ECEN 4517/5517

Power Electronics and Photovoltaic Power Systems Laboratory

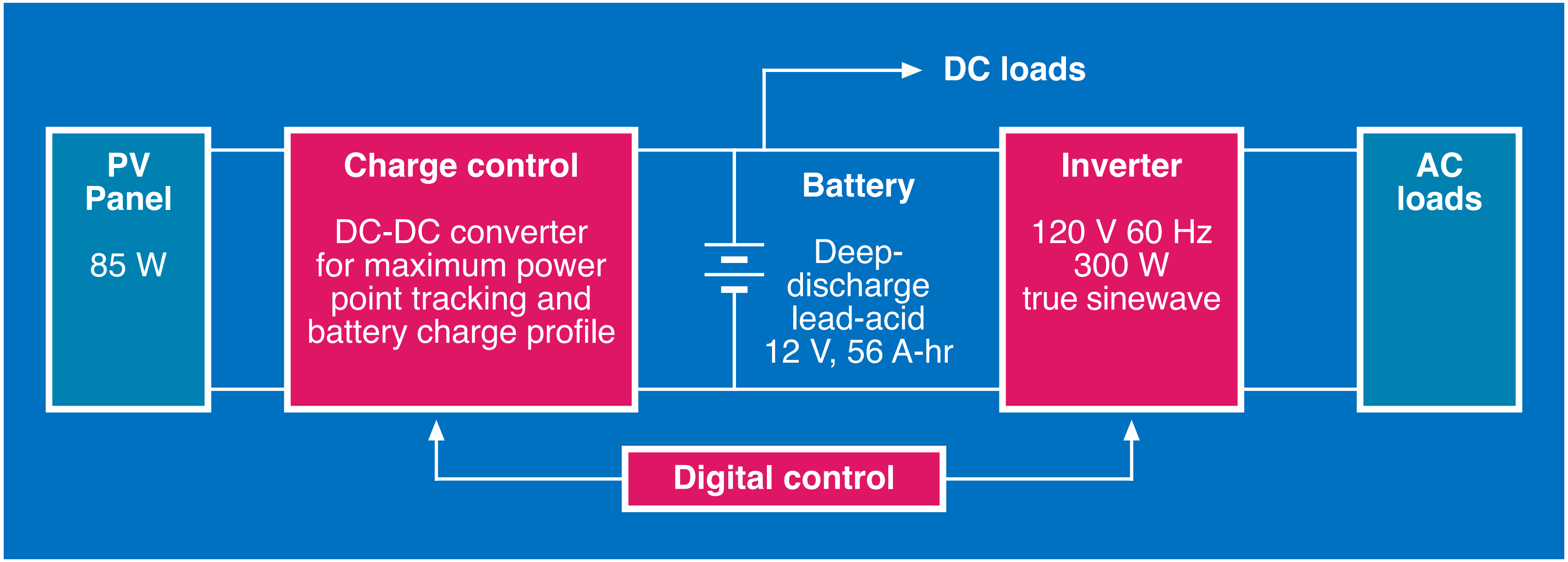
Lecture 11

Solar Power Competition
and Grid-Tied PV Systems

Announcements

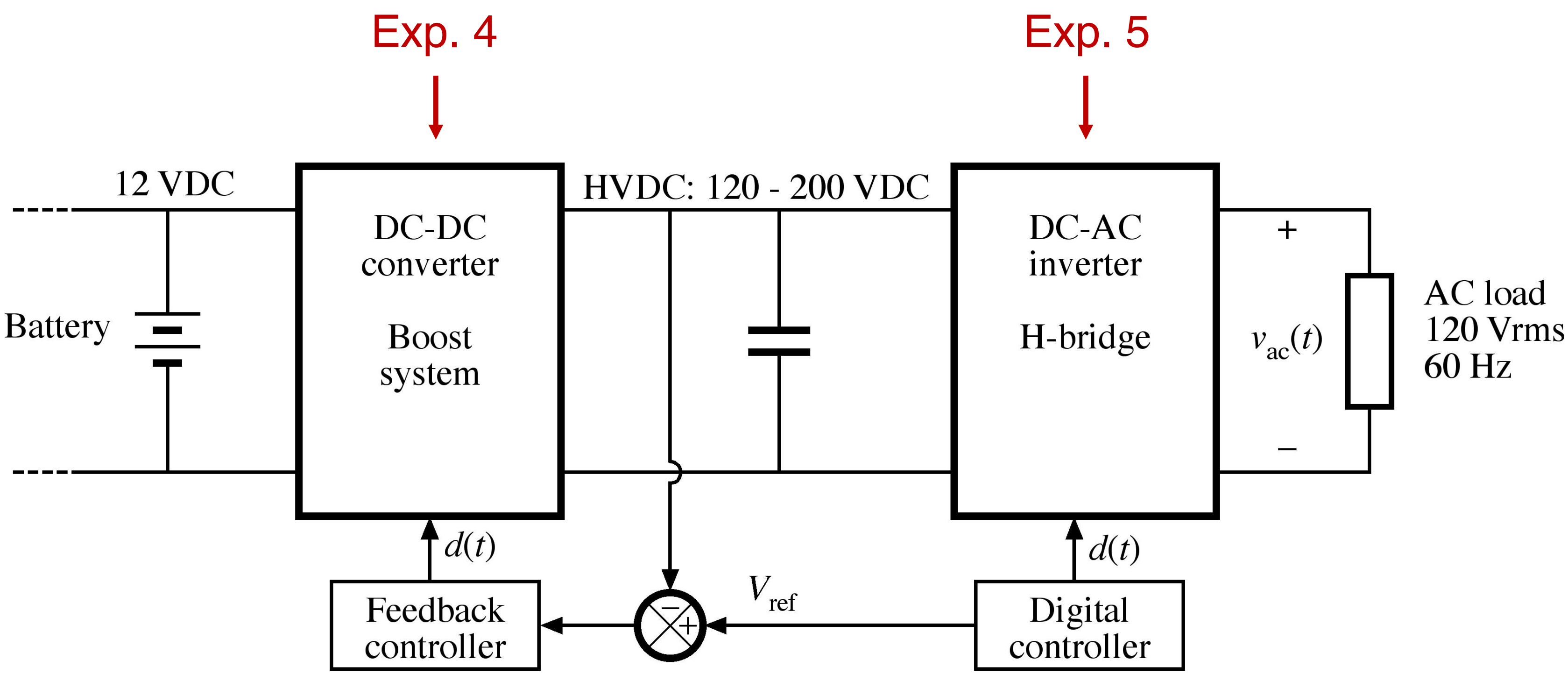
- Exp 4 Lab Report due by 11:59 pm (MT) on Monday April 10, 2017
- This week's lab: Continue Experiment 5
  - Have 2 weeks to work on Experiment 5
  - Exp 5 Lab Report due by 11:59 pm (MT) on Friday April 21, 2017
- After that: Assemble Complete System
- Lecture 12 (April 17, 2017): Quiz Review
- Quiz 2 on Monday April 24, 2017
