Maximizing the Potential of WBG Devices for EV Battery Chargers

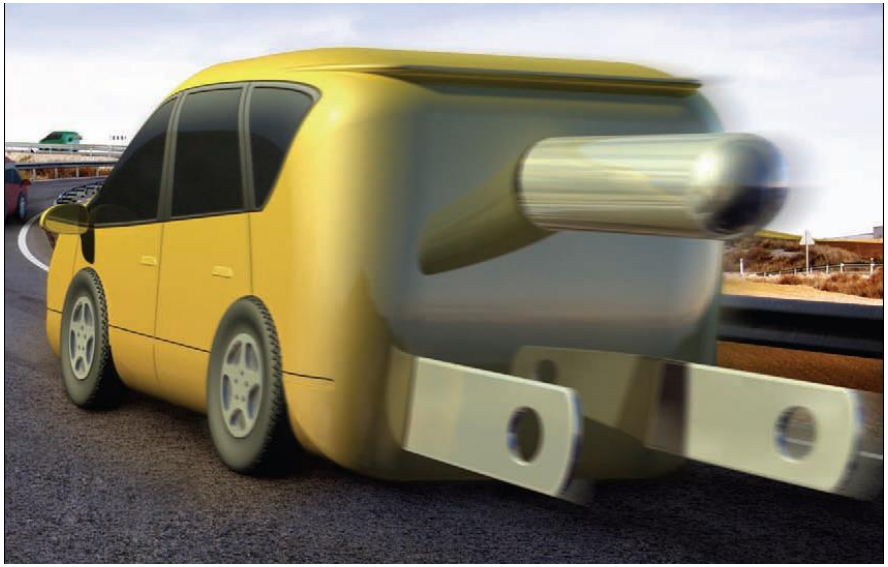
Hua "Kevin" Bai

Presentation for

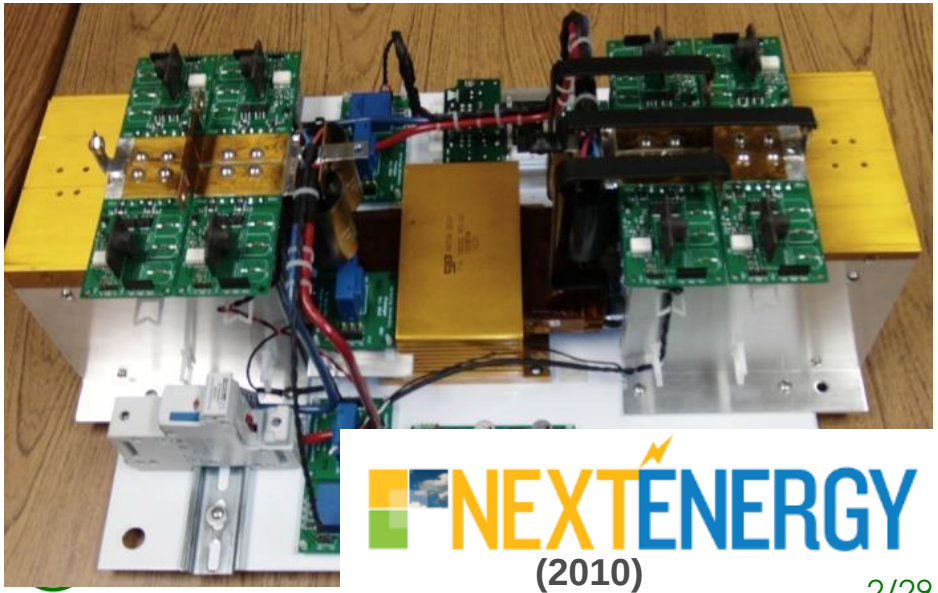
Knoxville, TN

August 24th, 2018

Battery Chargers- Si Version



11kW charger (grid side, 2011)

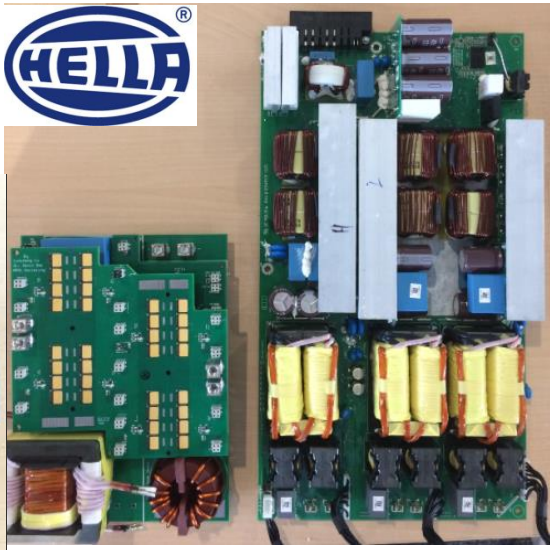


(2010)

