Integration and Reliability of HEV Power Electronic Systems

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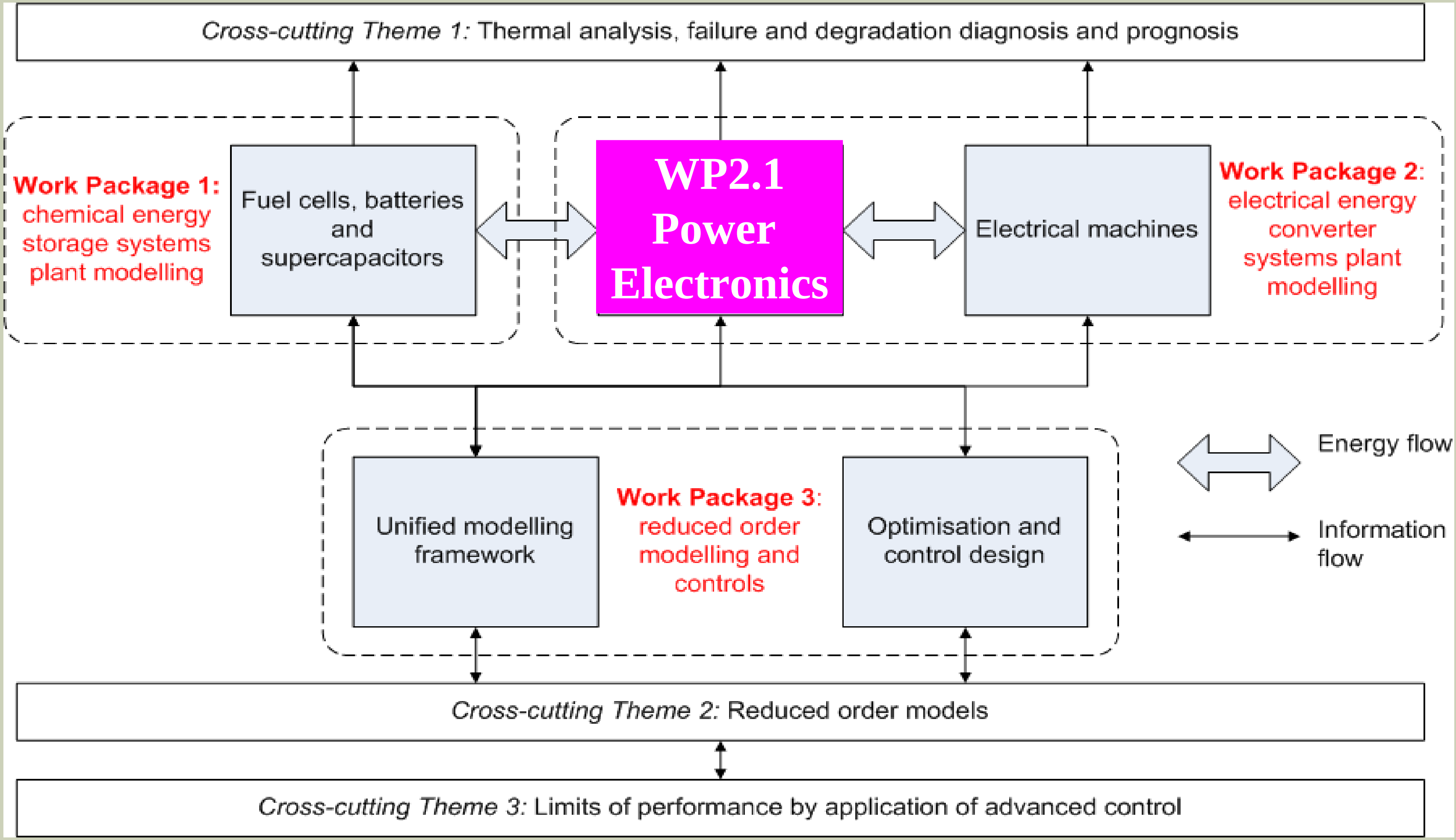
OUTLINE

- Research objectives of the WP 2.1
- Outcomes
- Part 1: New power converters for HEVs
- Part 2: Reliability assessment of the power converters
- Conclusions

WP STRUCTURE



RESEARCH OBJECTIVES OF THE WP 2.1

- **a) Reliability of power electronic systems (Dr. Xin Zhang)**

1) Investigate and identify the most vulnerable components in power electronic systems;
2) Propose mitigating measures to address the reliability issues caused by the most common causes of failure identified
3) To build a set of models suitable for real-time diagnosis of power converters.

