EEESAT 2005, October 17-19, 2005, San Francisco, CA

# *An Advanced Power Converter System Based on High Temperature, High Power Density SiC Devices*

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# ACKNOWLEDGMENTS


- Funded by the Small Business Technology Transfer (STTR) program of the U.S. Department of Energy (DOE/ESS) and managed by Sandia National Laboratories (SNL).

# *Outline*

**1. Introduction**

**2. Objective**

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**4. Work scope (Design, Modeling and Simulation)**

**5. Summary**


- **Acknowledgment: DOE STTR Phase I (DE-FG02-05ER86234), supervised by Stanley Atcitty (Sandia National Lab.), Imre Gyuk (DoE)**


- **Aegis Technology Inc.: Power electronics and thermal management for wide bandgap semiconductor**

# *1. Introduction – Advantages and Challenges*

- **Si technology is approaching its theoretical limits.**
- **SiC devices are superior to present Si devices.**
  - **High temperatures, breakdown voltages, frequency and thermal conductivity**
  - **High efficiency, light weight, small size in SiC conversion system**
- **Challenges in utilizing SiC power devices.**
  - **High cost (expensive material, low yield) and limited availability (Schottky diodes, JFET)**
  - **New circuits, passive components, gate drivers and thermal management (high temperature, high power density package)**

## *2. Objectives*

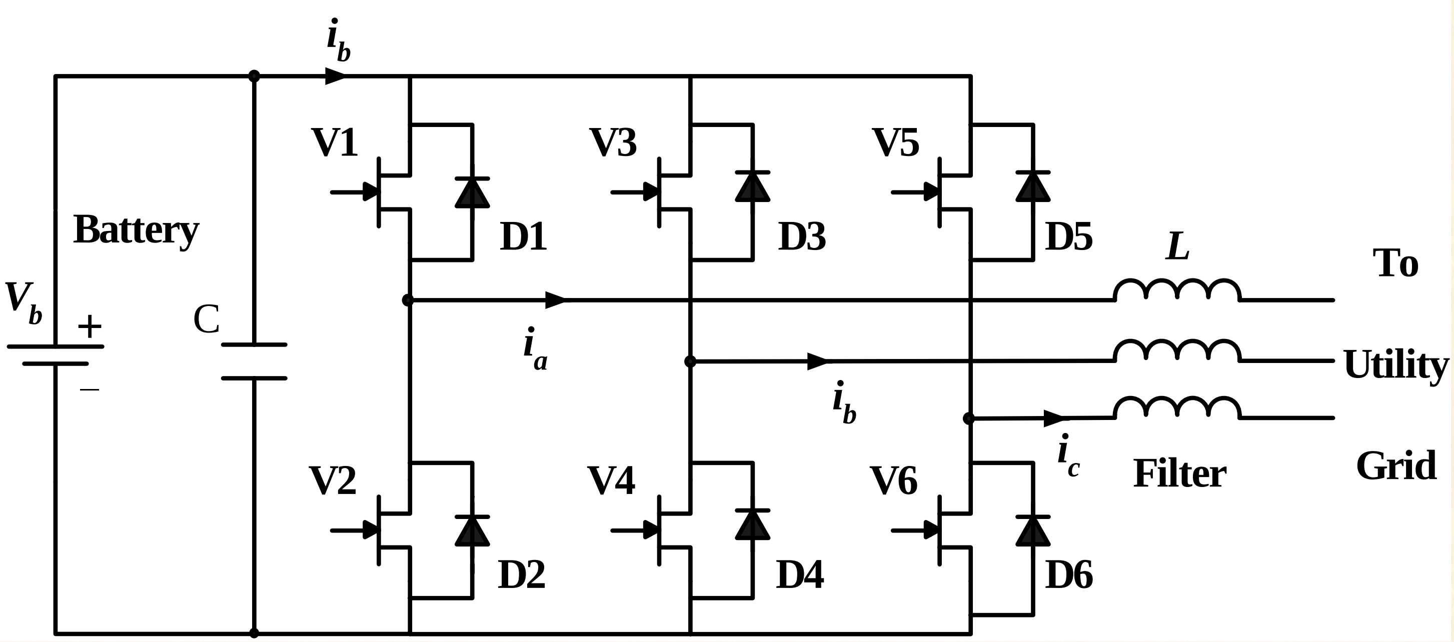
- **Develop an innovative power converter using high temperature, high power density SiC devices.**
  - **High efficiency, small size, and light weight**
  - **High power density, high temperature, and high frequency**
  - **Scalable current ratings for various motor controls**
- **Insert the technology for the applications in electric energy storage, motor control, and others.**

