FUTUREVehicles

Work Package 2.1

Power Electronics and Transmission

Qing-Chang Zhong, David Stone, Jun Cai, Wen-Long Ming

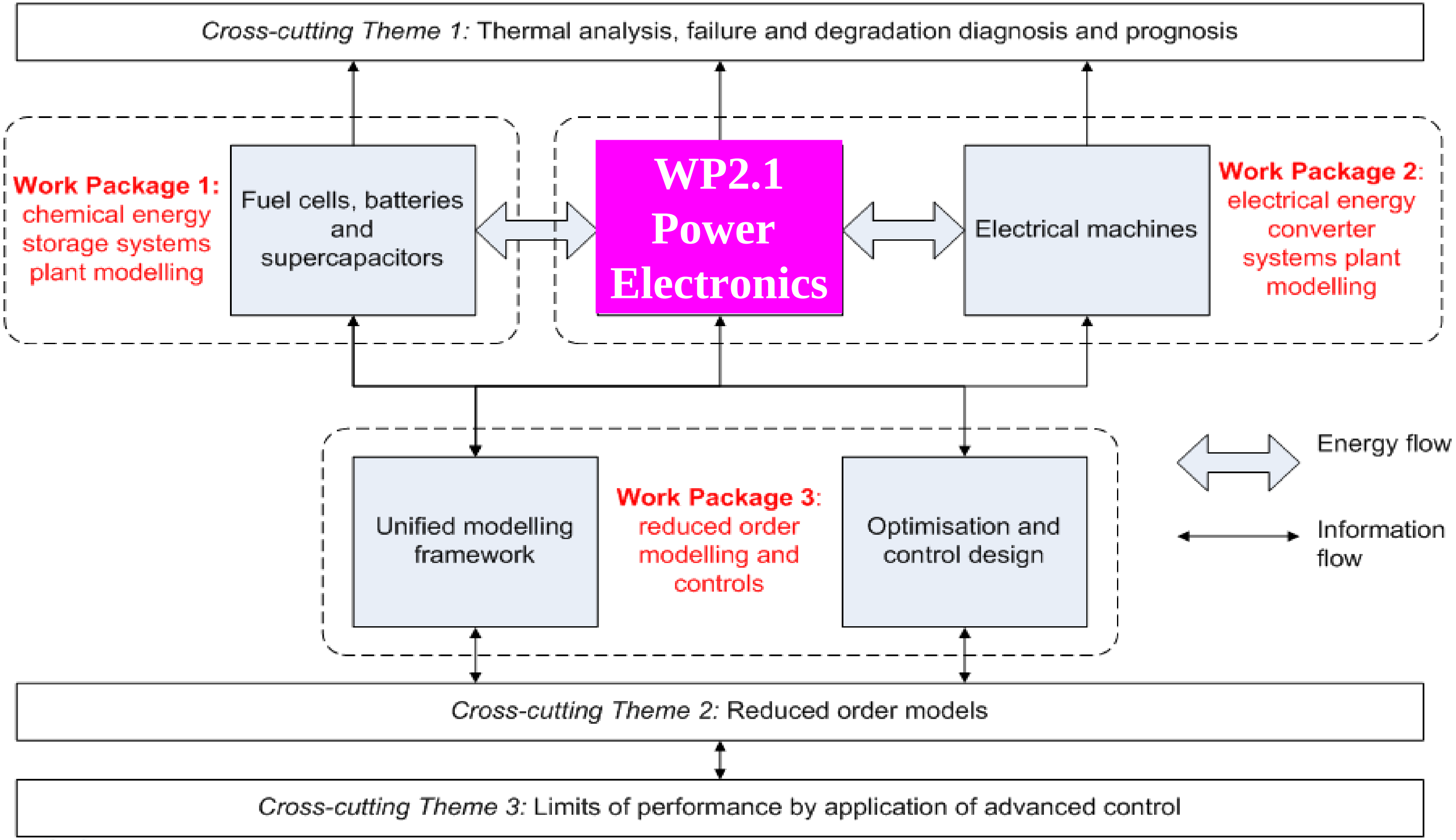
The University of Sheffield

Coventry University · Cranfield University · Imperial College London · Loughborough University · University of Oxford · The University Of Sheffield.

Outline

- A brief introduction of the work package
- Lab facilities and researchers
- Overall progress and outcomes
- A ΓZ-source converter based hybrid power converter for battery FCHEVs
- Conclusions and Discussions

WP structure



Cross-cutting Theme 1: Thermal analysis, failure and degradation diagnosis and prognosis