  - In-class 40-minute quiz administered during lecture time
  - Closed book/notes, calculator allowed
  - Will cover Experiment 4 and 5 material
- Expo (Final Demo) on Thursday May 4, 2017

Experiments



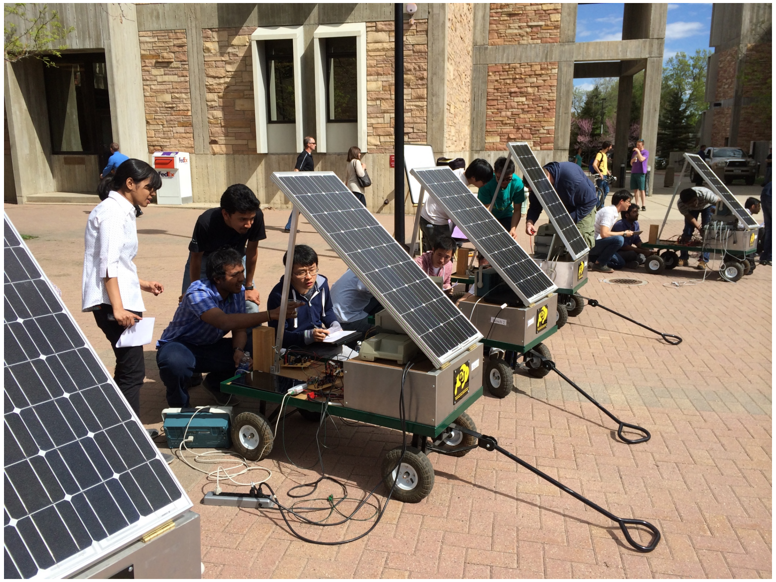
- Exp 1 – PV panel and battery characteristics and direct energy transfer
- Exp 2 – TI MSP430 microcontroller introduction
- Exp 3-1, 3-2 – Buck dc-dc converter for PV MPPT and battery charge control
- Exp 4 – Step-up 12V-200V dc-dc converter
- Exp 5 – Single-phase dc-ac converter (inverter)
- Expo – Complete system demonstration