# *3. Approach*

- **Circuit design and modeling of converter to evaluate the effects of SiC devices on power loss and efficiency.**
- **High temperature, high power density packages for the thermal management of SiC power devices.**
- **Gate drive that enables SiC power devices under high temperature.**

# *4.1 Design – Converter*

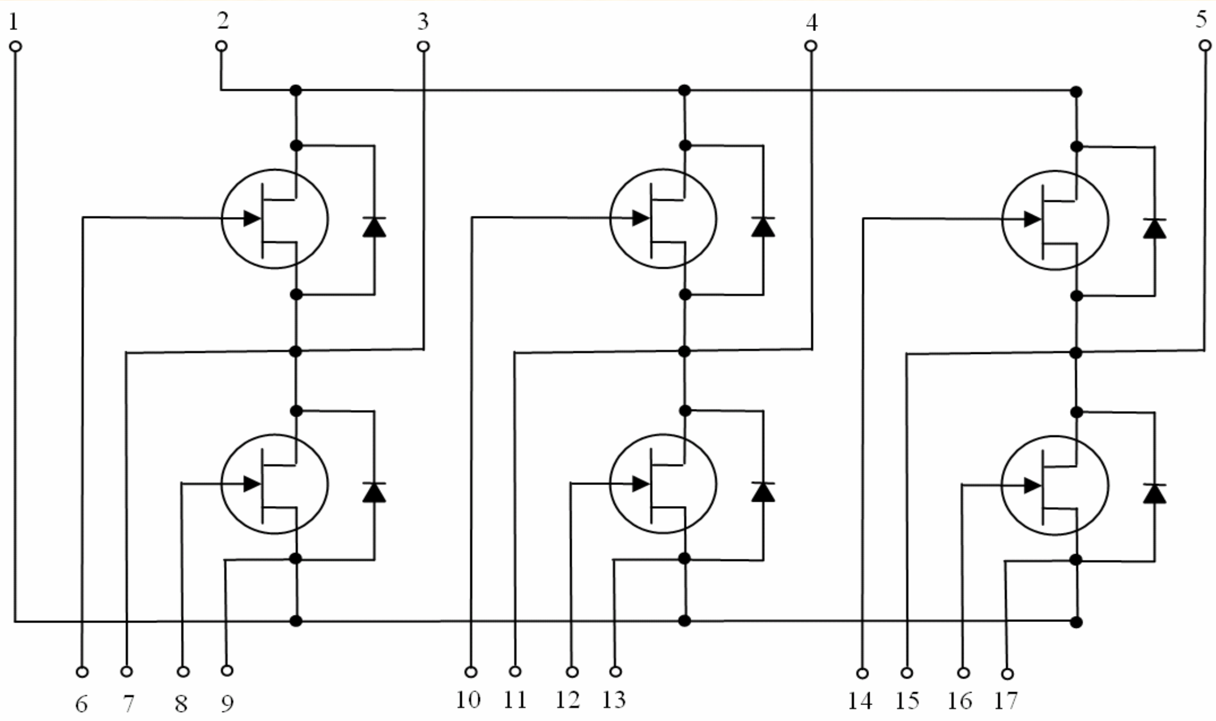
- **Battery: Lead acid battery**
- **Converter: SiC devices (JFET, Schottky diode)**
  **Bi-directional conduction**
- **Utility grid: 3-phase, 60Hz, 480 V line-line voltage**