Work Package 1: chemical energy storage systems plant modelling

Fuel cells, batteries and supercapacitors

WP2.1 Power Electronics

Electrical machines

Work Package 2: electrical energy converter systems plant modelling

Unified modelling framework

Work Package 3: reduced order modelling and controls

Optimisation and control design

Cross-cutting Theme 2: Reduced order models

Cross-cutting Theme 3: Limits of performance by application of advanced control

Research objectives of WP2.1

a) Reliability of power electronic systems

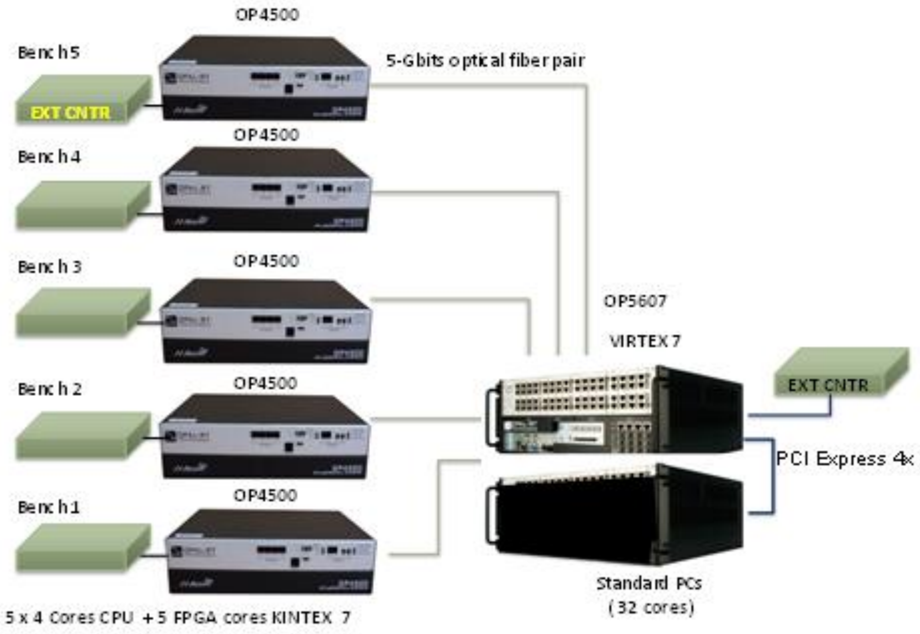
1) Investigate and identify the most vulnerable components in power electronic systems;
2) Propose mitigating measures to address the reliability issues caused by the most common causes of failure identified
3) To build a set of models suitable for real-time diagnosis of power converters.

b) On-board energy management

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

Lab facilities

- **Hybrid powertrain: 80kVA gen-set, three 200kVA converters, 750V 100A DC bus**
- **Largest OPAL-RT real-time digital simulator in EU and North America**

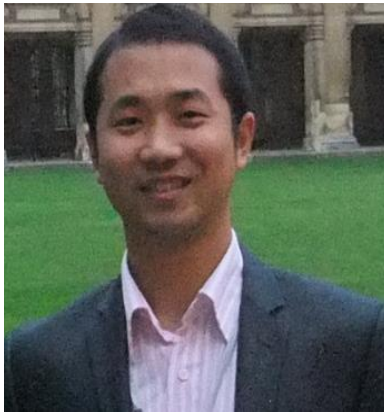


Coventry University
Cranfield University
Imperial College London

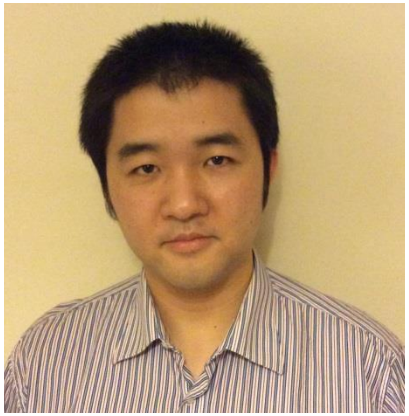
Researchers

Prof. Qing-chang Zhong
WP leader

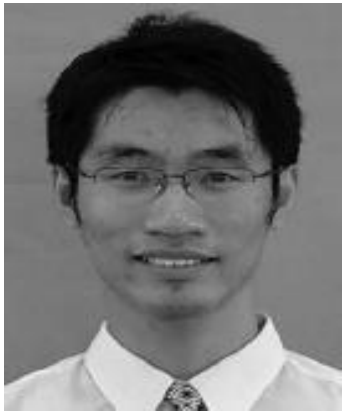
Prof. David Stone



Dr. Jun Cai



Mr. Wenlong Ming



Dr. Xin Zhang

Overall progress

- DC bus voltage ripple eliminator: to eliminate DC bus voltage ripples and remove bulky electrolytic capacitors
- Energy management topologies based on ΓZ-source converters for battery-fuel cell HEV, which can achieve hybrid power flow control and high reliability
- Compact DC-DC converters for pure EV and battery-fuel cell HEV to reduce system cost and enhance system reliability
- Synchronverters: Converters that mimic synchronous machines. This is the key technology to build the architecture for next-generation smart grids, which allows all power systems to grow organically and to be operated autonomously.