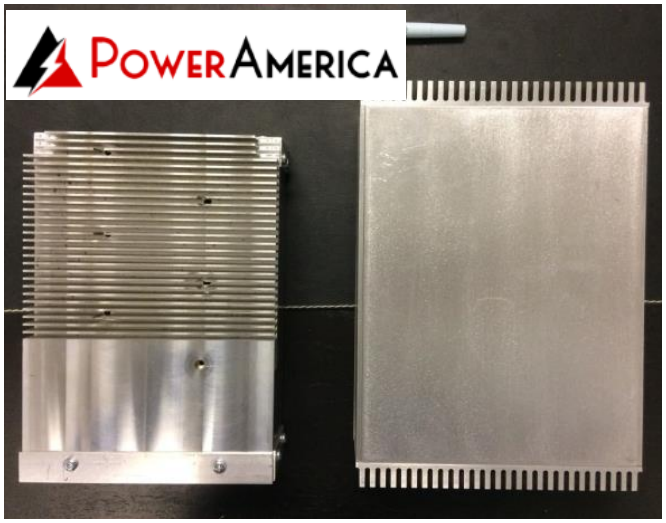
11kW charger (battery side, 2011)

Battery Chargers – WBG Version

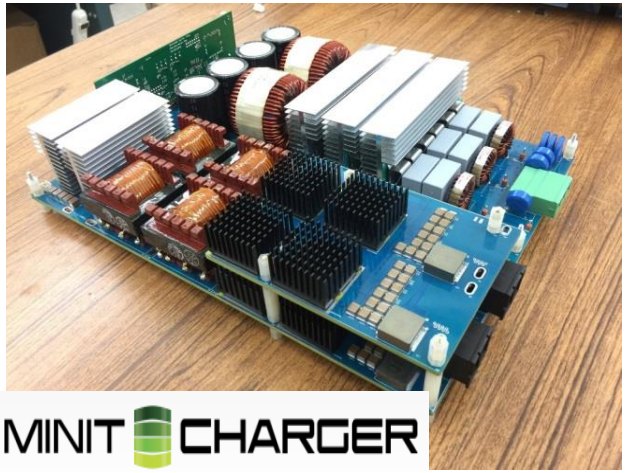
DC-grid non-isolated charger, 2013



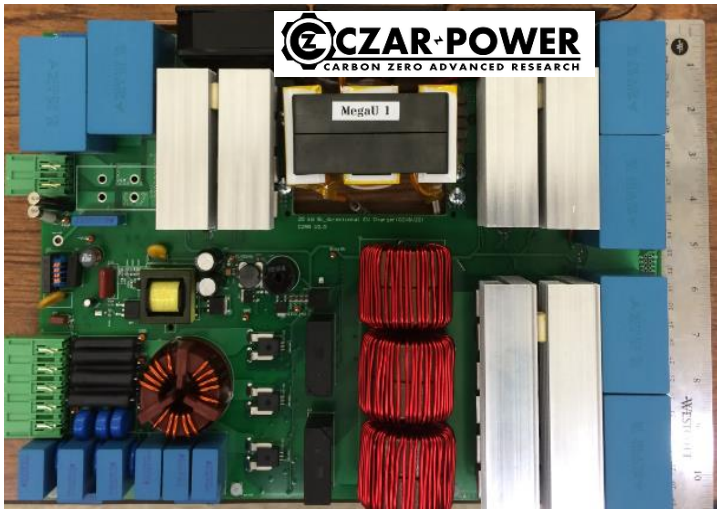
6.6kW charger (GaN vs Si), 2015



6.6kW charger (GaN vs SiC), 2016