**Converter Design for Battery System**

# 4.1 Design – Power Module

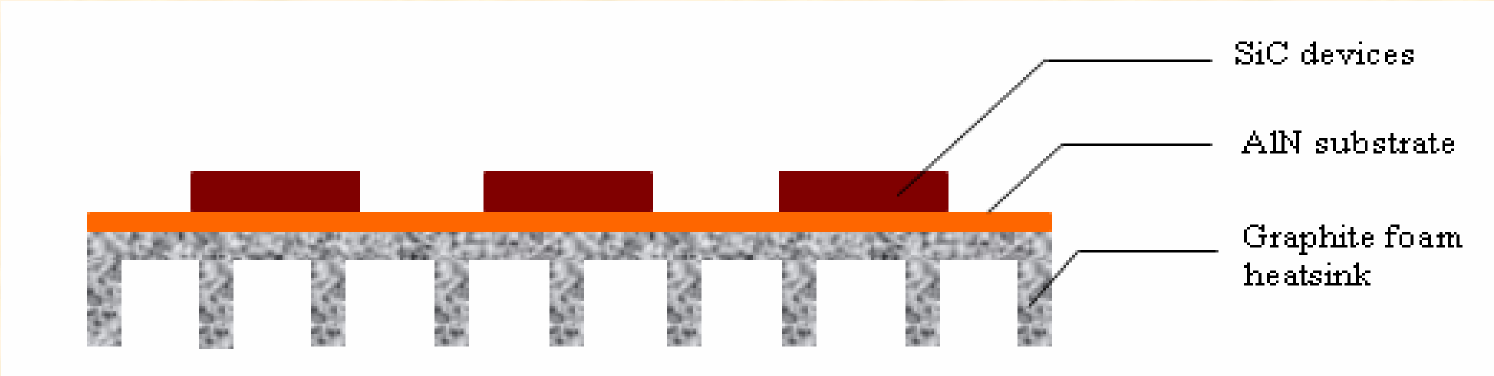
## Power module circuit

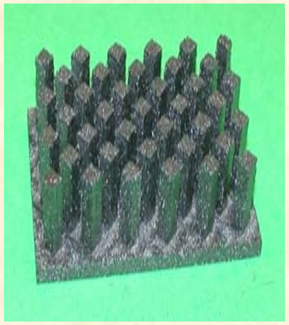



- Feed throughs of 1 - 5 for the power input (1,2) and output (3,4,5).
- Feed throughs of 9 -17 for the circuit control.

# *4.1 Design – Thermal Management*

**High temperature, high power density package**



**High temperature AlN package**

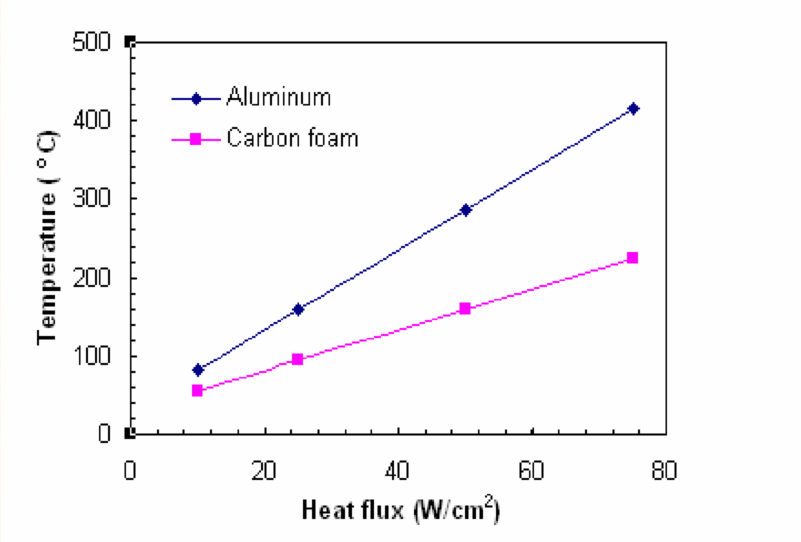
**High efficiency graphite (carbon foam) heatsink**