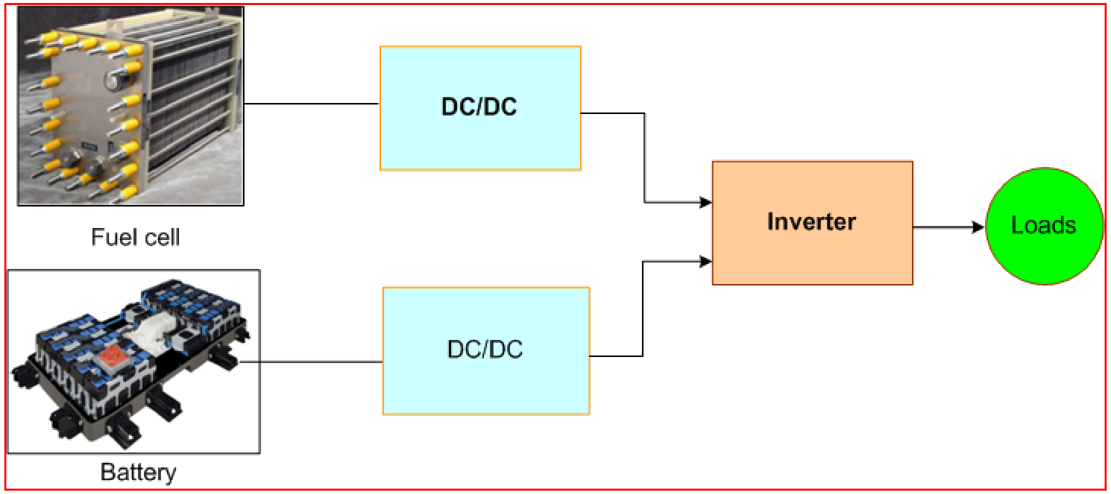
Publications

- 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 - 38th Annual Conf. IEEE Industrial Electronics Society, 2012, pp. 708–713.
- 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.
- Jun Cai, Qing-Chang Zhong, David Stone, “A ΓZ-source converter based hybrid power converter for battery FCHEVs,” to be submitted.
- Jun Cai, Qing-Chang Zhong, David Stone, Wen-long Ming, “ A compact bidirectional DC-DC converter for battery-ultra capacitor hybrid vehicle ,” to be submitted.
- Jun Cai, Qing-Chang Zhong, David Stone, “ Modified SVPWM control scheme for a new compact bidirectional DC-DC converter ,” to be submitted.
- Jun Cai, Qing-Chang Zhong, David Stone, “A new power converter for switched reluctance motor drive in pure electric vehicle,” to be submitted.

A ΓZ-source Hybrid Power Converter for battery-FCHEVs

- Topology of the converter
- Control strategies and analysis
- Matlab simulation results and RT-Lab real time simulation results

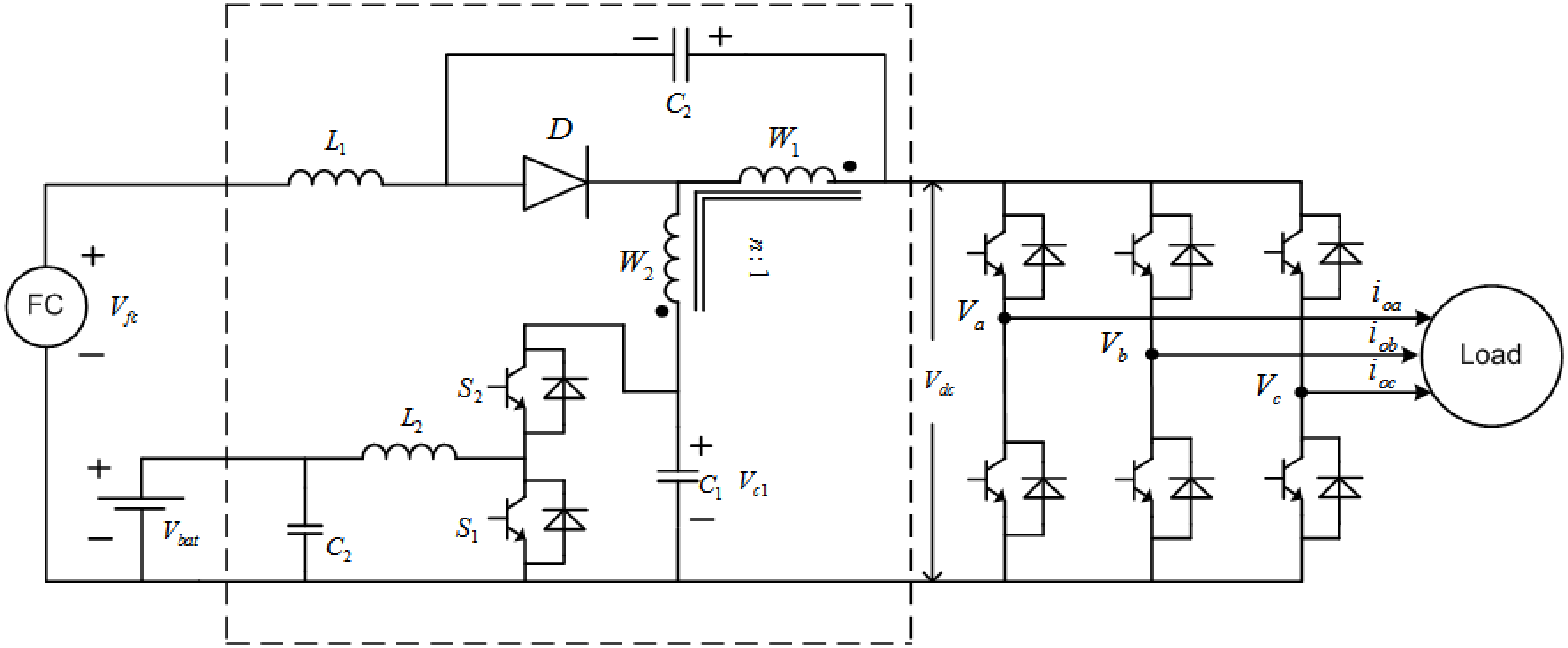
Traditional Battery-FCHEV power system



- ✓ The power of each source channel can be controlled properly
- ✓ The unnecessary interactions between FC and battery can be eliminated