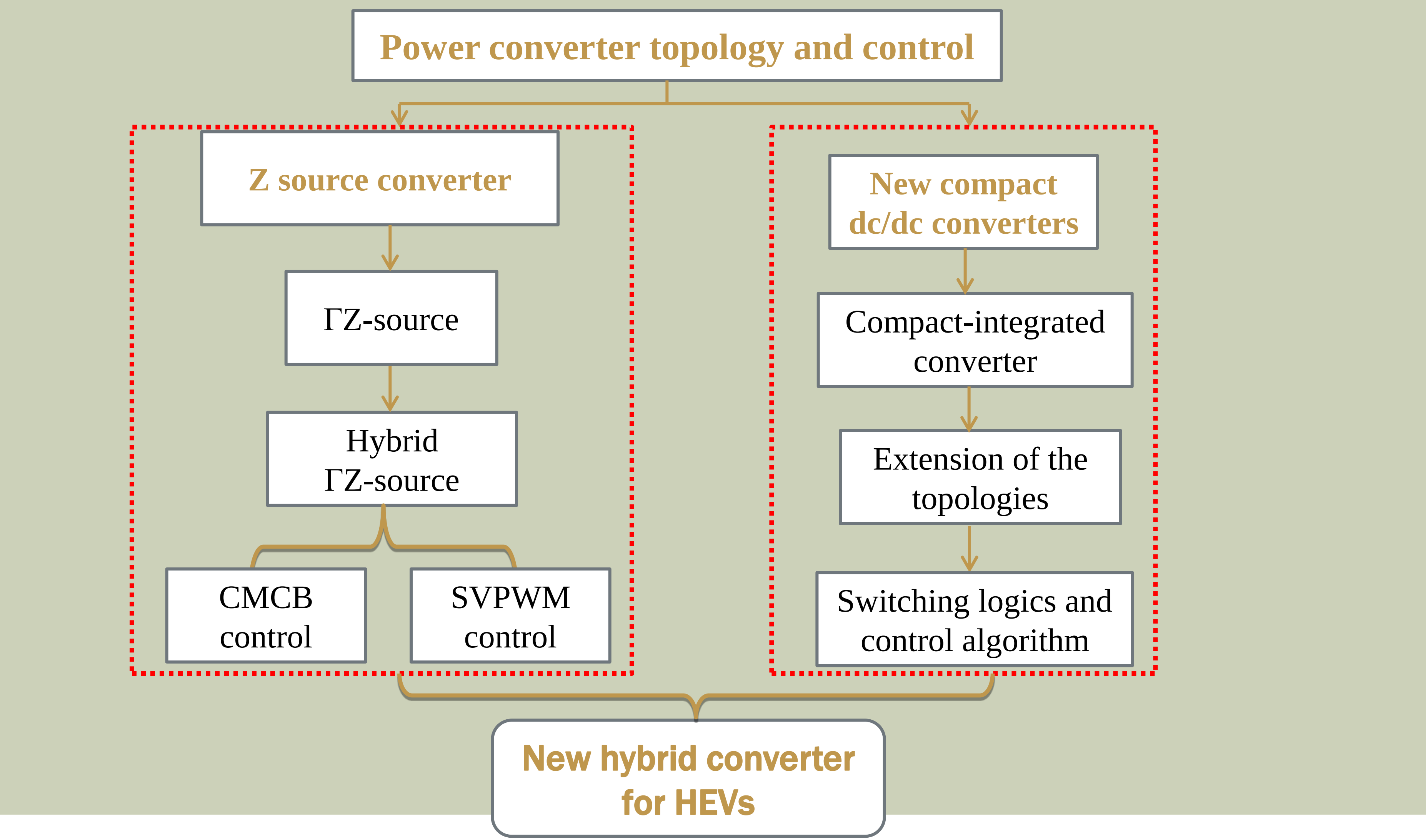
- **b) On-board energy management (Dr. Jun Cai)**

