Active Battery Management Systems and High Power Density Switched Capacitor Converters

ECE 590 Seminar
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Outline

- Dickson Switched Capacitor Converter
  - Motivation
  - Capacitors Versus Inductors
  - Interleaved Dickson
  - Experimental Results

- Battery Management Systems
  - Motivation
  - System overview
    - Passive
    - Active
  - Hardware
Motivation

- Use Capacitors for High Voltage Step Up Conversion
- Pulsed Power Applications
  - Particle Accelerators
  - Very Strong Magnetic Fields
  - Fusion Research
  - Lasers
  - Water Purification
  - Radar
Switched-inductor vs. Switched-capacitor converters

- Switched-inductor converters
  - Simple and robust
  - Wide input/output voltage range
    - High device stress
    - Inductor is bulky

- Switched-capacitor converters
  - Low device stress
  - Capacitors have large energy density
    - Large number of components
Energy Density Comparison

- Desire to create high power density converters
- Capacitors have greatly superior energy density
The Dickson SC Converter

- Switched-capacitor converters
  - ✓ Lower device stress
  - ✓ Capacitors have high energy density
  - × Large number of components
  - × Fixed conversion ratios

- Converter characteristics
  - Low switch stresses: rated for $V_{in} (S_1, S_5, S_8)$ or $2 \times V_{in} (S_6, S_7)$
  - Capacitor ratings: $V_{C_1} = V_{in}$, $V_{C_2} = 2 \times V_{in}$, $V_{C_3} = 3 \times V_{in}$
Design Goals

- Demonstrate a larger step up – 1:6, 35 V to 210 V
  - Leverage work on Dickson Split-Phase
- Achieve higher power density
  - Achieved through interleaving multiple stages
- Resonance
Current Hardware Implementation

- Two phase interleaved converter with split phase control
**Results**

- Achieved 25 V to 150 V operation
- Demonstrated interleaved resonant operation at 200 kHz
- Observed excellent current sharing between phases
Results (continued)

- Reached peak efficiency of 95.7% for single phase, 95.6% for two phase
- Reached peak single phase power of 40 W, 60 W for two phases
Battery Management Systems

- Lithium-Ion Battery Packs
  - Strings of many cells

- Battery Management Systems
  - Monitor cell voltages
  - Protect cells from over voltage, under voltage, and over current
  - State of Health (SOH)
  - State of Charge (SOC)

- Cell balancing
Why We Care!
Passive Battery Management System

- Easy to implement
- Easy to control
- Cheap
- High heat dissipation
- Slow charging
- Inefficient
Battery To Pack – Unidirectional or Bidirectional

- Extremely fast charging
- Extremely efficient
- Little heat dissipation
- Complex SMPC
- Very complex control
- Isolated communication
Charge Every Battery Cell Individually

- Extremely fast charging
- Easy to control
- Moderate heat dissipation
- Moderately efficient
- Complex SMPC
- Single point failure

Focus of the Research

- Isolated SMPC
- Cell1
- Cell2
- Cell3
- Cell4

Microcontroller

Pack Data

Battery Output +

V_sense

UV/OC Protection

Precision Amplifier

Temperature Sensor

Battery Output -
Forward Converter with Planar Magnetics

- **Forward Converter**
  - Two modes of operation
    - S1 on
    - S2 on
  - Duty cycle determines output voltage

- **Planar Magnetics**
  - Transformer windings in PCB
Forward Converter

- Switching at 1-2 MHz
- GaN Switches
- Planar Magnetics
- Current and Voltage Controlled
Conclusion

- High Power Density Switched Capacitor Converter
- Active Battery Management System

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Questions