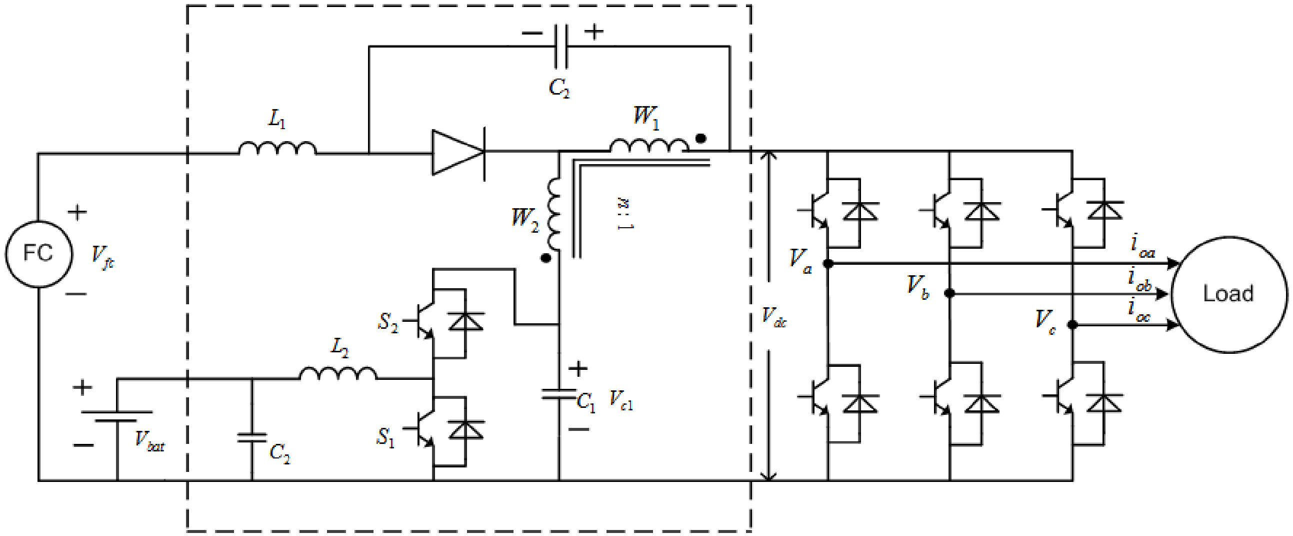
- ❖ With two full power/size DC/DC converters, the complicity and the costs is increased
- ❖ Phase leg cannot be shorted. This is a basic problem for the operation of the traditional inverters.

The proposed ΓZ-source hybrid power converter for FCHEVs



- ✓ Use a ΓZ-source converter to interface the fuel cell, with high boost gains and high reliability.
- ✓ Use a bidirectional DC/DC converter to charge/discharge the battery.
- ✓ The voltage V_{c1} can be controlled.

Theoretical analysis



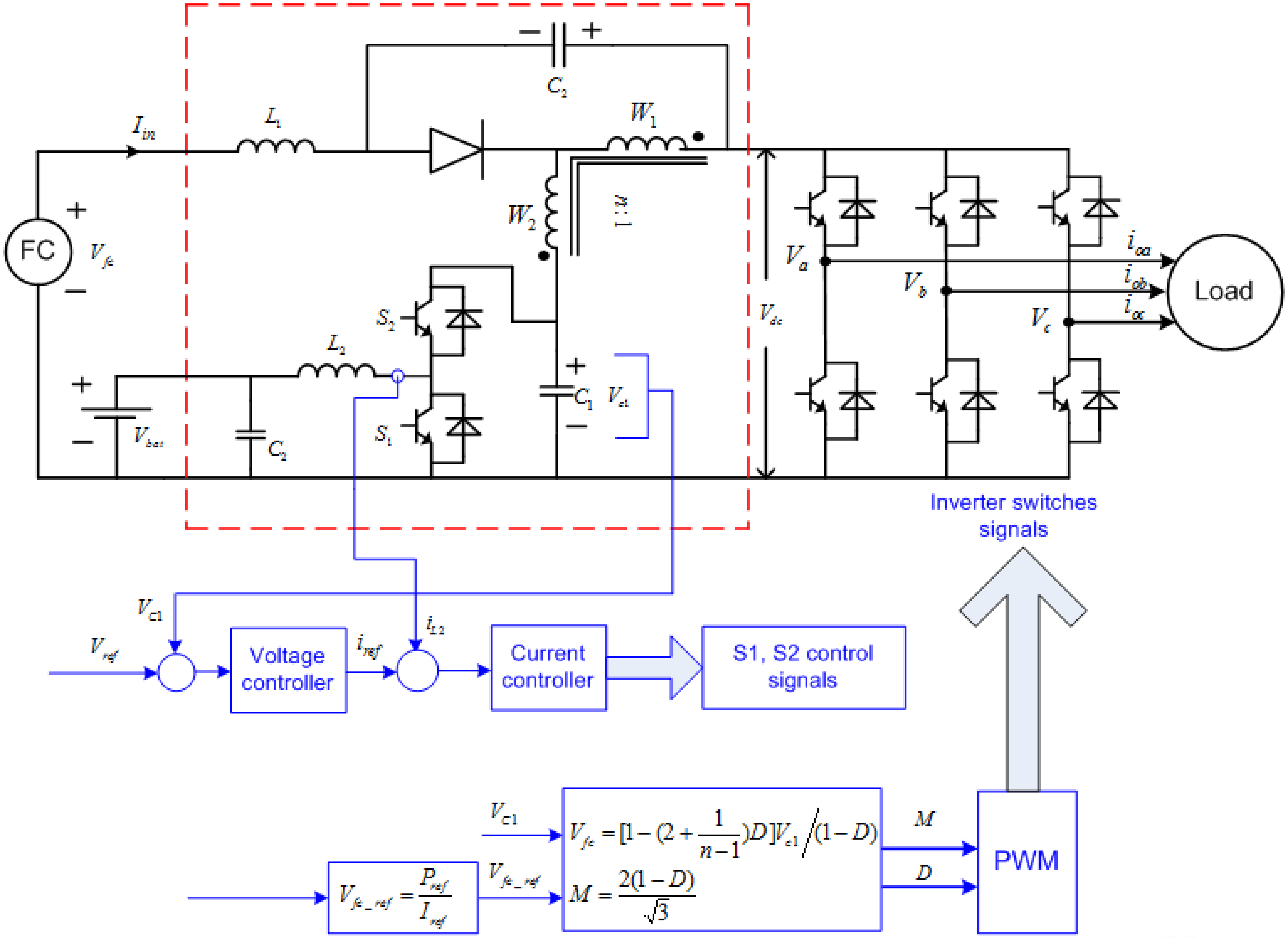
$$V_{C1} = (1 - D)V_{fc} / \left(1 - \left(2 + \frac{1}{n-1}\right) D\right)$$