# *4.1 Design – Thermal Management (cont.)*

- AlN package substrate
  - High thermal conductivity
  - Low CTE matchable with SiC
  - High thermal shock resistance and insulation

| | AlN | Alumina |
|---|---|---|
| Thermal conductivity (W/m K ) | 200 | 20 |
| Dielectric strength (kV/cm ) | 140 - 170 | 100 |
| CTE ($x10^{-6}$/°C ) (25 ~ 400 °C) | 4.5 | 7.3 |
| Density ($g/cm^3$ ) | 3.3 | 3.9 |
| Flexure strength (MPa) | 300 - 500 | 240 - 260 |

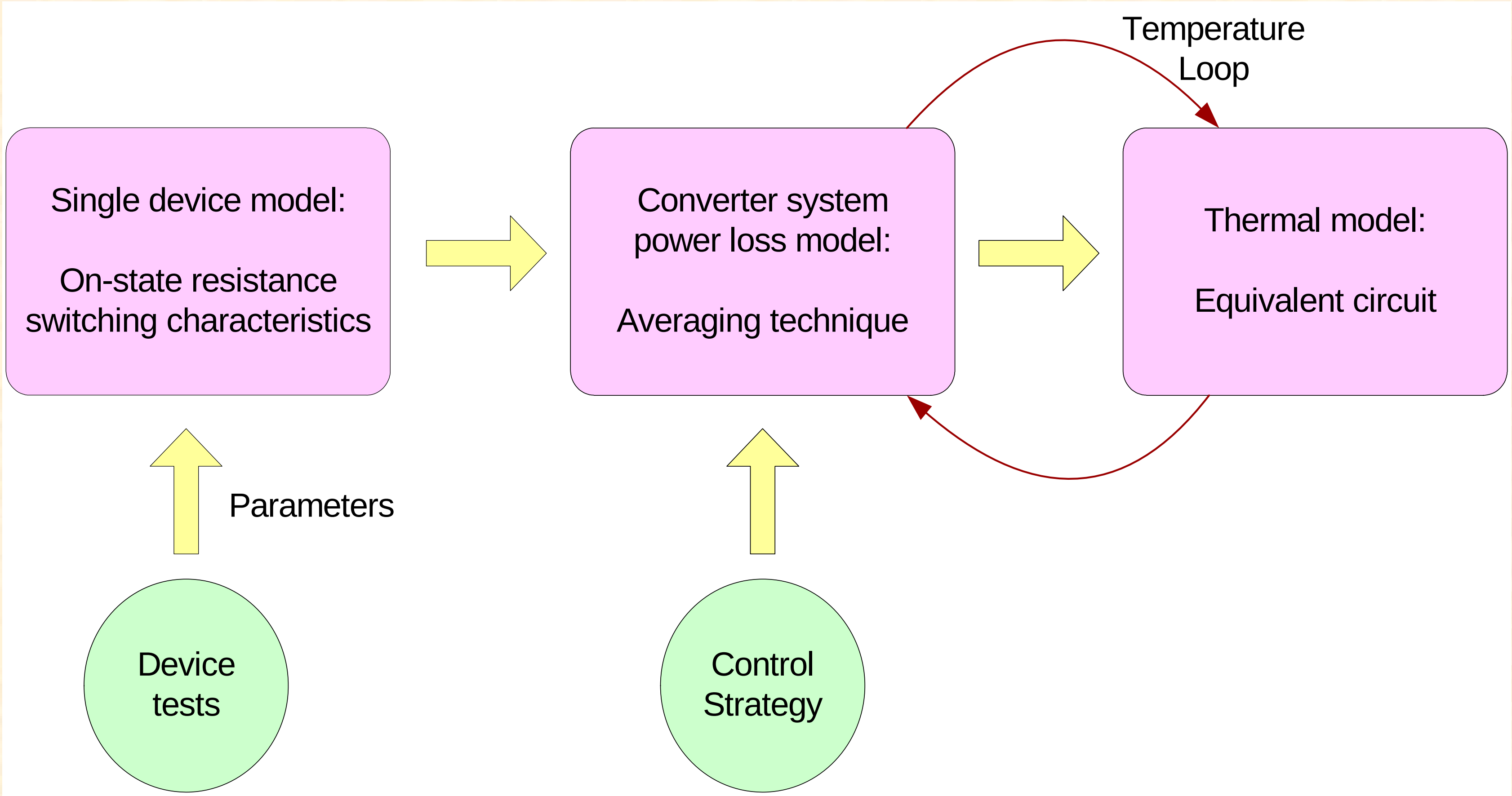
- Carbon foam heatsink
  - High thermal conductivity
  - Interconnected pores acting like network microchannel
  - High convective heat transfer (100% enhancement over Al heatsink).