1) To investigate the power electronic topology for the electric vehicle;
2) To develop optimum control of bi-directional DC-DC converters;
3) To develop control strategy for extending the constant power region over a wide range of speeds

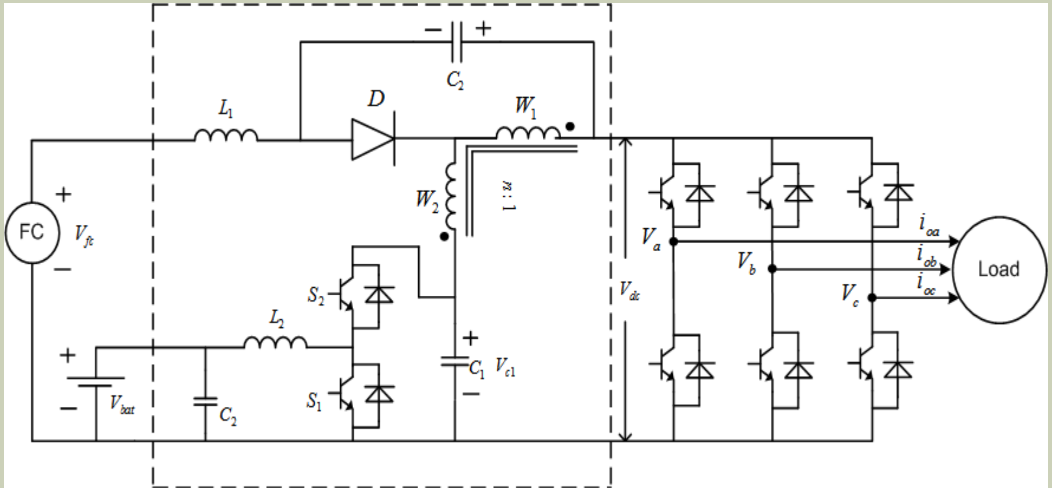
OUTCOMES

1. Q.-C. Zhong, W.-L. Ming, X. Cao, and M. Krstic, “Reduction of DC-bus voltage ripples and capacitors for single-phase PWM-controlled rectifiers,” in Proc. IECON 2012, 2012, pp. 708–713.
2. Q.-C. Zhong, W.-L. Ming, and M. Krstic, “Improving the power quality of traction power systems with a single-feeding wire,” in Proc. IEEE Green Technologies Conference, 2013, pp. 233–238.
3. Xin Cao, Qing-Chang Zhong , Wen-Long Ming, “Analysis and Control of Ripple Eliminators in DC Systems”, IEEE Green Tech 2014.
4. Jun Cai, Qing-Chang Zhong, David Stone, “A ΓZ-source converter based hybrid power converter for battery FCHEVs,” UKACC 2014.
5. Jun Cai, Qing-Chang Zhong, “ A compact bidirectional DC-DC converter with two sources,” IEEE PEDG 2014.
6. Jun Cai, Qing-Chang Zhong, “An Asymmetrical Gamma Z -source Hybrid Power Converter with Space Vector Pulse-width Modulation ,” IEEE ECCE 2014.
7. Jun Cai, Qing-Chang Zhong, David Stone, “A new power converter for hybrid energy storage systems,” IECON 2014.