If V_{C1} is controlled

$$V_{fc} = \left(1 - \left(2 + \frac{1}{n-1}\right) D\right) V_{C1} / (1 - D)$$

By adjust D, V_{fc} and P_{fc} can be controlled

Control strategy



$$V_{fc\_ref} = \frac{P_{ref}}{I_{ref}}$$

$$V_{fc} = [1-(2+\frac{1}{n-1})D]V_{c1} \Big/ (1-D)$$

$$M = \frac{2(1-D)}{\sqrt{3}}$$

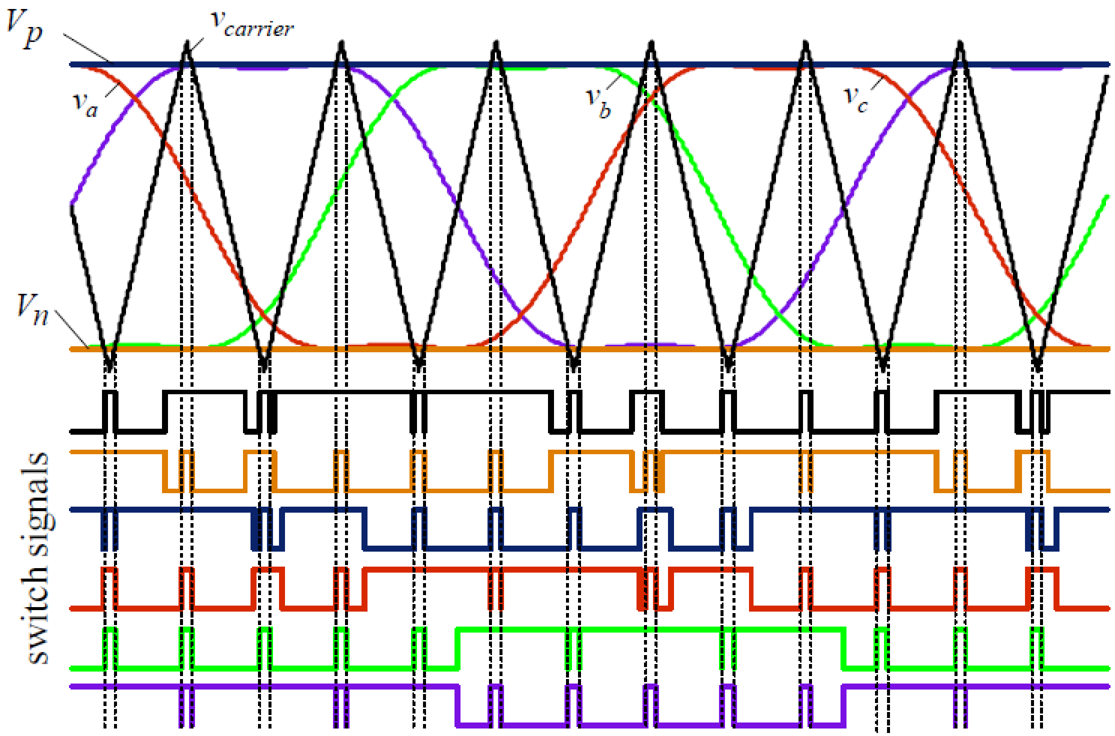
Traditional carrier based maximum constant boost control

- ✓ With third harmonic signal injection, can achieve higher modulation index
- ✓ Can keep the *D* constant to lower current and voltage ripple, reduce system volume and costs
- ❖ In shoot through states, all phase legs are shoot through simultaneously. The number of switching is increased remarkably

SVPWM control

- ✓ Have all the features of the carrier based control method
- ✓ Can reduce the number of semiconductor switching, thus can lower the switching loss