48V/11kW charger, 2017

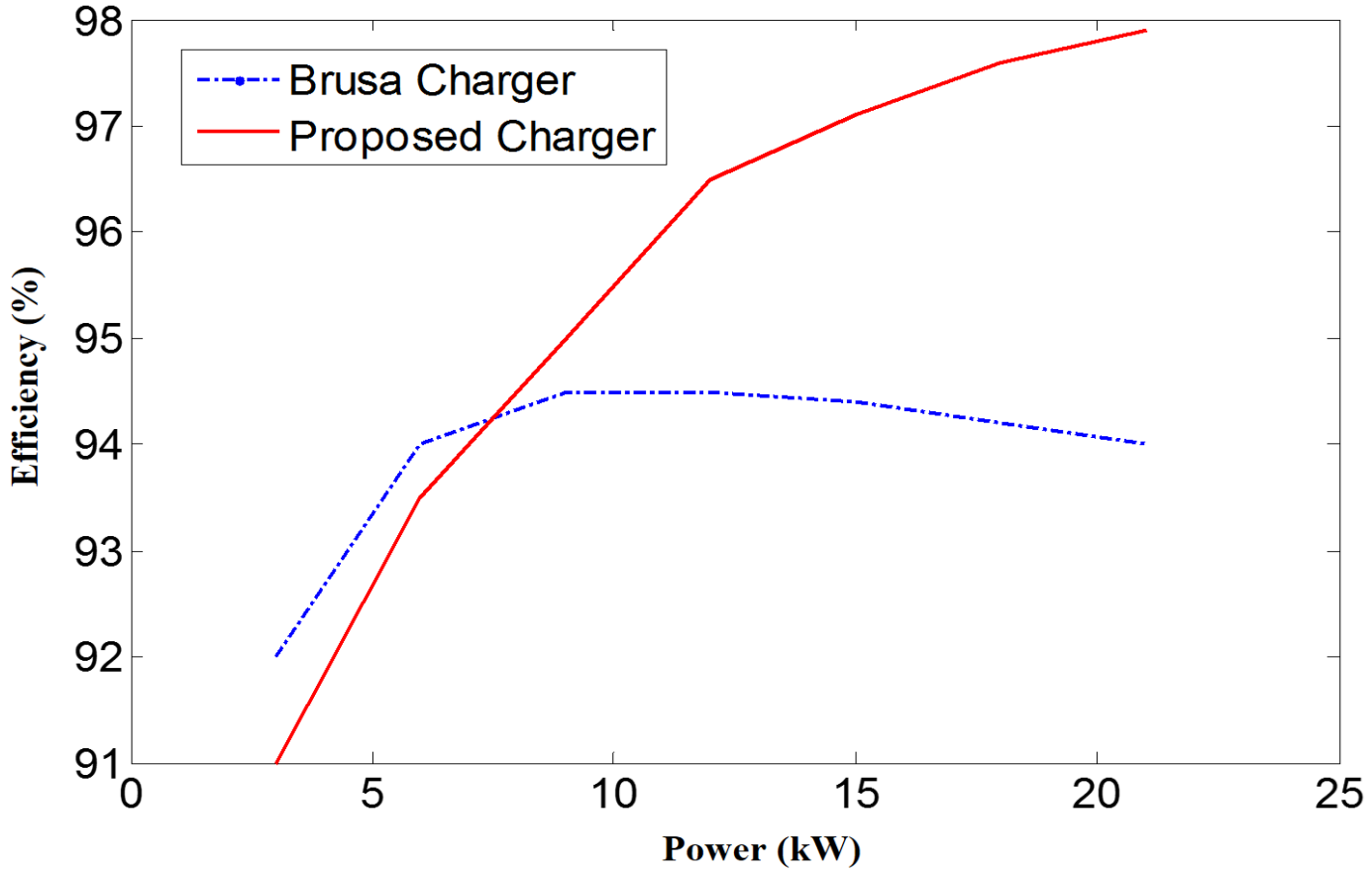


20kW SiC charger, 2014

Puzzles

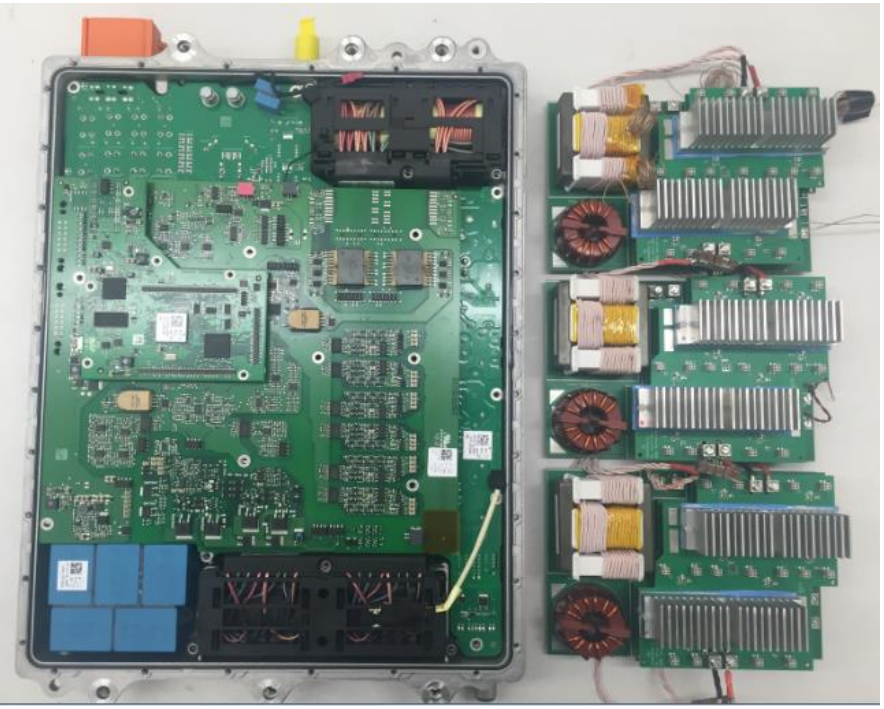
- Why do they sit on the desk collecting dust?
- What are their/my problems?
- What shall we fight for next?

Efficiency?