Experiment 5 – Off-Grid Inverter



- **Required**: Demonstrate modified sine-wave inverter
- **Extra Credit**: Demonstrate PWM inverter

Solar Power Competition at the ECEE Expo



- Demonstrate your complete system
- Produce the most power and win a prize

Solar Power Competition and Expo Details

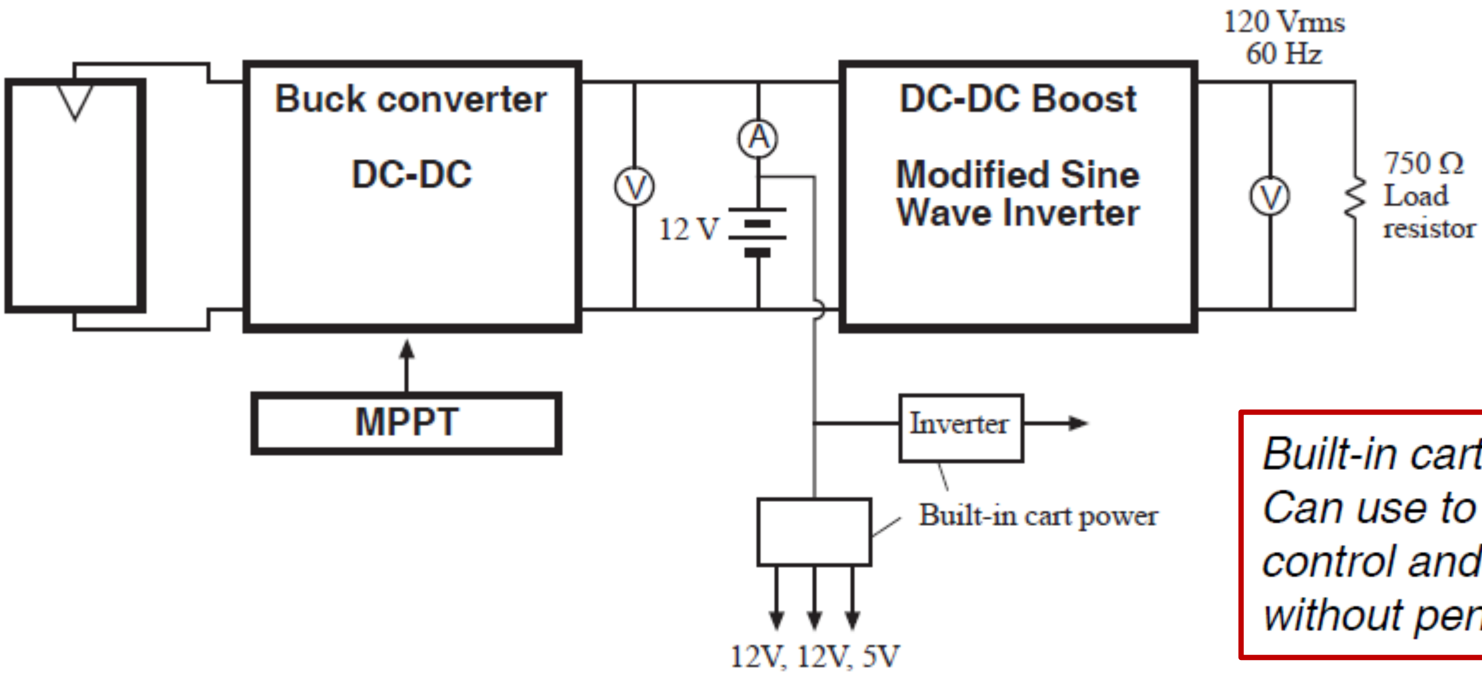
- Venue: Herbst Plaza, CU Engineering
- Date: Thursday, May 4, 2017
- ECEE Expo is open to public
  - 9:00 am – 1:30 pm
- Solar Power Competition
  - Tuesday Section: 9:00 am – 10:30 am
  - Wednesday Section: 10:30 am – 12:00 pm
  - Thursday Section: 12:00 pm – 1:30 pm