Carrier based maximum constant boost control

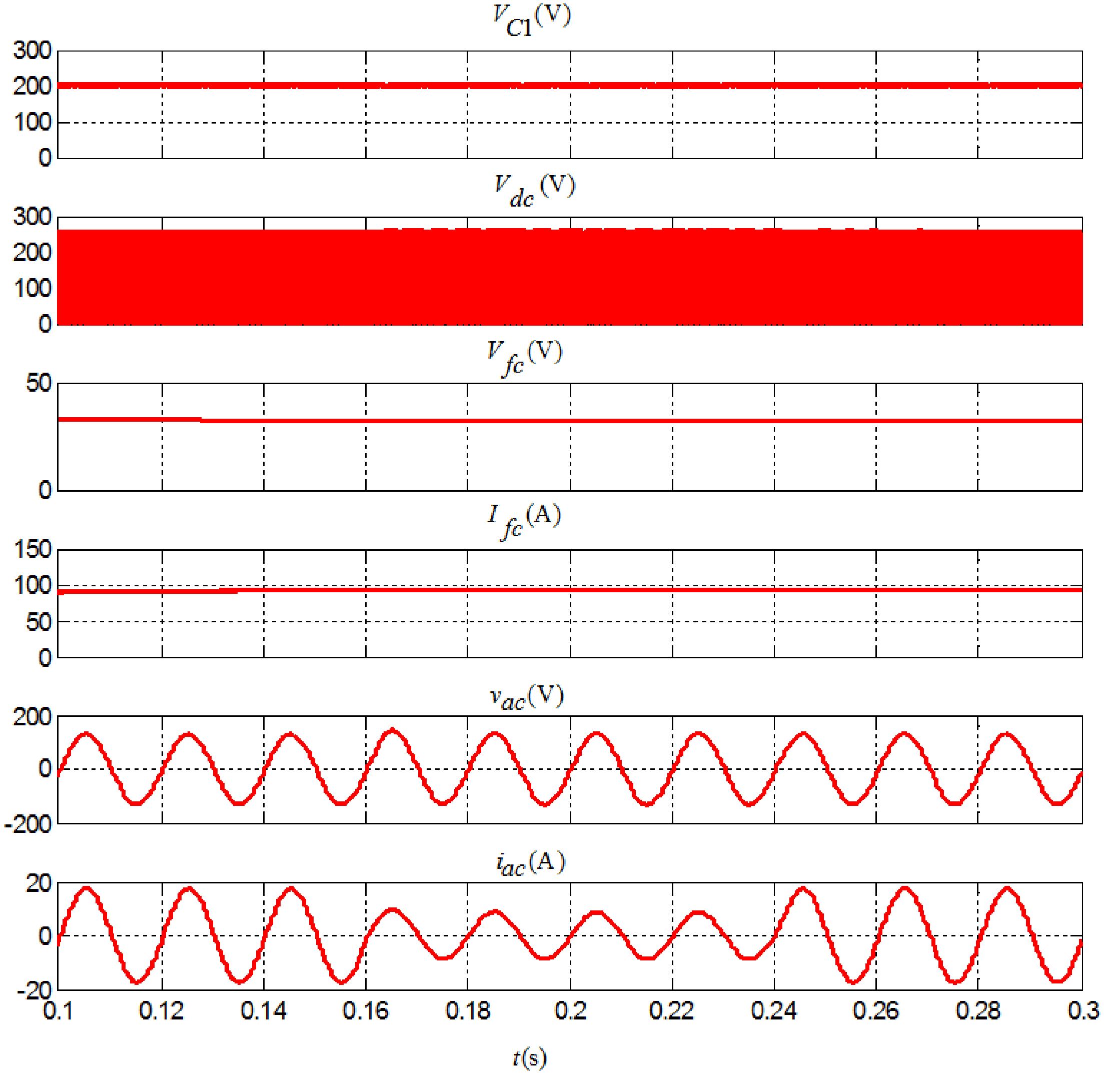


$$\begin{cases} V_p = \dfrac{\sqrt{3}M}{2} \\ V_n = -\dfrac{\sqrt{3}M}{2} \end{cases}$$

$$D = 1 - \frac{\sqrt{3}M}{2}$$

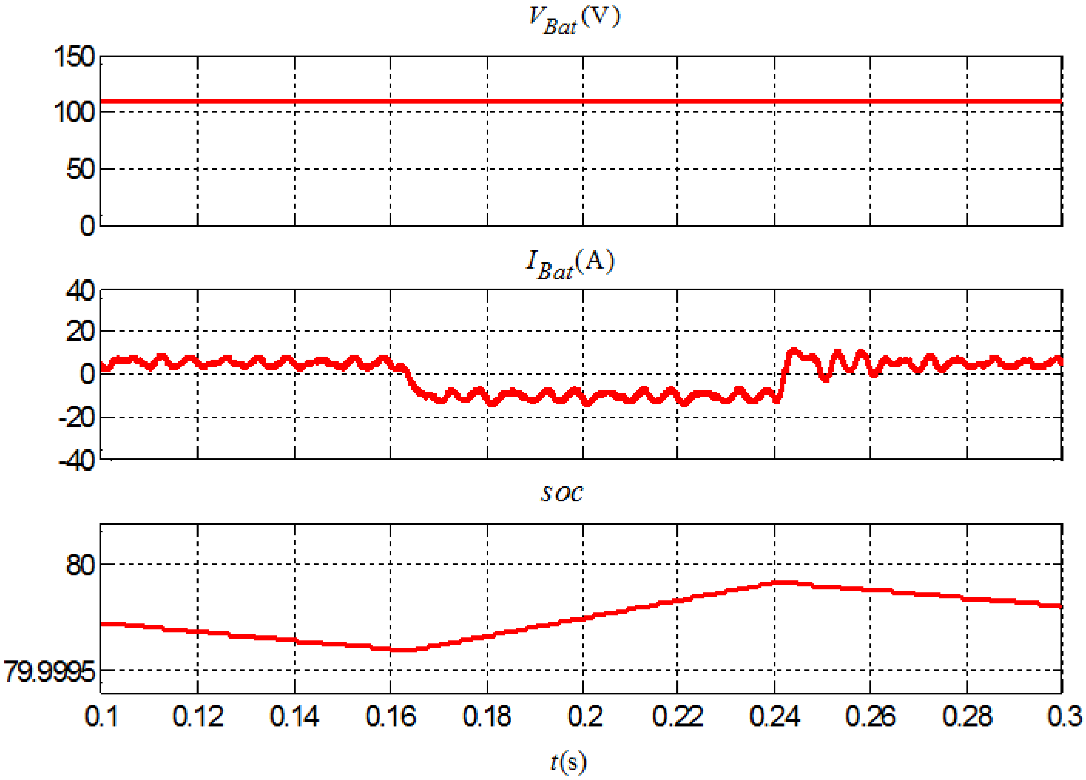
The maximum *M* reaches 1.15.