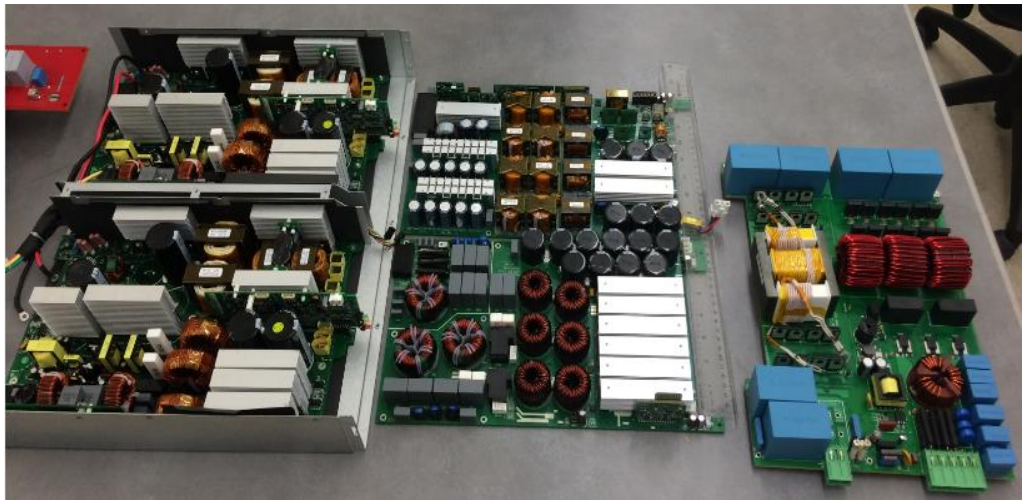


Juncheng Lu, **Hua Bai**, et al, "A Modular Designed Three-phase High-efficiency High-power-density EV Battery Charger Using Dual/Triple-Phase-Shift Control", IEEE Transactions on Power Electronics, online.

Size?



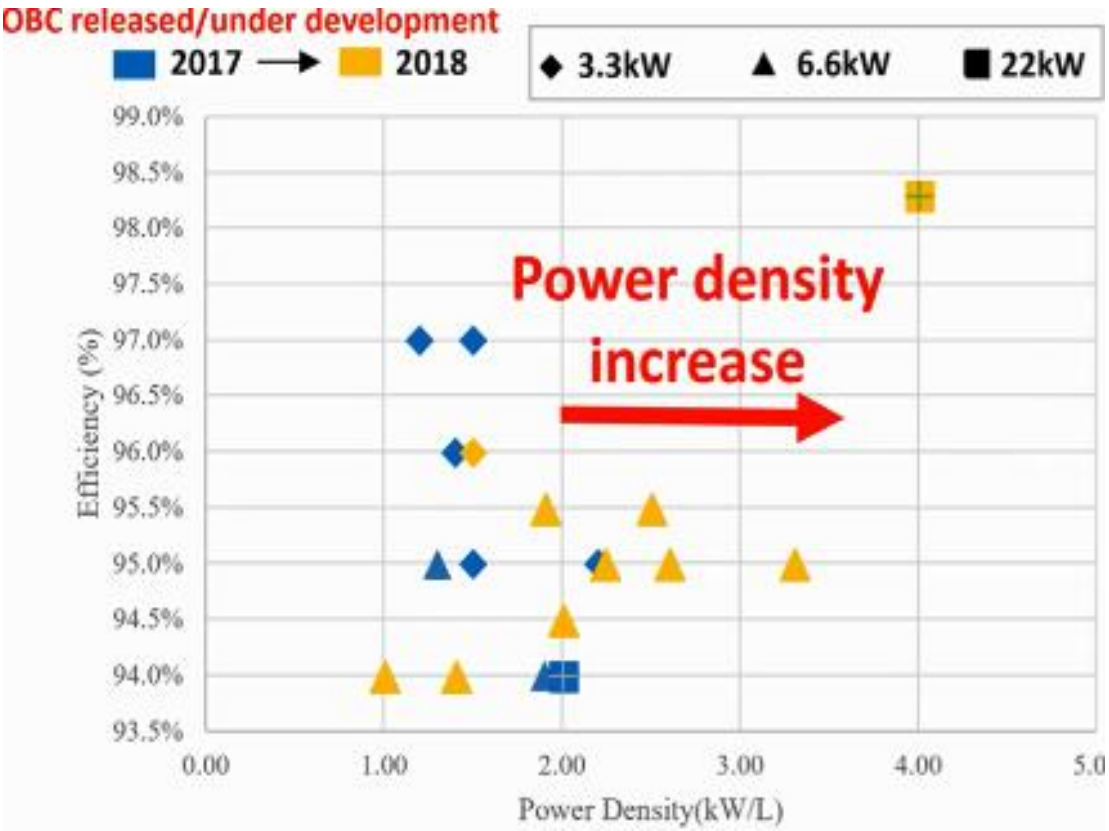
On-board Charger(Brusa vs ours)



Off-board Charger(Two vendors vs ours)

Juncheng Lu, **Hua Bai**, et al, "A Modular Designed Three-phase High-efficiency High-power-density EV Battery Charger Using Dual/Triple-Phase-Shift Control", IEEE Transactions on Power Electronics, online.