If your system doesn't work: please demo as much as you can; partial credit will be given

- Time Breakdown

	Tuesday Section	**Wednesday Section**	**Thursday Section**
Setup	9 am – 9:45 am	10:30 am – 11:15 am	12:00 pm – 12:45 pm
Judging	9:45 am – 10:15 am	11:15 am – 11:45 am	12:45 pm – 1:15 pm
Take down	10:15 – 10:30 am	11:45 am – 12:00 pm	1:15 pm – 1:30 pm

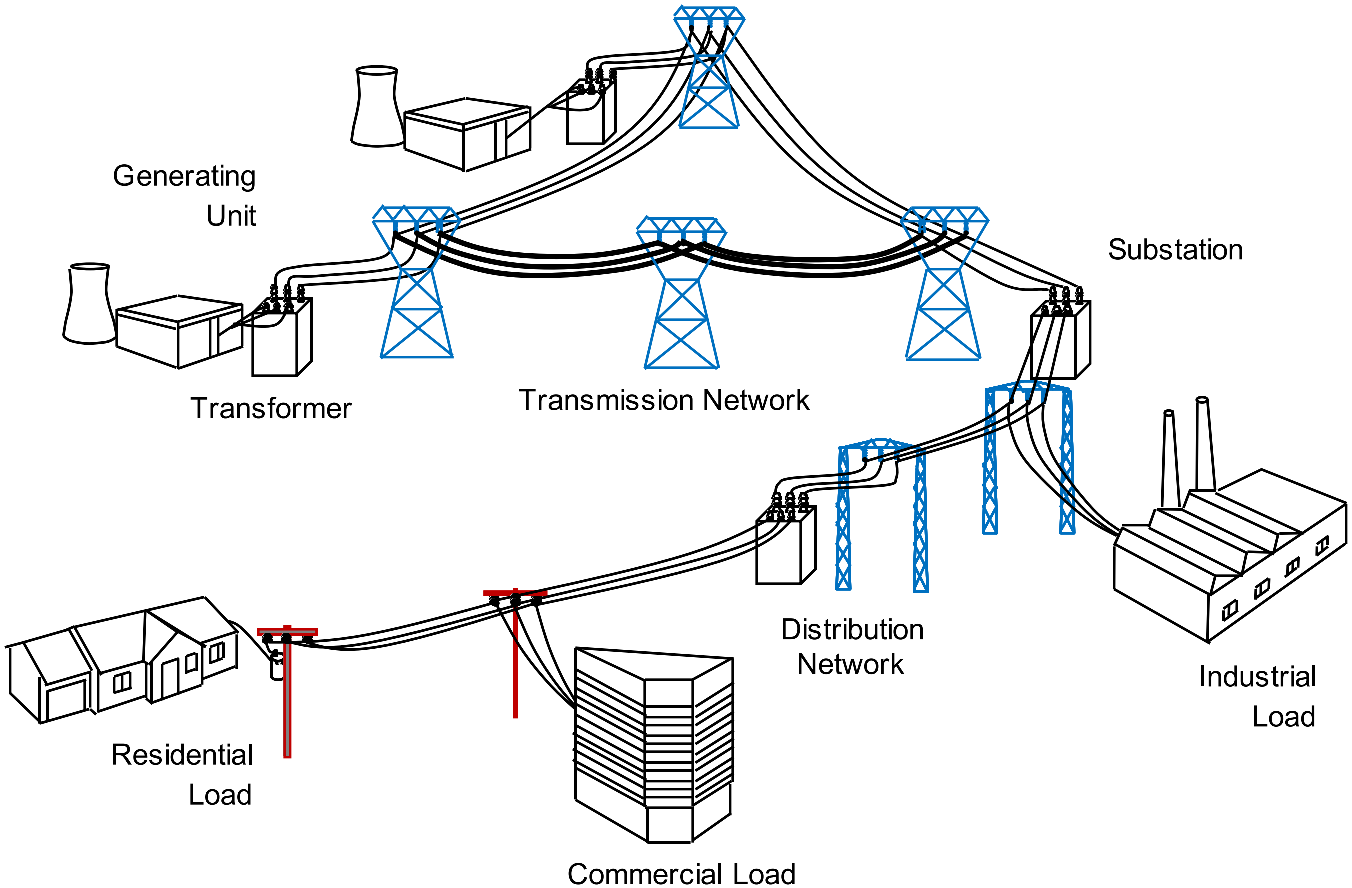
Solar Power Competition Setup



Built-in cart power: Can use to power control and test circuitry, without penalty