Simulation results



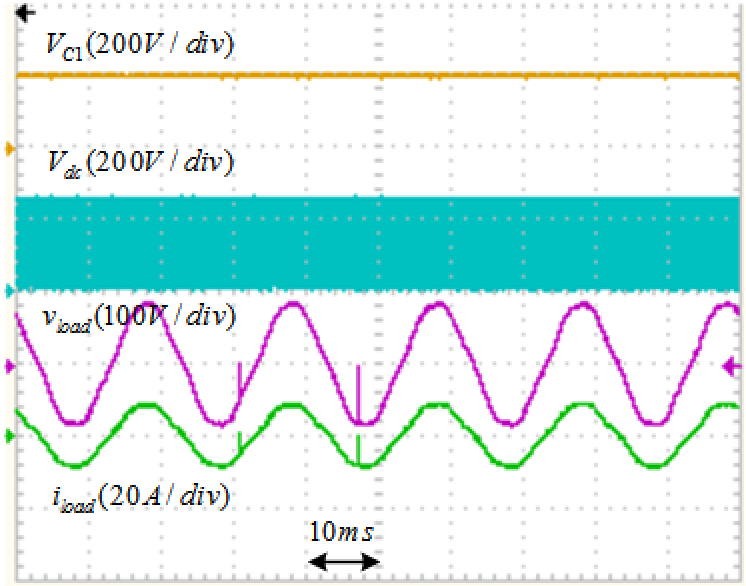
- ❖ The ΓZ-source capacitor voltage V_{C1} can be controlled by the DC/DC converter
- ❖ The V_{fc} can be controlled by controlling the M
- ❖ The fuel cell output power kept constant under load transient conditions
- ❖ The V_{dc} is a pulse voltage, the output voltage of the inverter is not change.

Simulation results

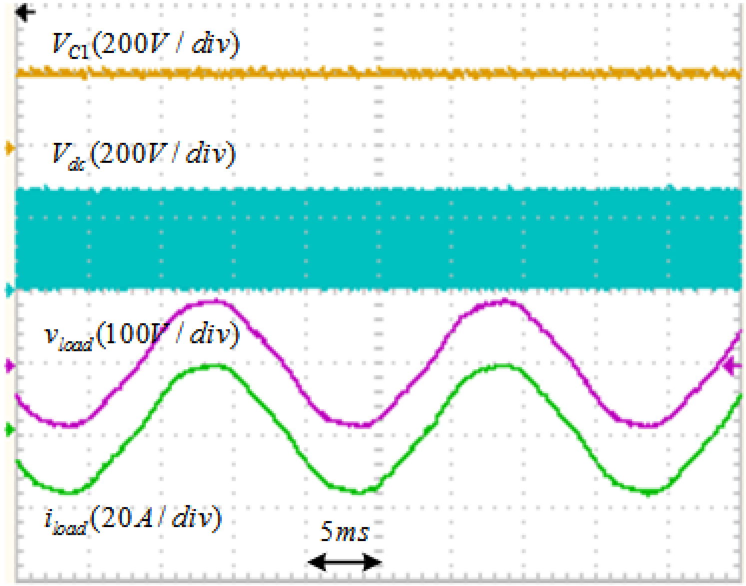


- The load power transients can be handled by the battery
- The battery can be charged and discharge through the bidirectional DC-DC converter

Opal -RT real time simulation



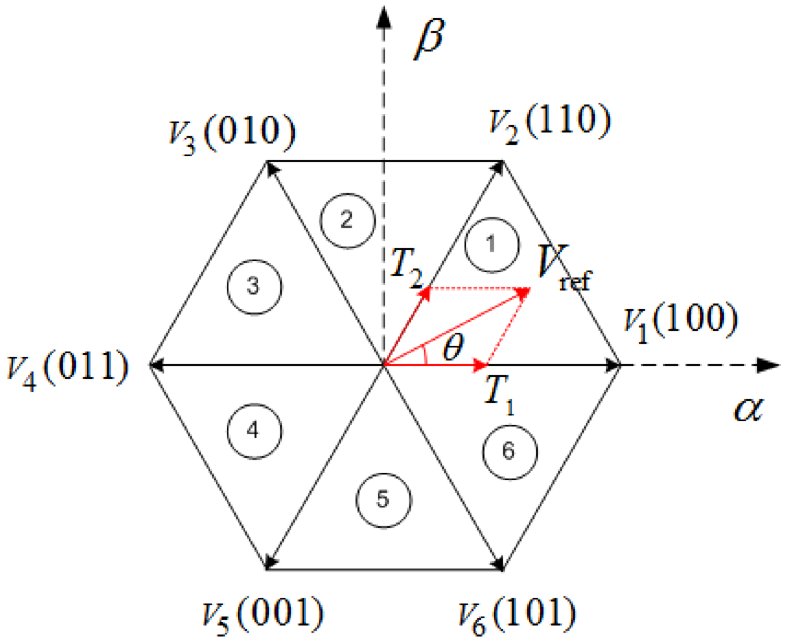
Light load case



Heavy load case

- ✓ The capacitor V_{C1} of the Z-source converter is controlled at a constant
- ✓ The bus voltage and output voltage of the inverter are stable