# *4.2 Circuit Modeling*

- **Compute power losses of SiC devices /power module/converter.**
- **Evaluate junction temperatures of the SiC devices and the energy efficiency of the converter.**
- **Demonstrate the advantages of the SiC inverter compared to its Si counterpart quantitatively.**
- **Investigate the effects of important parameters (package, heatsink etc.).**

# 4.2 Circuit Modeling – Methodology



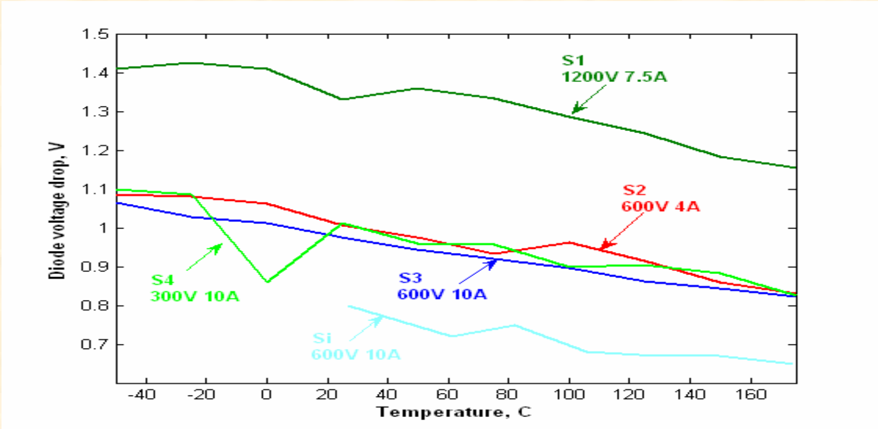
# *4.2 Circuit Modeling – SiC Power Devices*

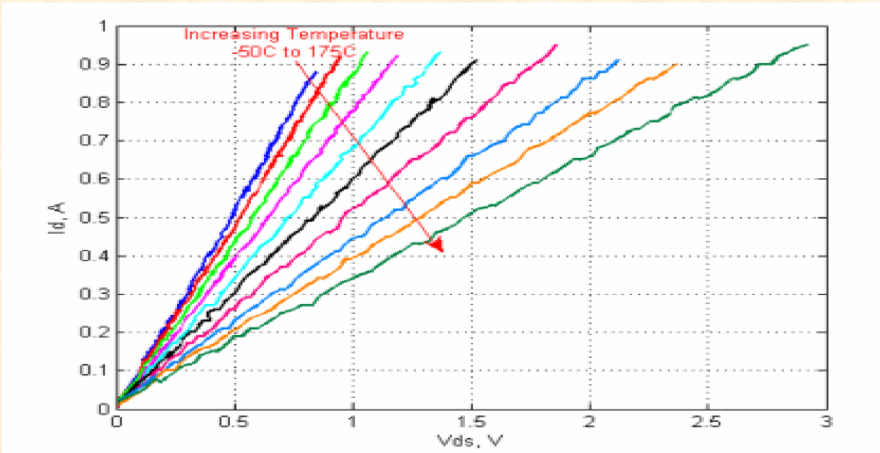
## Modeling and testing:

**Static/switching characteristics**

- SiC diode I-V, on-resistance, voltage drop (Vd) at different ambient temperatures
- SiC switch I-V, on-resistance, voltage drop (Vd) at different temperatures

**Forward Voltage of SiC Schottky Diode**




**I-V characteristics of JFET**

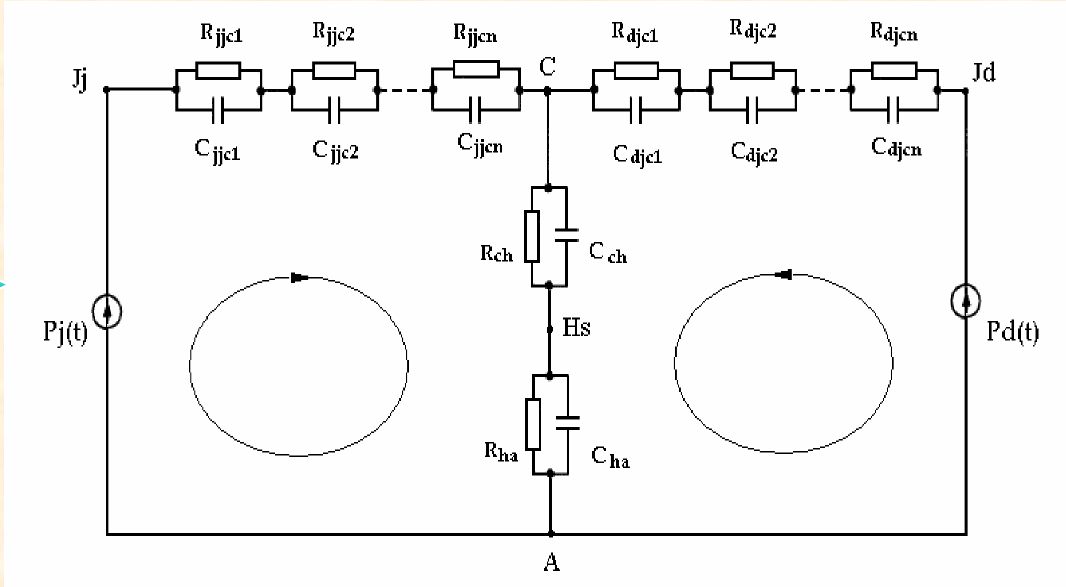
# *4.2 Modeling – Power Module*

- **Power loss : Sum of power loss in VJFET and diode**
  - **Conduction loss**
  - **Switching loss**