- You will be given a 25-W light bulb to load your inverter
- Connect ac voltmeter to measure inverter output voltage: you must produce at least 120 V_{rms}
- Measure dc current charging battery as shown; also measure battery voltage
- The winning group for each section will charge battery with the largest power, while driving ac load with at least 120 V_{rms}

Electric Grid



Types of PV Systems – Stand-alone

- This is what we built in this lab
- In the long term, the energy consumed by the load must exactly balance the energy generated
- When you battery is full in the afternoon, stop charging and quit peak power tracking
- When your battery is discharged at night, the loads will be unpowered
- "Reliability" means no blackouts: always have the capability to generate more energy than will actually be used. This capability costs money.

Types of PV Systems – Grid-tied

- This is currently the most common PV installation
- All energy that can be generated by the array is delivered to the public utility grid
- The utility must take your power, whether they want it or not
- Balancing load and generated power is the responsibility of the grid operators
  - The total load power on the grid must balance the power generated, on an instantaneous basis
- "Reliability" means no blackouts: always have the capability to generate more energy than will actually be used. This capability costs money. This responsibility is borne by the utility company

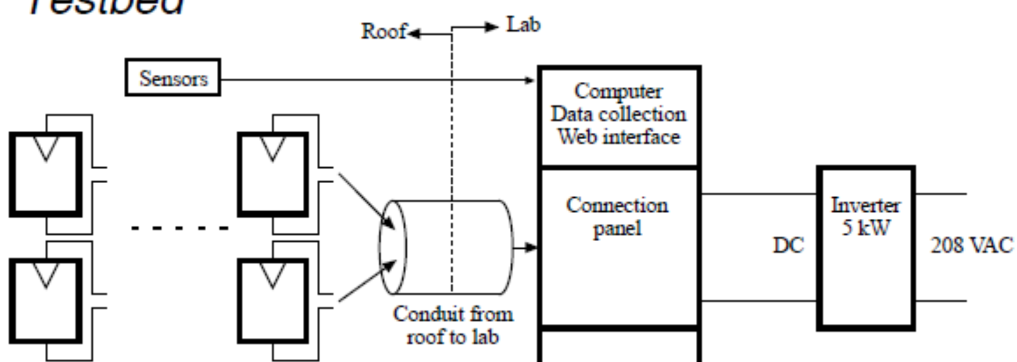
Types of PV Systems – Microgrid

- A collection of several AC sources and loads, which might include a PV array and its inverter
  - Example: a system with a solar array, battery bank, inverter, backup gas generator, maybe a wind turbine, and some ac loads
- Larger than the standalone system from this semester: there are multiple ac sources
- Not connected to the grid
- Reliability is your responsibility, not the utility company's

Example Grid-Tied PV System

- 8 x 3 array of PV panels on roof of EE wing
- 5 kW SMA inverter in power lab
- Each panel individually wired to switchboard in lab. System can be reconfigured in lab
- Monitoring system measures currents and voltages of each panel and bypass diode; results imported into Matlab