Pros and Cons



Highest efficiency;

Highest power density.

Highest cost;

Differentiation.

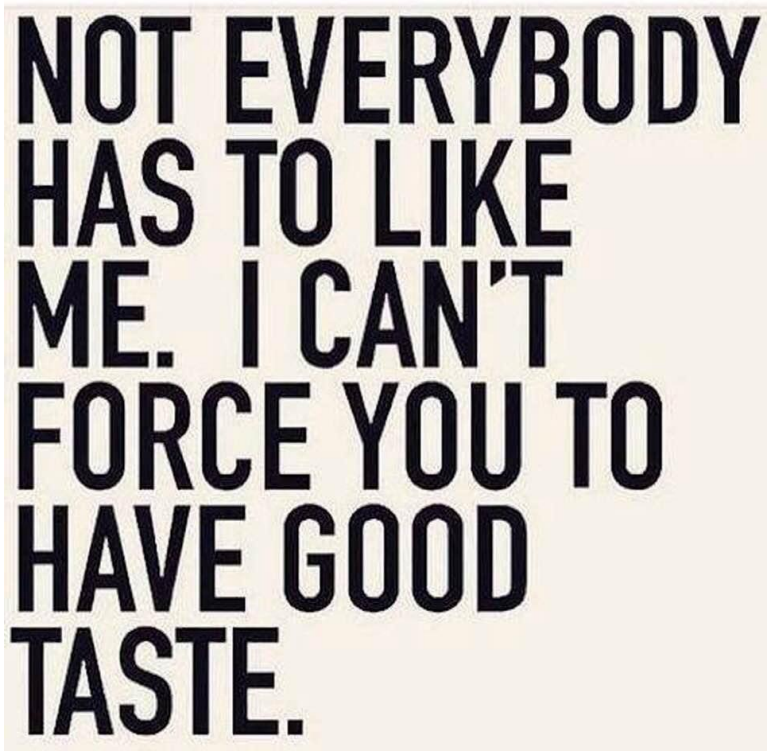
Juncheng Lu, Allan Taylor, Guanliang Liu, **Hua Bai*,** et al, "Applying Variable-Switching-Frequency Variable-Phase-Shift Control and E-mode GaN HEMTs To An Indirect Matrix Converter based EV Battery Charger", IEEE Transactions on Transportation Electrification, vol.3, no.3, 2017, pp.554-564.

Debates

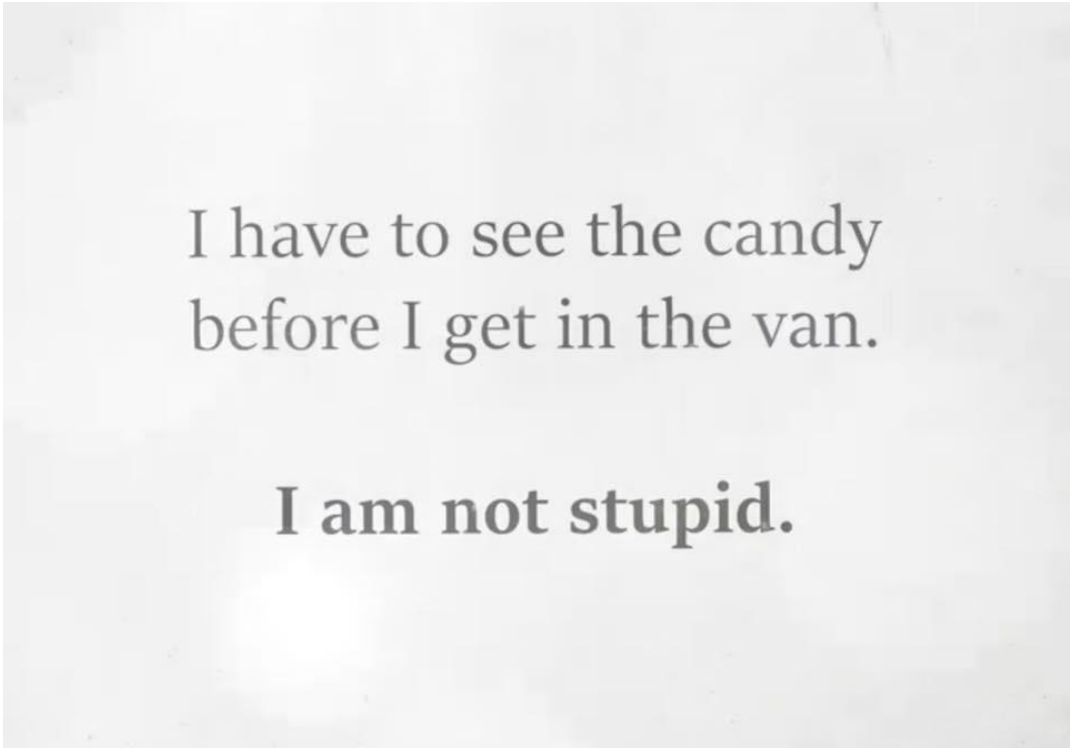
My Team	OEMs/Investors
High efficiency reduces the bill.	Less than one meal per year
High efficiency reduces the coolant usage	We have coolant. Why not use it?
High power density saves the space	Love it, but has to be cheap
High power density saves the weight	Love it, but has to be cheap
We offer multifunction	Needs differentiation
Can’t you just be happy for our chargers?	Because I need sell them