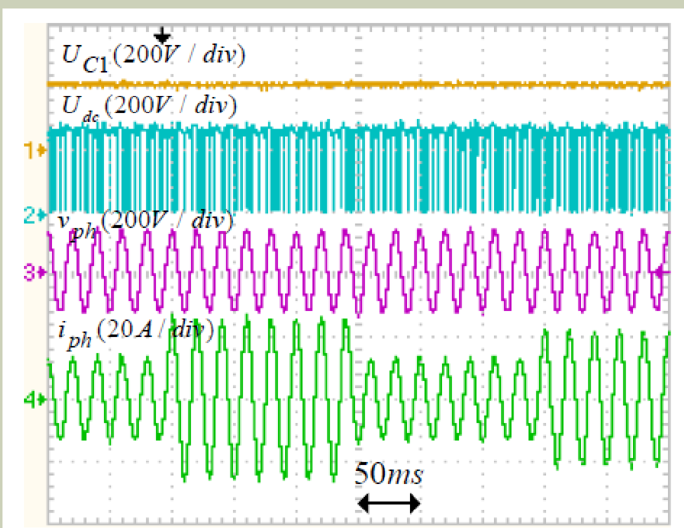
NEW POWER CONVERTERS DESIGN FOR HEVS

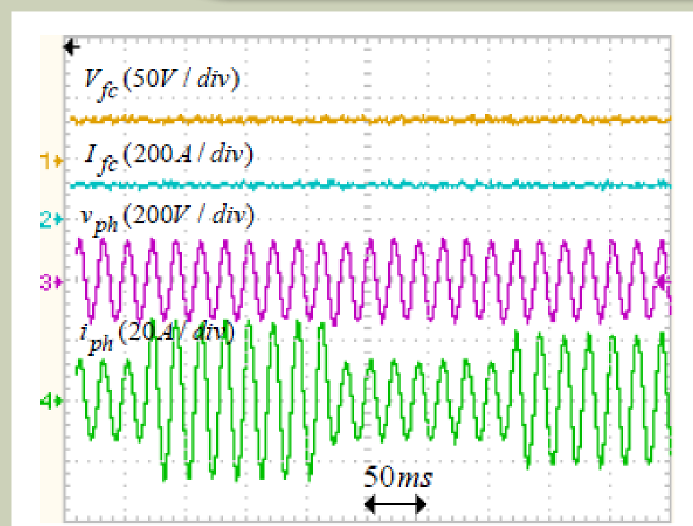


ΓZ-source Hybrid Power Converter for FC-Battery HEVs

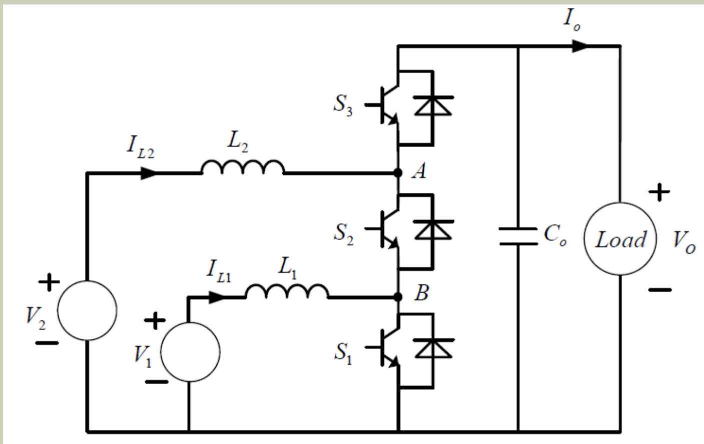


- ✓ Use ΓZ-source converter to interface the fuel cell, with high boost gains and high reliability
- ✓ Use a bidirectional DC/DC converter to control the voltage V_{c1}
- ✓ The power difference between fuel cell and loads can be handled by the battery