$$P_{tot} = \left(P_J + P_D\right) \times 6$$

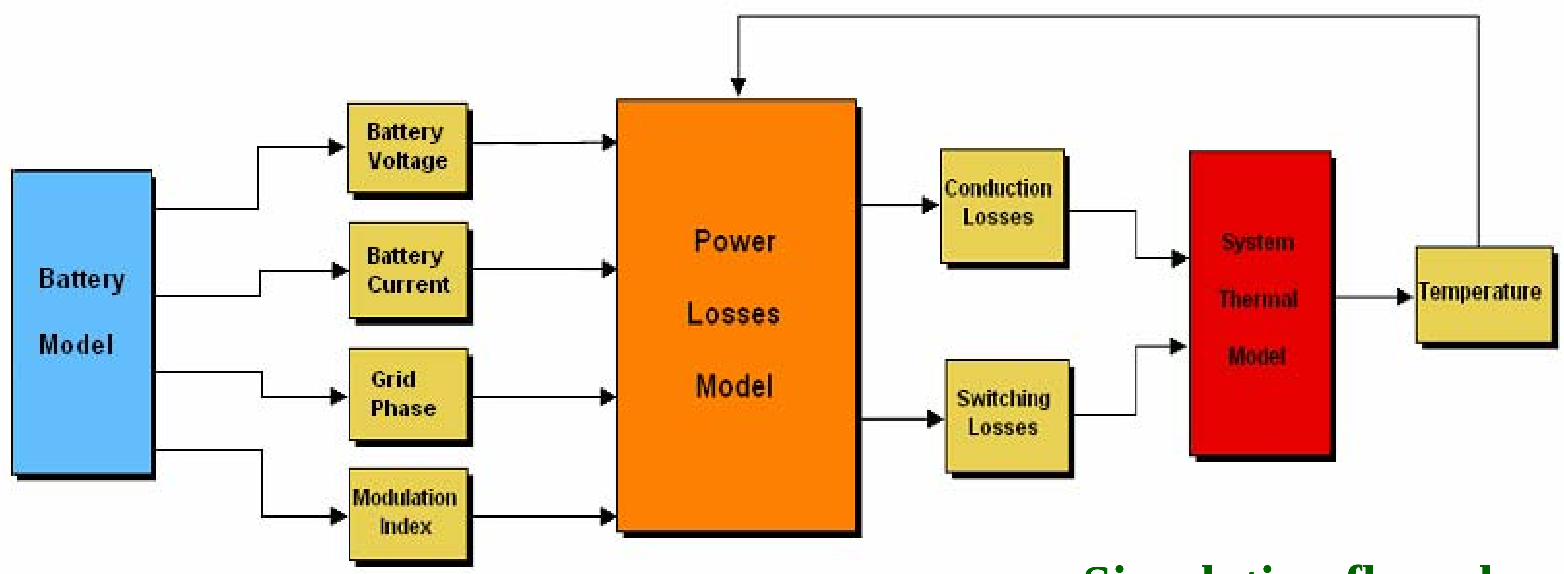
- **Thermal model**

**Thermal equivalent circuit of the power module**



# *4.3 Simulation*

## Implement model  using Matlab Simulink




**Simulation flow chart**

**Battery model, power loss model, and system thermal model**

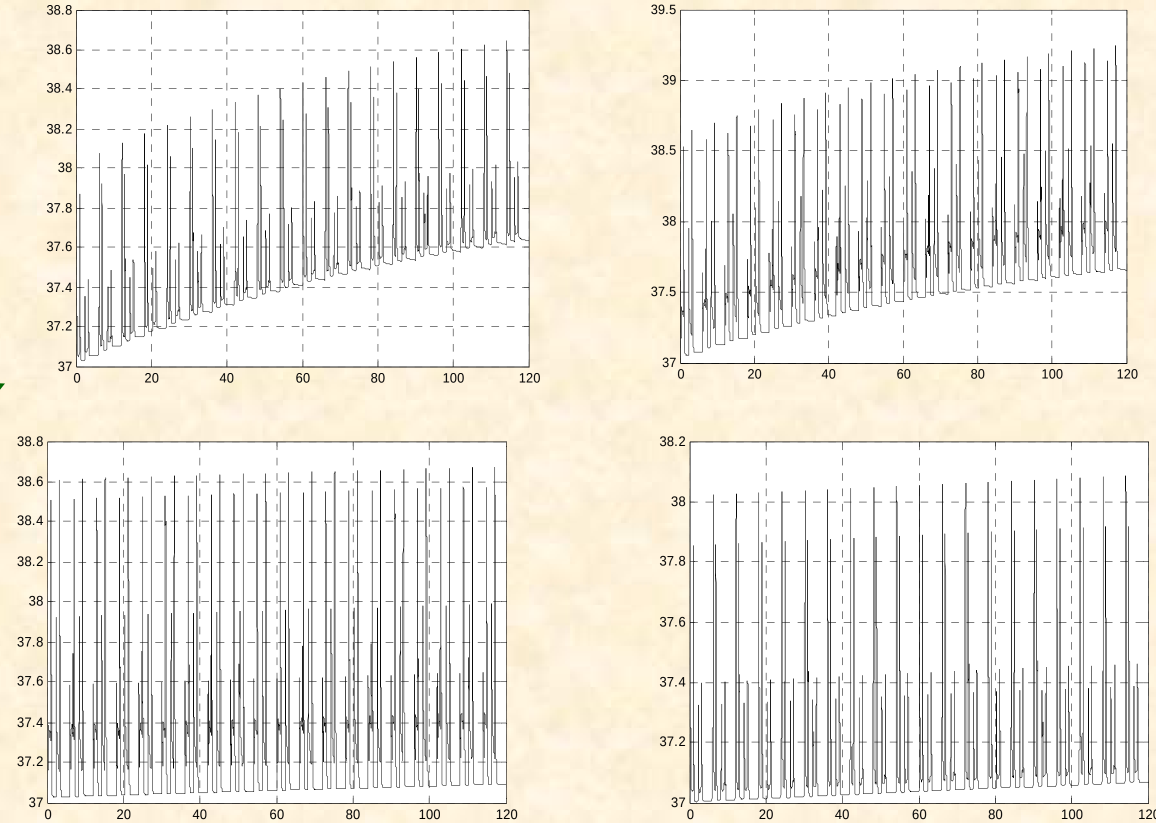
# *4.3 Simulation – Results*

A periodical input was modeling to compute the junction temperature increase of devices

**Junction temperature after 20 cycles**

**Heatsink 1**

**Heatsink 2**




**(a) JFET** **(b) Diode**

# *4.3 Simulation – Results (cont.)*

| Material | | Maximum temperature for 1st cycle (°C) | | Ave. temperature rise per cycle (°C) | | Maximum power loss (W) |
|---|---|---|---|---|---|---|
| | | JFETs | Diodes | JFETs | Diodes | |
| **Heatsink 1:** $R_{ch}$=0.0026, $t_{ch}$=0.01; $R_{ha}$=1, $t_{ha}$=900; | SiC | 38.025 | 38.639 | 0.041 | 0.065 | 89.496 |
| | Si | 71.844 | 111.773 | 0.548 | 2.660 | 1791.5 |
| **Heatsink 2:** $R_{ch}$=0.0026, $t_{ch}$=0.01; $R_{ha}$=0.01, $t_{ha}$=60; | SiC | 38.021 | 38.612 | 0.007 | 0.032 | 89.496 |
| | Si | 71.748 | 111.276 | 0.104 | 2.217 | 1791.5 |