Testbed

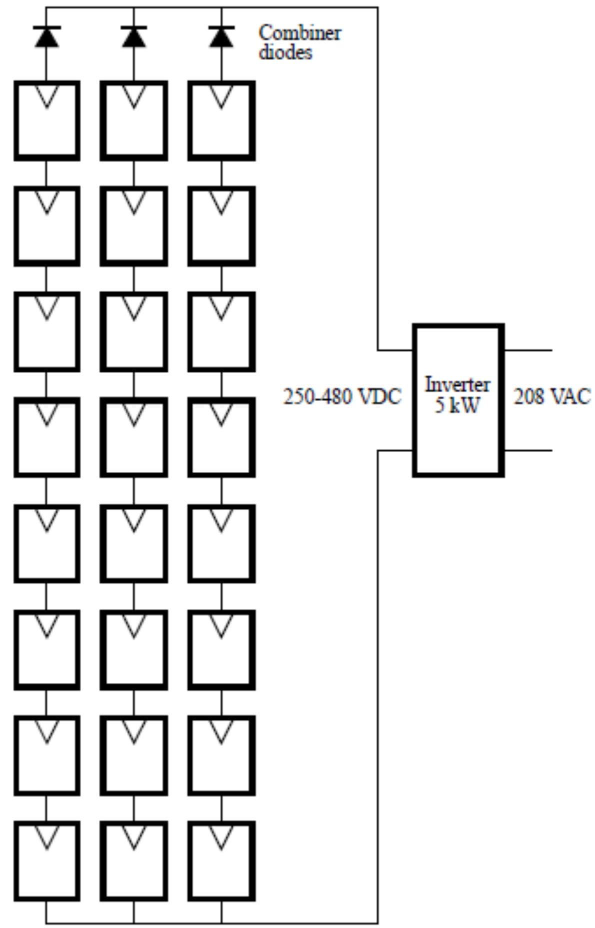


Photovoltaic array: 24 panels, each 35V/5A

72 cell, 180 W PV panels

24 total panels, 4.3 kW system

Nominal schematic

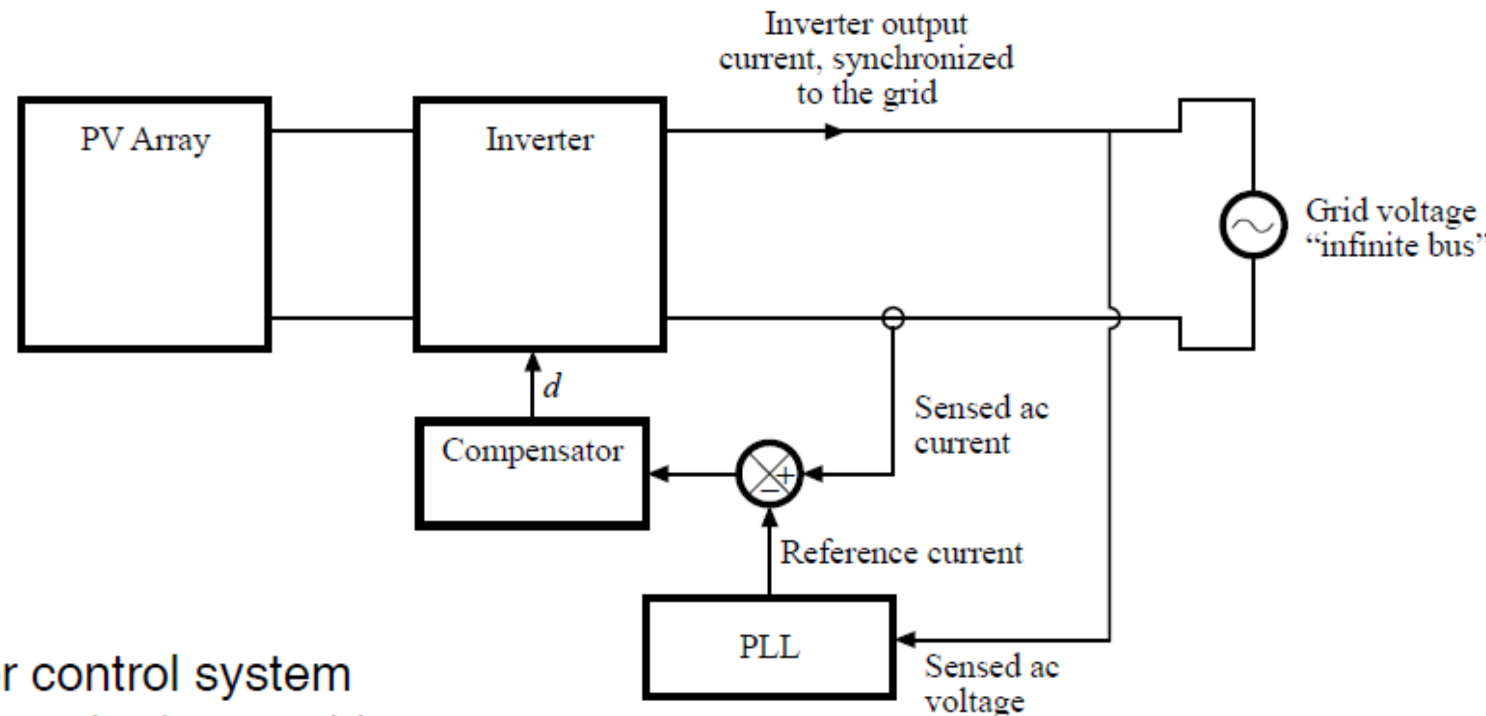


Photovoltaic array: 24 panels, each 35V/5A

PV System on Roof of EE Wing

Racking system is anchored to building structure and is able to withstand Boulder wind storms. Array is south-facing with panels tilted at 10°.

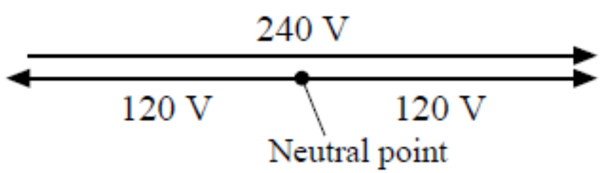
Inverter Controller in Grid-Tied System



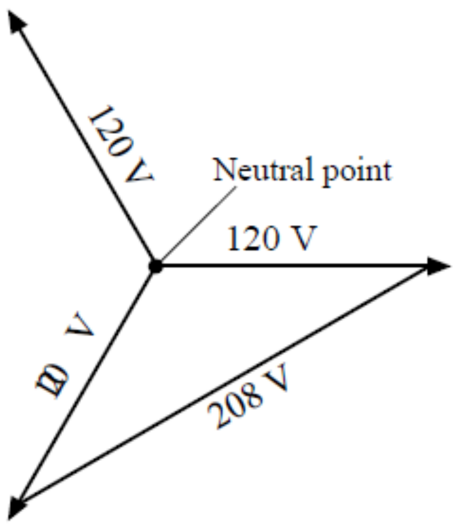