Debates

My Team



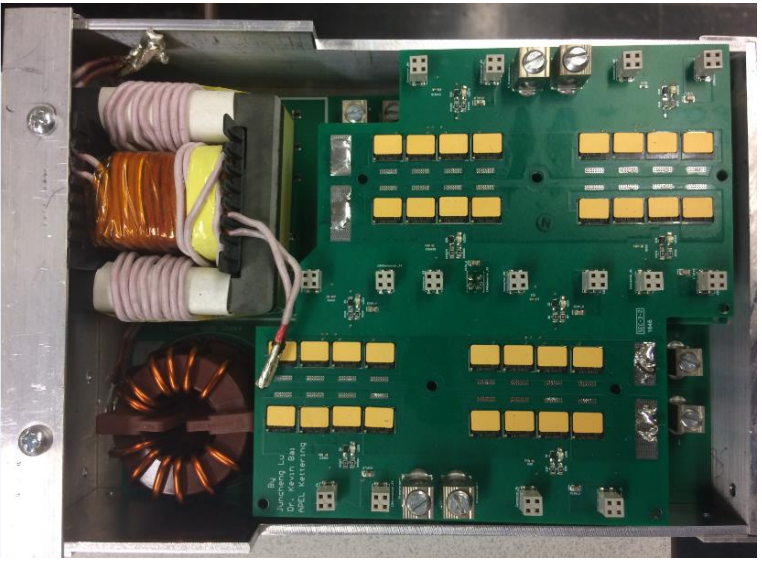
OEMs/Investors



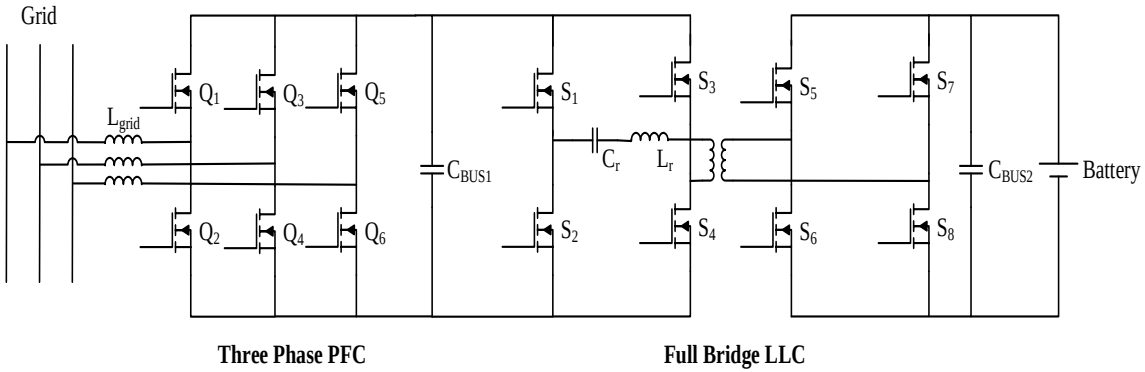
Agenda

- Reducing the cost;
- Differentiation Design.

GaN Chargers



Single-phase charger 4*8=32 pcs



14*2*$5=$140 (conventional design)

4*8*3=96 pcs 96*$6=$576

Reduce the switch number?

1) Thermal challenge!

2) Market challenge!

