ARPA-E Power Technologies Workshop

Breakout Group:

Power Converters

(Chair: David Perreault, MIT)

For integrated PV inverters (8V/40W & 48V/240 W), what are the critical performance metrics for components?

- Switches:
  - The on-resistance times capacitance
  - You can optimize which terminal capacitance depending on the application
  - Higher frequency switches, suitable for more than 10 mhz
- Electrolytic capacitors – or more generally bulk energy storage
  - Low esl, low esr
  - Energy density
  - Alternative could be to improve film capacitor
- Magnetics – integrated passives
  - suitable for more than 10 mhz
  - High q, low loss, basically
  - Cooling might be required – winding material could be the issue
  - Eddy current loss

Temperature applies to all of these - High temperature performance of 150 C or higher

For integrated PV inverters (8V/40W & 48V/240 W), what are the critical performance metrics for components?

- System Architecture/Circuit Topology
  - Capacitor requirements
  - Isolation - allow you to ground the panel, gives reliability and lifetime advantages
  - Circuits that can take advantage of switch improvements
  - Ultimately want to reduce system cost or the cost of energy
- Control electronics and power switches

Temperature applies to all of these - High temperature performance of 150 C or higher

For <u>integrated SSL AC/DC</u> (10W & 50W), what are the critical performance metrics?

Differences from PV - Lifetime may be less. Cost is more important.

- Switches
- Electrolytic capacitors
- Magnetics
- Control electronics and power switches

Overall quality – light output per dollar. Need to get rid of the ripple and flicker that we are seeing now in the commercially available ballasts. 120hz flicker.

A control electronics systems approach - lighting features, dimmability

Thermal management/high temperature operation implies switches and magnetics need to be better.

Which component technologies (solid-state switches, magnetics, electrostatics, thermal management) need to be developed for the near-term, mid-term, and long-term?

For both PV and solid-state

- Near-term (1-3 years, low-hanging fruit):
  - Thermal management, could include running the LEDs cooler
  - Integration of light source with driver
  - Could do a system architecture study on pros/cons of DC lighting bus in residences, and determine whether it is worth it
- Mid-term (3-6):
  - Need to look at density – high frequency circuits and integrated passives or better magnetic materials
  - Single-chip integration
  - Film capacitors for bulk energy storage – may be long term
  - High speed semiconductor devices (wide-bandgap semiconductors)
- Long-term (pushing 10):
  - High temperature semiconductor devices

What is the application space for switched-capacitor (magnetics-free) converters? What are the technical barriers, performance trade-offs?

- How do you make tradeoffs within a converter, how do you trade off the complexity? Massive integrated arrays of small switches – Berkeley. What are the scaling laws, where do you use capacitive systems. Where do you make more semiconductor intensive converters.
- Integrated on-chip applications - widespread sensor arrays, energy harvesting (sub watt), low-power (cell phones are using this)
- Assume this is non-isolated applications?
- This is a system issue.
- Using this with an inductor based solution
- Barriers: barrier to a power MOSFET – can't do individual pin connections. There is a control and interface problem.
  - No energy storage, then you can't do reactive

What is the performance impact of micro-inverters (40 - 240W/ 48V to 220VAC) and rectifiers (10-50W) of not using electrolytic capacitors? What are alternative circuit topologies (high freq effective ripple), alternative capacitors (thin film, fast ultracaps), and magnetics?

- If you don’t use eletrolytics:
  - Improve lifetime
  - Allow high temperature operation
- Penalty for no electrolytics:
  - None for DC to DC
  - Increased system cost for DC to AC
  - Increased ripple for AC to DC (impacts lighting applications)
- Alternative circuit topologies:
  - Circuit techniques to reduce capacitance via high effective ripple
  - System architectures that eliminate the need for the capacitors
- Alternative capacitor:
  - That would be wonderful . . . Replacing with a film capacitor at reasonable cost – several startups working that.
  - Fundamental limit on how low the voltages can go. Need to expand
  - Ultra-capacitors with higher voltages and lower costs, and improved lifetime
- Magnetics:
  - Would require a materials breakthrough, perhaps superconductors?

What level of investment would be required to develop and deploy these technologies? What is the return on investment?

Area	Investment Required	ROI (hi, med, low)
Switches	High	High
Electrolytic capacitors	?	Could be very high
Magnetics	Low, depends on whether you need new materials	Medium (air core, if you can do it) to low (materials)
Control electronics	Can you integrate with power electronics on same substrate? Higher level of functionality? Using large numbers of sensors? Low to medium	low to medium
Circuit topologies	Doesn’t necessarily require a structural investment	Could be high
Integration	High	Should be high

- Need for a long-term roadmap on capacitors and magnetic materials

What is the appropriate target for integration (at 10W (rectifier), 50W (rectifier/inv), 240W (inv))?

- Controller + power electronics: Suitable for all of the above: 10W rectifier and 50 W rectifier/inverter and 240 W inverter. The rationale here is that further integration of controller + power electronics will enable significant advanced in efficiency (>95%)

- Power electronics + magnetics: At this stage of magnetics technology, the only suitable target is the 10 W rectifier. Thermal management will likely be an issue for the 50 W rectifier / inverter, and will definitely be an issue for the 240 W inverter.

- Power electronics + electrostatics: Suitable for the 10 W rectifier and the 50 W rectifier/inverter. It is not clear if a 240 W inverter design with a large electrolytic capacitor should be an integration target. New capacitor topologies should be considered, as well.

Grand Challenges

1. Super-high power density - kw/inch cubed, but it depends on the space. A high product to power density that would enable . . . Reduction of power consumption, enablement of new applications, PV and lighting examples.

   The (efficiency * density) / cost - that is what we want to improve. By how much? By more than 5-10x. Efficiency probably really means total loss. Might be more room to improve density than efficiency.

   The pv application – much higher efficiencies are required. Need to get to 97-98%. And need higher density as well.
2. Power electronics technologies roadmap?

ARPA-E White Space?

- PV balance of system. Don’t see similar sort of investment there.
  - Metrics could include:
- DOE should look at architecture – develop one best-suited
- Which areas of power electronics should ARPA-E invest heavily in?
  - Should it be tied only to technological improvement to traditional PV systems (ie., inverter integration and efficiency improvement?)
  - What level of technology (component development) should ARPA-E be involved in?
  - Can we leverage existing technology investment from other government agencies?
  - The duration of ARPA-E programs (2-3 years versus 4-6 years) will help to answer these questions.

Additional notes from during the Report Out

- Any specific reason on magnetics for high Q? No – using in a more general sense
- DOE coordination plan may be needed since you actually have about 5 different locations in DOE working this space. There is an electrical systems roadmap on high temp, SiC, and capacitors
- All advanced energy applications that we have been talking about are predicated on high performing low cost power electronics. What can be done to help across applications? Supply and usage charts. Need it to be universal.