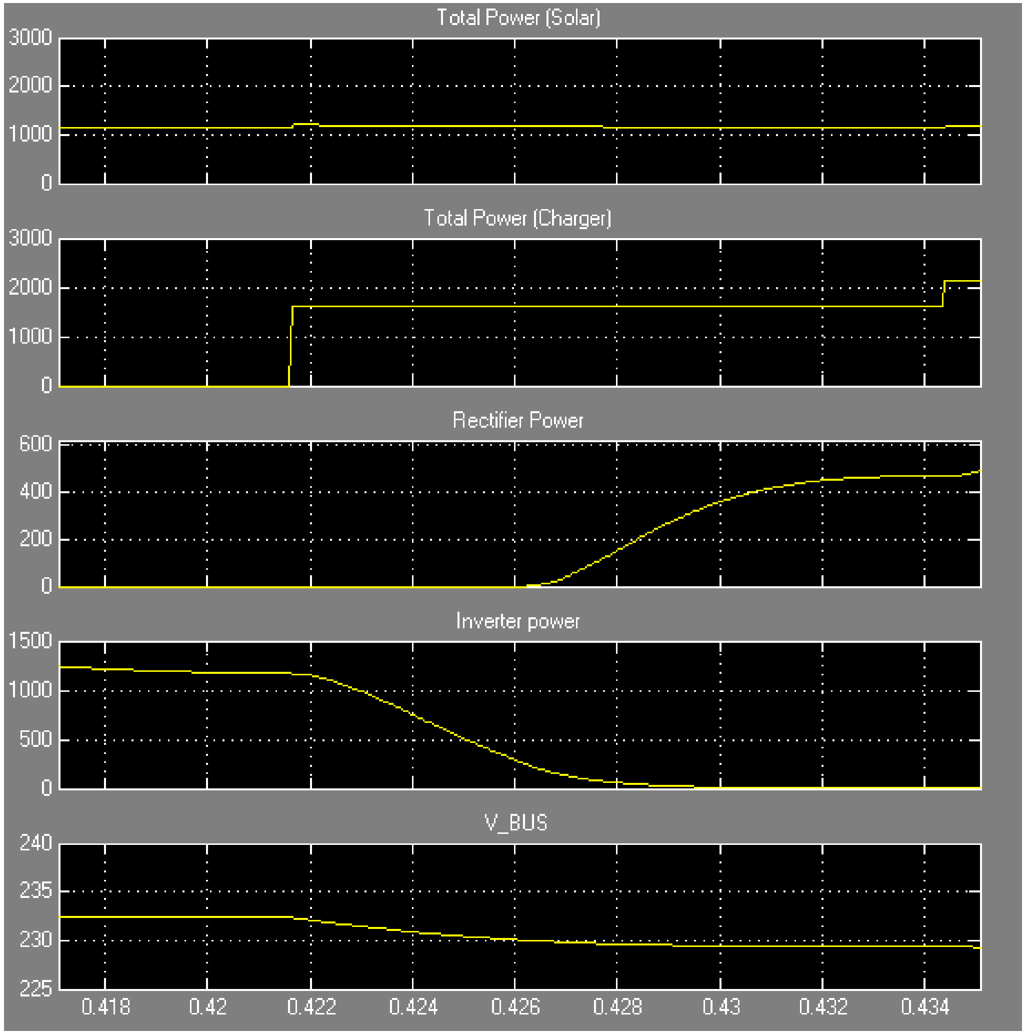
Control Strategy

- Droop Behavior
  - If all of the sources have the same droop voltage ranges, the sources will equally limit power delivered to the bus if the bus voltage rises
  - If all of the loads have the same droop voltage ranges, the loads will equally limit power delivered to the load if the bus voltage falls

Control Strategy

- Droop Behavior
  - The droop is used to keep the energy balance between the source(s) and the load(s) attached to the bus
  - There is no bus voltage regulation controller
  - Bus voltage will operate in between a certain range depending on the droop voltages that are selected