Modified SVPWM for ΓZ source converter



Zero vectors	$V_0(000)$	$V_7(111)$	
Shoot vectors	V_{SA}	V_{SB}	V_{SC}

$\alpha - \beta$ transformation

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

$$\theta = \arctan\frac{u_\beta}{u_\alpha}$$

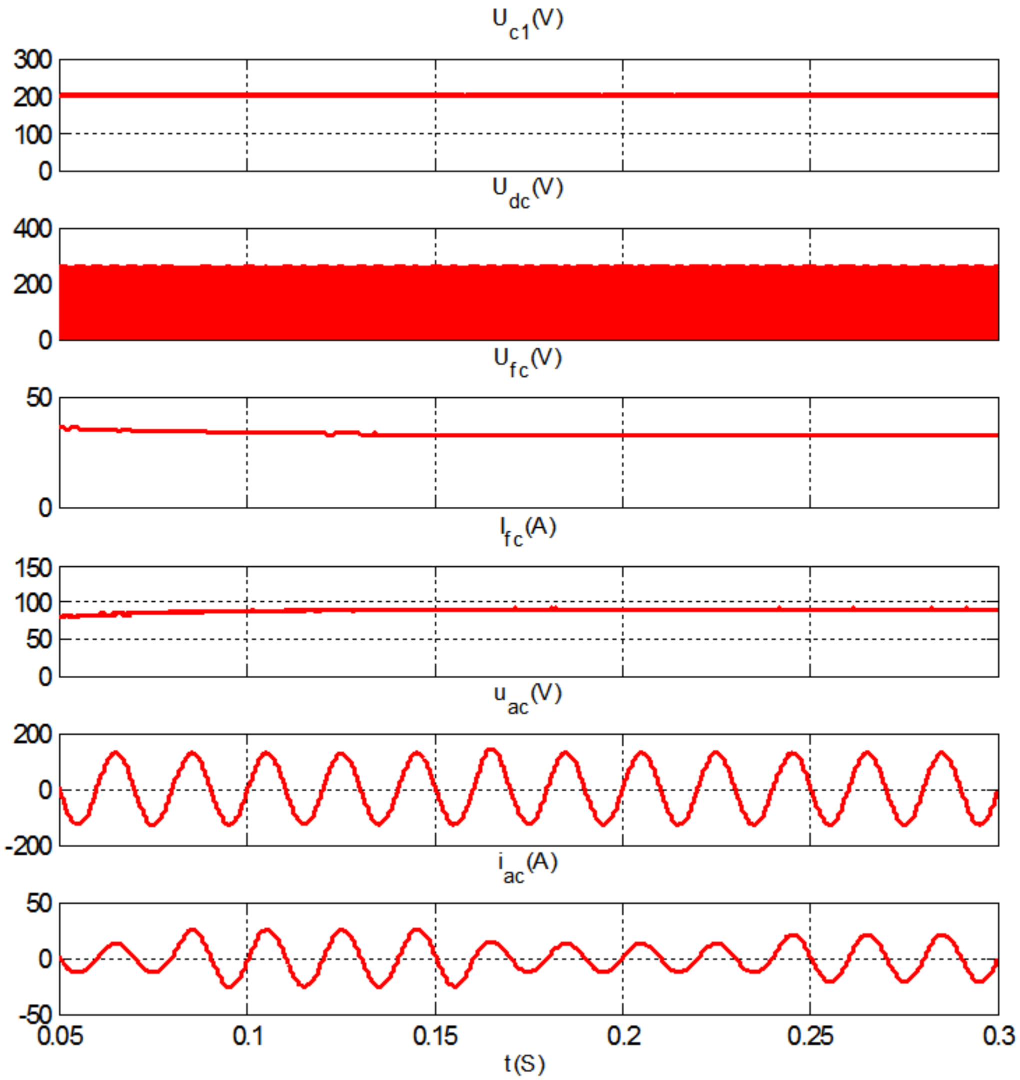
$$\|V_{ref}\| = \sqrt{(u_\alpha)^2 + (u_\beta)^2}$$

The space vector is

$$\overrightarrow{V_{ref}} = \frac{1}{T}\left[T_i\vec{V_i} + T_j\vec{V_i} + T_0(\overrightarrow{V_0}, \vec{V_7}) + T_{sh}V_{SN}\right]$$

With only one phase leg shoot through

Simulation results



- ✓ V_{C1} can be controlled by the DC/DC converter
- ✓ V_{fc} can be controlled by controlling the M
- ✓ The fuel cell output power can be controlled to achieve high efficiency and healthy operation

Conclusions

- Proposed a ΓZ-source based hybrid power converter for battery FCHEV
- Developed the modified SVPWM for the ΓZ-source based hybrid power converter
- Verified through simulations

Future work

- To develop an experimental test bed
- To verify the new topologies and related control strategies through experiments
- To investigate the energy management scheme for the new converters
- To cooperate with the other groups to optimise the simulation and experiments

Thank You

Questions ?