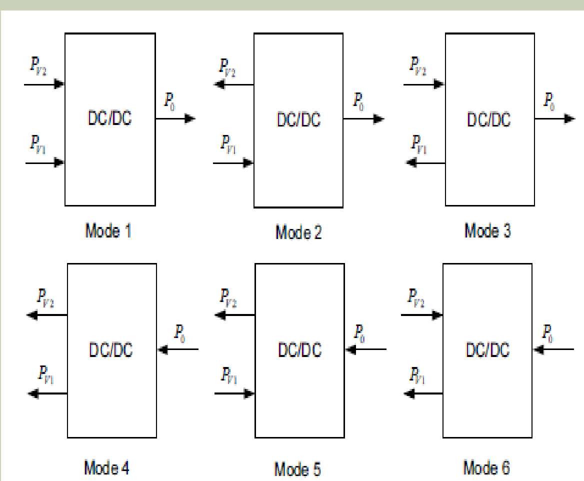


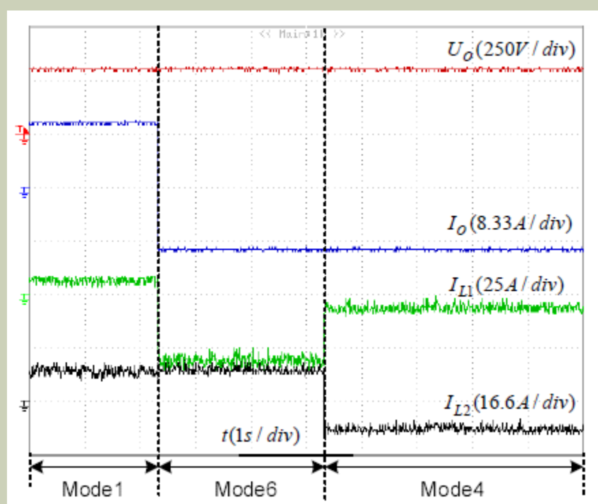


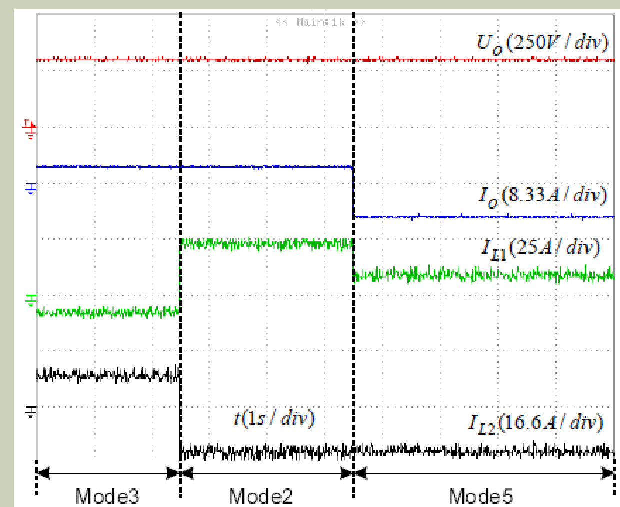
Compact Bidirectional DC-DC Converters with Two Input Sources



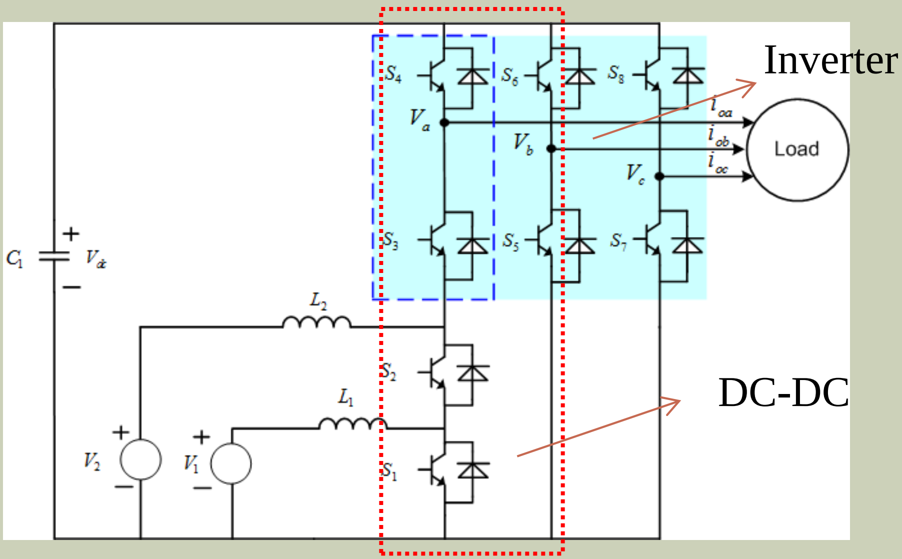
- ✓ All ports are bidirectional
- ✓ To interface two sources with only three power switches
- ✓ Easy for power flow control