The inverter control system regulates its output current to be sinusoidal and in phase with the grid voltage

Single Phase vs Three Phase Systems

Single-phase residential voltages in US



Three-phase commercial voltages in US



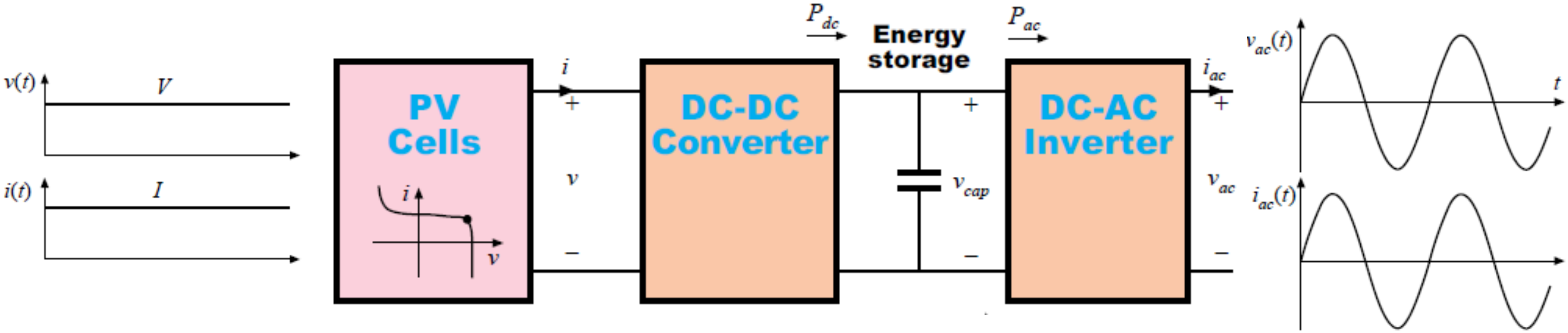
What is in your house

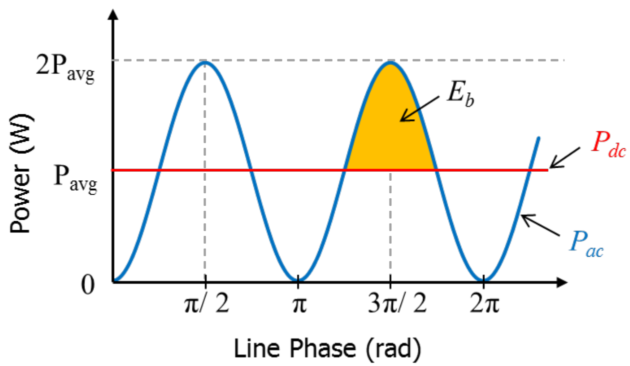
120/240 V single phase

What is in the engineering center

- 208 V three phase
- Note that three-phase is described by its line-line voltage
- To get single phase for wall outlets: use line-neutral voltage