Lessons Learned

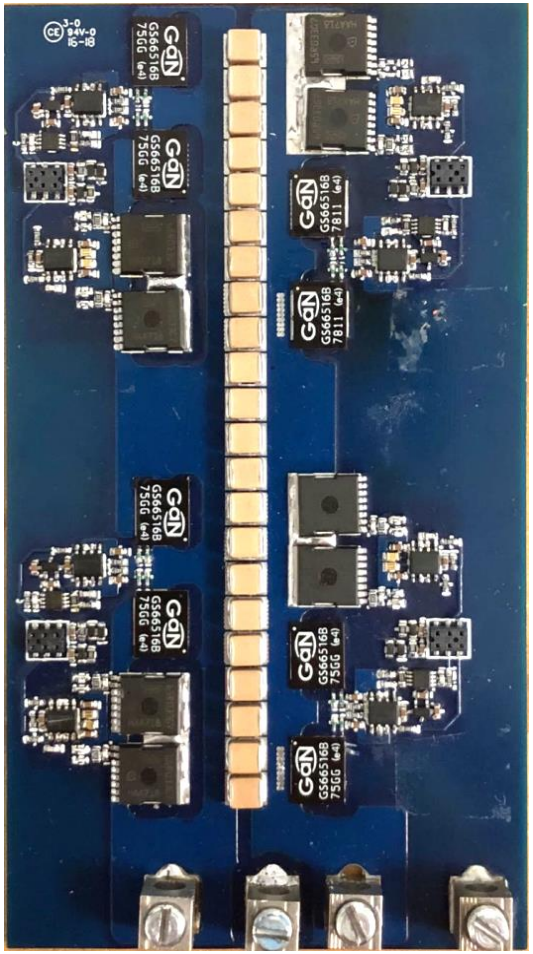
1. Topology: eliminates caps, increases PD,
   shifts the stress to switches, adds cost;

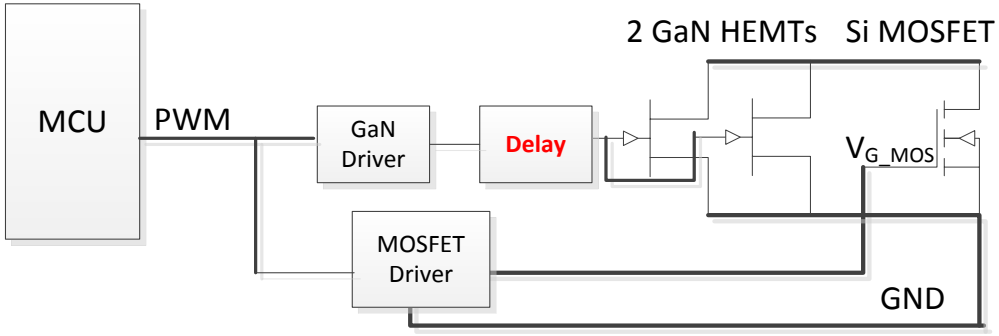
2. Switch: expensive, thermal challenged,
   in need of parallelization, adds cost;

3. We care about: efficiency > power density > cost

   OEMs care about: cost > power density > efficiency

Hybrid Switch





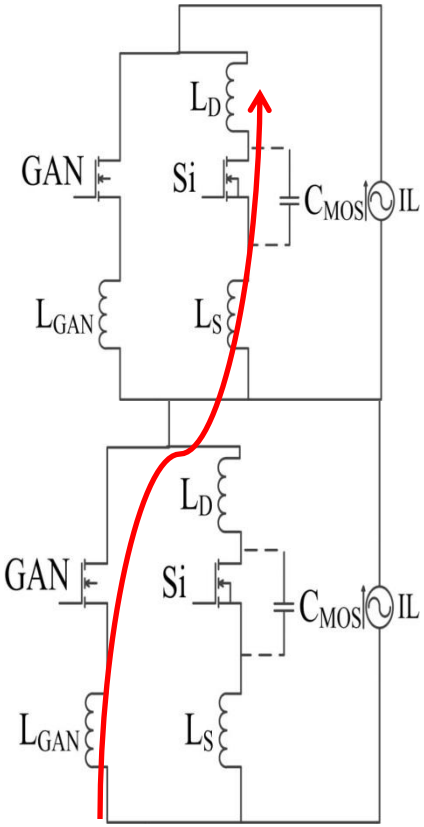
Hybrid Switch Solution

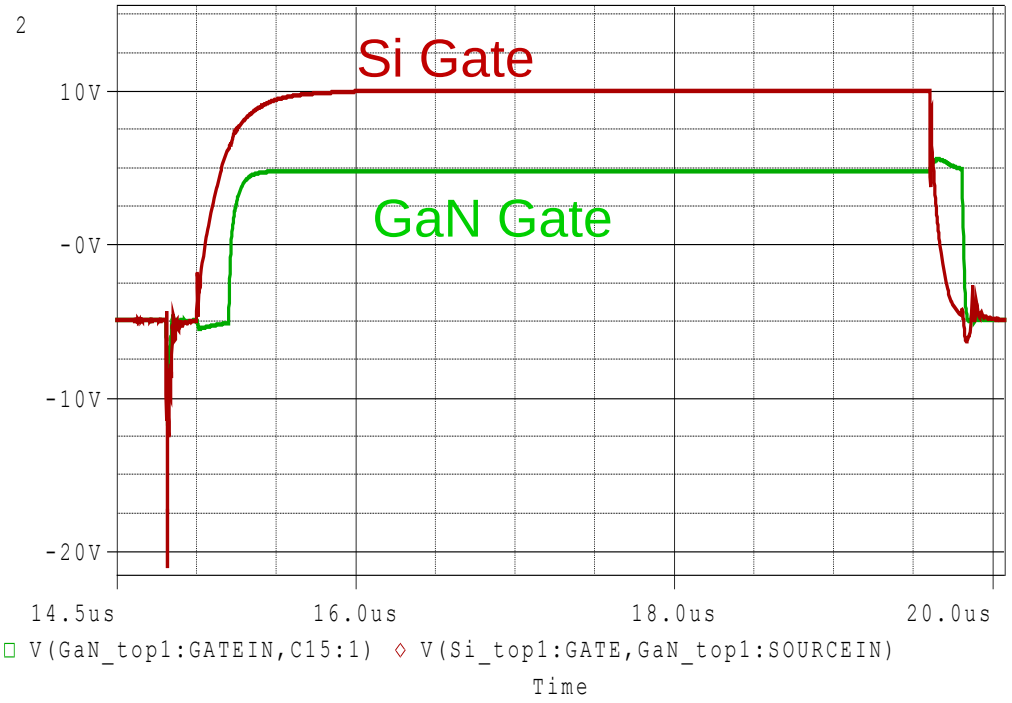
Rationale behind:

