Ultra Compact Electrolyte-Free Microinverter with Mega-Hertz Switching

Virginia Polytechnic Institute and State University, Blacksburg, Virginia

Jason Lai, Professor
Director, Future Energy Electronics Center
### Project Goals

- To develop a cost-effective PV microinverter that fully utilizes potential of wide bandgap semiconductor devices
- To reduce the size of bulky EMI passive filters and excessive potting materials
- To eliminate electrolytic capacitor for long life expectancy

#### Key Performance Indexes

<table>
<thead>
<tr>
<th></th>
<th>DOE Goal/State-of-the-Art</th>
<th>Proposed Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost for residential applications ($/W)</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Warranty life (years)</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>CEC efficiency (%)</td>
<td>97</td>
<td>98</td>
</tr>
<tr>
<td>Power density (W/liter)</td>
<td>91.5</td>
<td>9150</td>
</tr>
<tr>
<td>Mass density (W/kg)</td>
<td>187</td>
<td>1000</td>
</tr>
<tr>
<td>Electrolytic capacitors</td>
<td>yes</td>
<td>No</td>
</tr>
<tr>
<td>Switching frequency (kHz)</td>
<td>100</td>
<td>1000</td>
</tr>
</tbody>
</table>
How to achieve the goals?

• Soft switching with ZVZCS – loss reduction
• Synchronous rectification – loss reduction
• Mega hertz switching – magnetic size reduction
• Height shrinking – potting compound reduction
• Two-stage design along with resonant controller – passive size reduction by low-frequency ripple and electrolytic capacitor elimination
• Quasi-resonant mode along with phase dropping – light load efficiency improvement
100-kHz vs. 1-MHz 300-W micro-converters

100 kHz

1 MHz

Top view

Side view

10.65 in³ vs. 1.34 in³ ➔ 87.5% volume reduction
Proposed electrolyte-free solar PV microinverter

- $C_{PV}$, $C_{dc}$, $C_r$, and $C_f$ are all high-frequency capacitors
- Boost stage controller has a high gain at 120 Hz to push current ripple to $C_{dc}$
- PAM stage has a high gain at 60 Hz to ensure smooth sinusoidal output
- Output stage mega-hertz ripple can be easily filtered with leakage inductance of the common-mode EMI filter
Voltage waveforms at each conversion stage

- Soft-switching resonant converter switching at megahertz frequency utilizing wide bandgap devices with a sine wave envelop modulation
- Resonant converter modulated with advanced pulse density and pulse amplitude control to improve light-load efficiency
- Boost converter output voltage is modulated to form a quasi-sinusoidal wave to allow the resonant converter operating at zero-voltage and zero-current to maximize the resonant converter efficiency
Target specifications

- Target Specifications: 400 W, 25-50V MPPT input, 240V output for 72-cell PV panel
- Target BOM cost: $24 or $0.06/W for 500k quantity
- Target life: >35 years
- CEC Efficiency: 98%
- Power density: 9.15 kW/l or 150 W/in\(^3\)
- Mass density: 1 kW/kg or 455 W/lb

Mega-hertz frequency soft switching to make the board smaller than a business card
Technical challenge – transformer design

• PCB winding with <2oz copper to avoid skin effect
• Interleaving configuration to reduce proximity effect
• EI core for fringing effect reduction
• FEA for design optimization
• Custom-made cores with support from key manufacturers
Other technical challenges

• Need highly integrated GaN devices/modules for low parasitic inductance and reliable gate drives
• Need low-cost low-power consumption microprocessor but sufficient processing power
• Need reliable synchronous rectification implementation
• Need high-voltage GaN devices with low junction capacitance
• Need to cool GaN devices with special thermal design
Research & development flow of each budget period

**Budget Period 1:**

- Design of µ-inverter
- Comparing GaN devices
- Design of magnetic components
- Design of synchronous rectifier

**Power Stage Design and Implementation**

- Power stage circuit layout
- Open-loop controller
- Commercial magnetics
- Open-loop testing

**Budget Period 2:**

- Simulation & analysis
- Simulation & device testing
- Finite element analysis

**Control Design and Implementation**

- Dynamic modeling
- Closed-loop design
- Design with custom magnetics
- DSP software coding
- Dynamic & A/D signal tuning
- Simulation & analysis
- Simulation verification
- Design with custom magnetics
- Finite element analysis

**Budget Period 3:**

- IEEE-1547 compliance algorithm
- EMI filter design
- BOM and cost estimate
- T2M plan and analysis

**Design Iteration and Compliance Testing**

- Final version hardware
- IEEE-1547 coding
- EMI filter hardware
- Integration & 3rd party testing

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Power Electronics Program Kickoff
Key milestones

• Budget Period 1 (Aug 2018 – July 2019): The power stage efficiency meets the target of 98% efficiency or higher
• Budget Period 2 (Aug 2019 – July 2020): Demonstrate operation with power stage efficiency >98%, THD <5%, MPPT efficiency >99.8%, and ripple current<10%
• Budget Period 3 (Aug 2020 – July 2021): Pass required tests to IEEE 1547 and UL requirements and efficiency target with third-party test
• Technology-to-Market (T2M) plan follows
QUESTIONS?