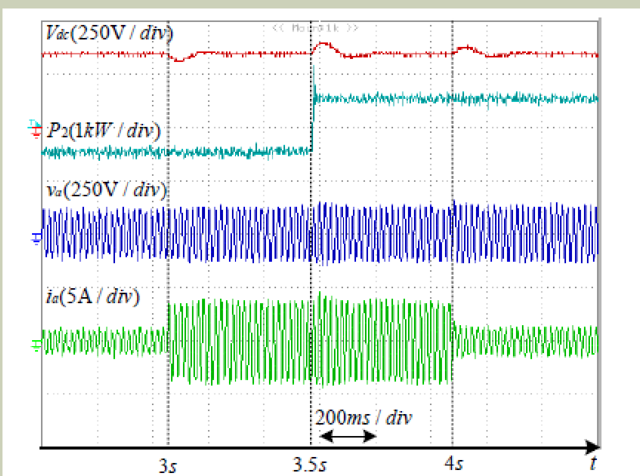


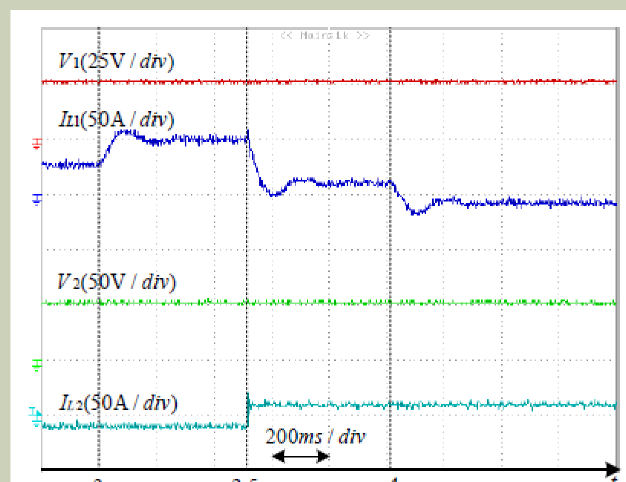


Compact-integrated Power Converter for UC-Battery HEV

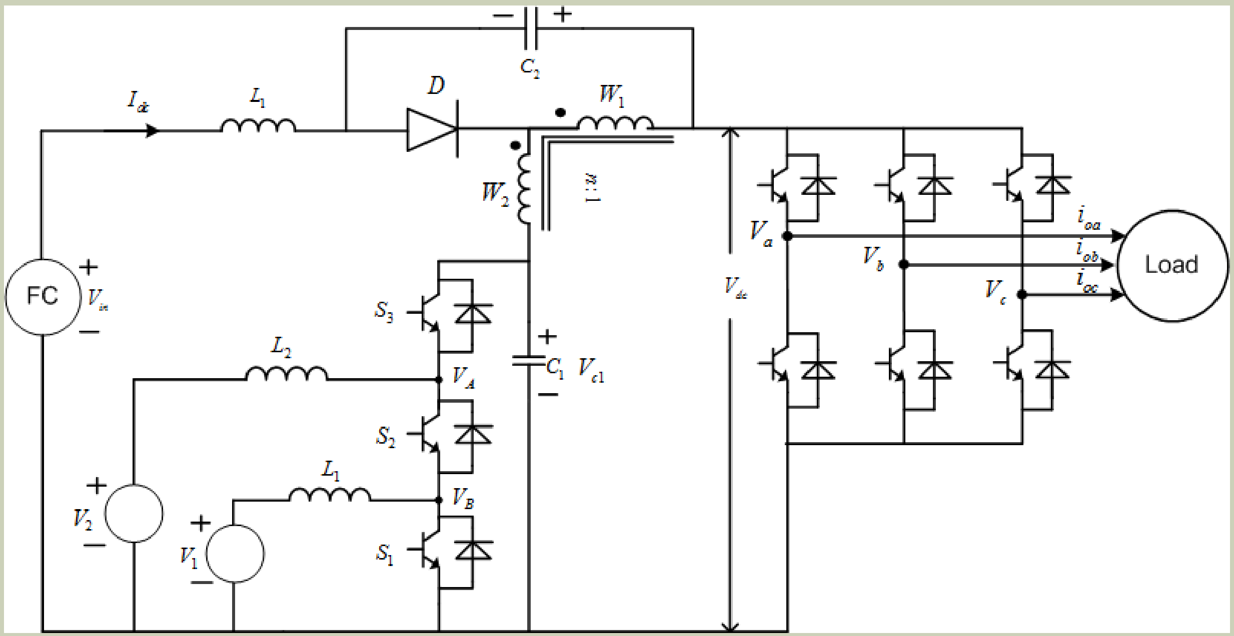


- ✓The inverter and the DC-DC converter are integrated
- ✓The DC-DC converter can interface two sources with only two additional power switches. More compact with higher power density, and cost effective
- ✓All ports are bidirectional
- ✓The DC-bus voltage and the power of the sources can be controlled