**Maximum temperature, average temperature and maximum power loss**

# *4.3 Simulation – Results (cont.)*

| Material | Average power input (W) | Average power loss (W) | Average temperature for 1st cycle (°C) | | Inverter efficiency |
|---|---|---|---|---|---|
| SiC | 1131.21 | 5.92 | Heatsink 1: $R_{ch}$=0.0026, $t_{ch}$=0.01; $R_{ha}$=1, $t_{ha}$=900; | 37.090<br>37.228 | 99.48% |
| | | | Heatsink 2: $R_{ch}$=0.0026, $t_{ch}$=0.01; $R_{ha}$=0.01, $t_{ha}$=60; | 37.066<br>37.205 | |
| Si | 1131.21 | 77.69 | Heatsink 1: $R_{ch}$=0.0026, $t_{ch}$=0.01; $R_{ha}$=1, $t_{ha}$=900; | 38.777<br>44.730 | 93.13% |
| | | | Heatsink 2: $R_{ch}$=0.0026, $t_{ch}$=0.01; $R_{ha}$=0.01, $t_{ha}$=60; | 44.110<br>57.808 | |

**Average power loss and efficiency of a SiC inverter and a Si inverter**

# *5. Summary*

- SiC power converters are expected to provide higher efficiency and reduced size/weight.
- Feasibility demonstration a SiC converter through
  - Circuit design
  - System modeling
  - Packaging and thermal management
- Integration of circuit design and thermal management will enable SiC converters and their applications.
- System prototype including high-temperature gate drive is under investigation.