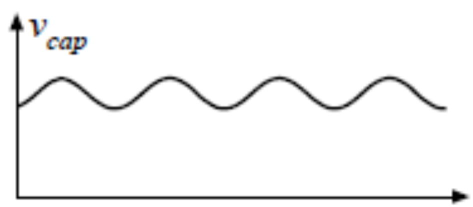
Single Phase Inverter Energy Storage Requirement





$$E_b = \frac{P_{dc}}{\omega_{line}}$$

The power supplied by the PV array is constant, but the power supplied to the AC grid pulsates at twice the ac grid frequency. A capacitor must store the difference.



In a single-phase system, the inverter must include a 120 Hz energy storage capacitor

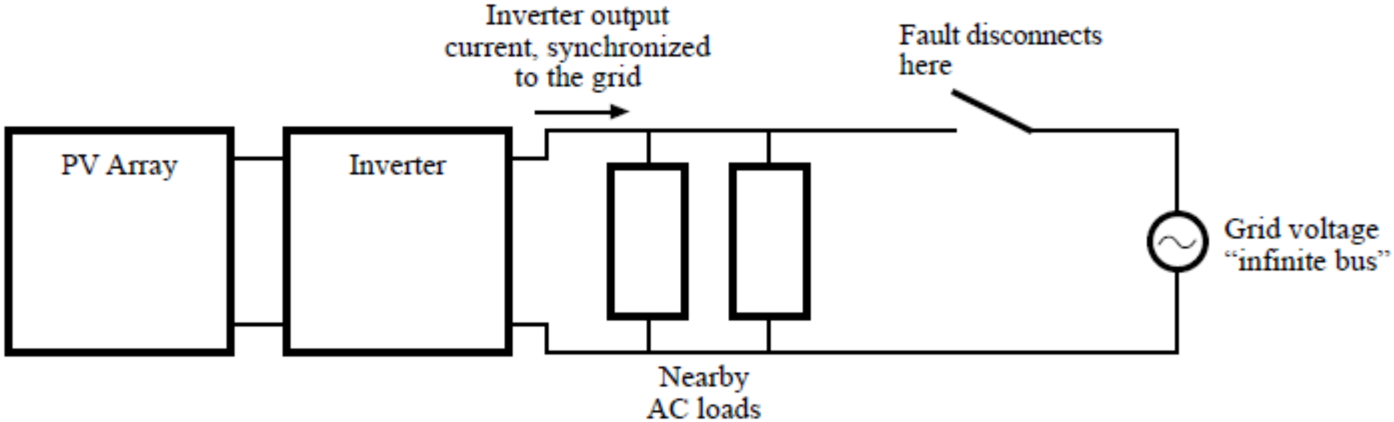
IEEE Standard 1547

IEEE Standard for
Interconnecting Distributed Resources with Electric Power Systems

Requirements on grid-tied PV inverters. Some highlights:

- Inverter disconnects when grid voltage or frequency are outside normal range. Reconnection happens after the normal range is restored, plus a delay (nominal 5 minutes)
- Regulation of local grid voltage is not allowed
- AC current injected into grid must have THD < 5%
- Anti-islanding: inverter must shut down in less than 2 seconds under islanding conditions
- Withstand surges from grid
- No injection of dc into grid

Islanding



In the event of a grid failure, it is possible that the PV inverter could continue to supply power and energize nearby loads. This is called “islanding”

- The utility company considers this to be very dangerous for their linemen
- During islanding, the PV inverter can backfeed power into the grid, through the local pole-mounted transformer, to the local distribution feeder (13.6 kV in Boulder)
- The utility line worker expects the distribution feeder to be de-energized. Backfeeding by household PV arrays can cause unexpected energizing
- The power company wants to know where all the PV arrays are, so that line workers can turn them off (with their padlocks on the ac disconnect switches)