Simulation Results



Prototyping and Results

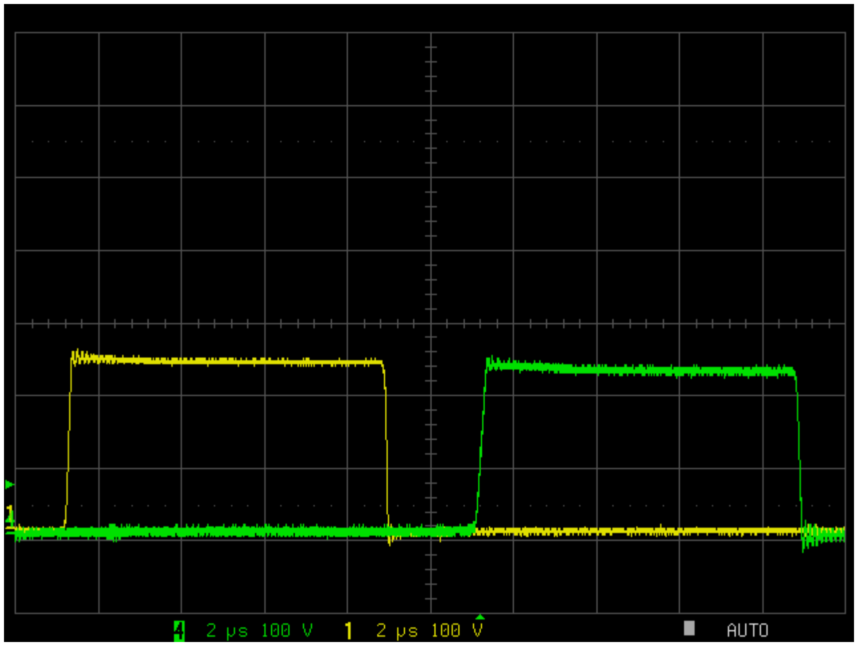
(Above) Controller, MOSFET driving and sensing circuit board

(Right) Battery Charger board with board above plugged in. Power stage is two interleaved channels for current handling capability