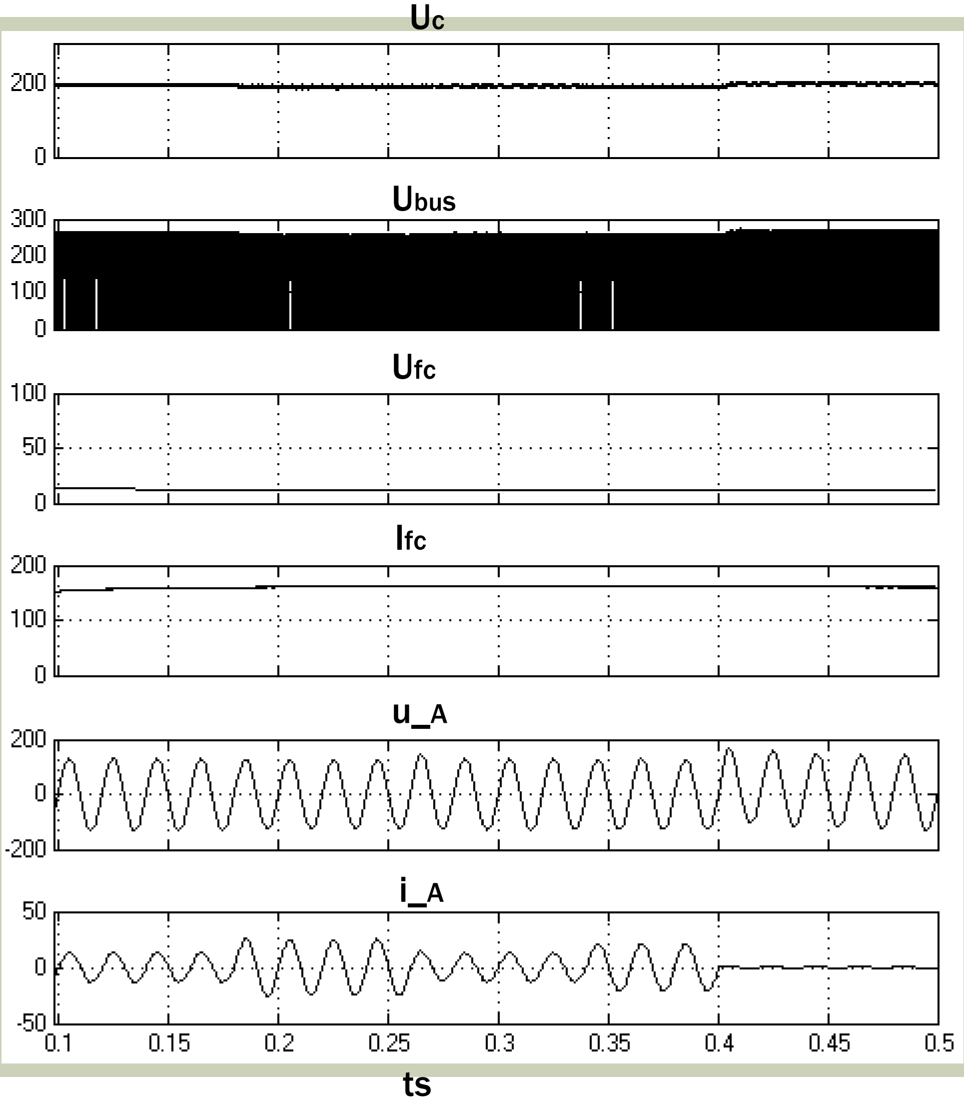


New hybrid Converter for FC-UC-Battery HEV



- ✓Suitable for FC-UC-Battery HEV
- ✓The integration of ΓZ-source converter and the compact DC-DC converter.
- ✓All the features of these two kinds of converters are included
- ✓High power density and high reliability, and compact with low costs
- ✓The power flow control is quite flexible

Simulation Results



- ✓ ΓZ-source converter capacitor voltage can be controlled
- ✓The fuel cell power can be controlled in to the optimal reference value
- ✓ Battery and UC can be fully controlled under different load conditions

Traditional reliability assessment methods

Reliability prediction metrics

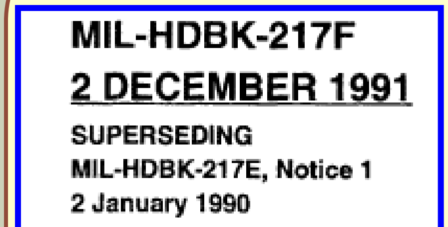
$$R(t) = e^{-\int_0^t \lambda(\tau) d\tau}$$

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t+\Delta t)}{R(t)\Delta t} = -\frac{1}{R(t)} \frac{dR(t)}{dt}$$

$$MTTF = \int_0^{+\infty} R(t) dt$$

- MTTF can be treated as the only indicator
- Larger MTTF means higher reliability

Component-level reliability model


MIL-HDBK-217F
2 DECEMBER 1991
SUPERSEDING
MIL-HDBK-217E, Notice 1
2 January 1990

Temperature cycles ⇩ IGBT

System-level reliability model

a) Part-count model
b) Combinatorial model

} Series system

c) Markov model → Redundant system

Challenges of traditional methods and the proposed assessment method

Challenges

(1) Reliability indicators

- MTTF is not enough for reliability assessment when system's power distribution is varied.

(2) Reliability models

2.1 Component-level reliability model

- Should we consider all of the failure rates or not?

2.2 System-level reliability model

- Part-count and combinatorial models are simply but cannot evaluate the reliability of fault-tolerant system.
- Markov model can evaluate the fault-tolerant system's reliability but complex.

Three-step assessment method

Step 1:Compare failure rates of all components at all states and select necessary ones

- List components in the system
- List the working conditions of components
- Calculate and compare failure rates $\lambda(t)$ of components at all states

Footstone

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Step 2:Build Hybrid reliability model

- Distinguish the non-redundant subsystems and redundant subsystems
- Build part-count model for non-redundant subsystems
- Build Markov model for redundant subsystms

Core

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Step 3: Calculate MTTF and MTTFr

- Calculate MTTF
- Calculate MTTFr → Proposed metric

Results

CONCLUSIONS

- A method for developing power converter topologies for HEVs with high integration, high power density, high reliability and low cost characteristics is proposed

- Point out the drawbacks of the traditional reliabil ity   assessment methods and proposed an impro ved approach

THANK YOU FOR YOUR TIME!

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