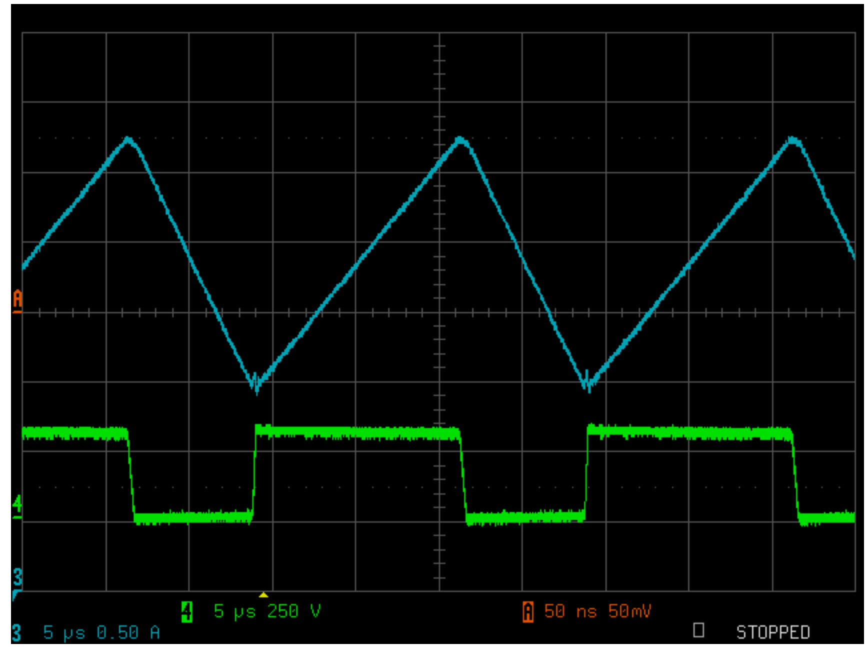
Prototyping and Results

Constructed charging station on UCF campus.
9.6kW in solar power

Prototyping and Results



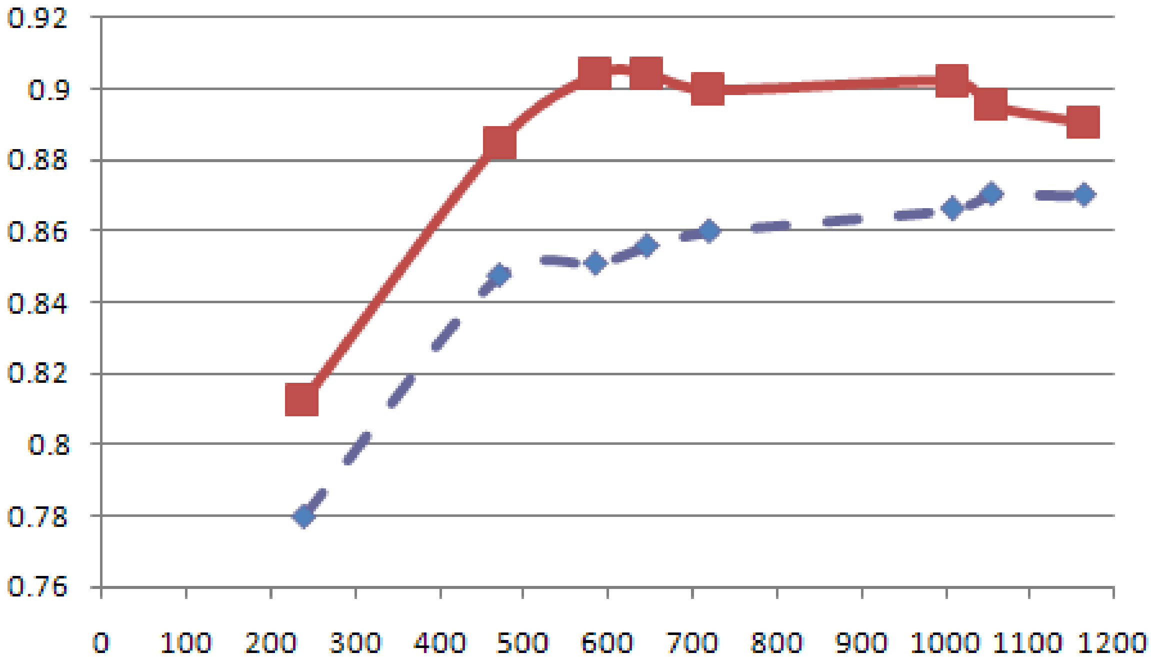
Switch nodes of both stages of battery charger with interleaving



Switch node (Green) and inductor current (Blue) of single stage of solar converter

Prototyping and Results

- Charger and Solar Efficiency > 95% above ¼ of rated power



Cascaded converters (Solar -> Charger) Efficiency Results

Prototyping and Results

- The droop characteristic is still in the testing phase
- We have been getting results that match the simulation results shown earlier
- Due to limitations with testing equipment, all controls testing has been done at much lower power and lower voltage (<100V)
- As the controls are finalized and testing is done with controls, power level and voltage level will be increased to match that of the charging station

Prototyping and Results

- Future tasks:
  - Implement the grid to bus interface to allow bidirectional flow to and from the grid and bus
  - Implement ground fault for all stages of the carport to allow for highest level of safety to the user and our research group
  - Implement a monitoring system to provide a user-friendly website for monitoring power flow throughout the day at the charging station

Summary and Conclusions

- A lot of time has been spent on simulation in Simulink to prove the concept of direct DC-DC charging
- Prototyping has been completed to verify that the power stage is capable of the power level that we expect at the solar charging station on campus
- The hardware shows very high efficiency curves
- Controls are still in the implementation and testing stage, however we are getting results that match the simulation

Thank you!

- Thank you for your attention!

- Please feel free to ask me any questions or email me at **chamilton@knights.ucf.edu**