1. **Si is cheap;**
2. **Si has more options;**
3. **The cost is reduced with no efficiency drop.**

Challenges

1. Are we able to parallel fastest switches with slowest switches?





Challenges

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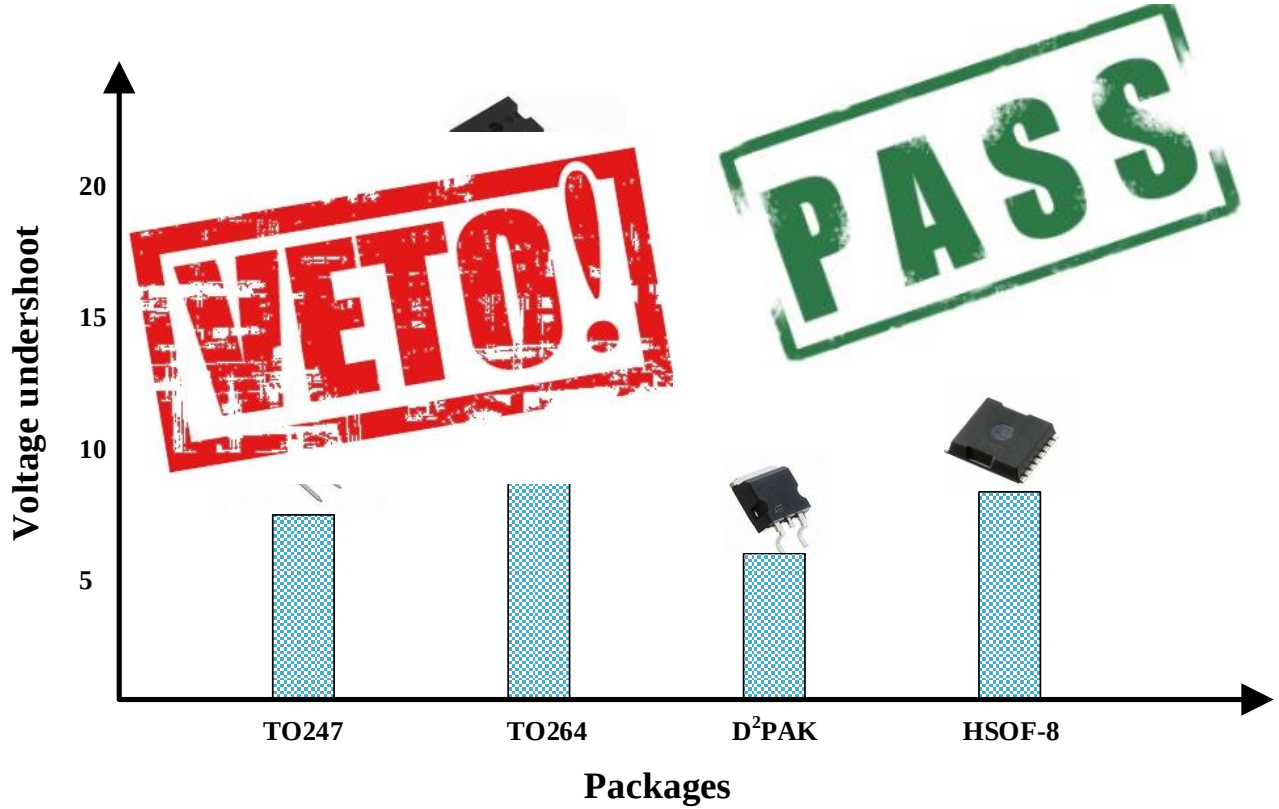


Challenges

PowerAmerica

2. How much cost can we on earth save? Are Si automotive qualified?

GaN HEMTs: $6

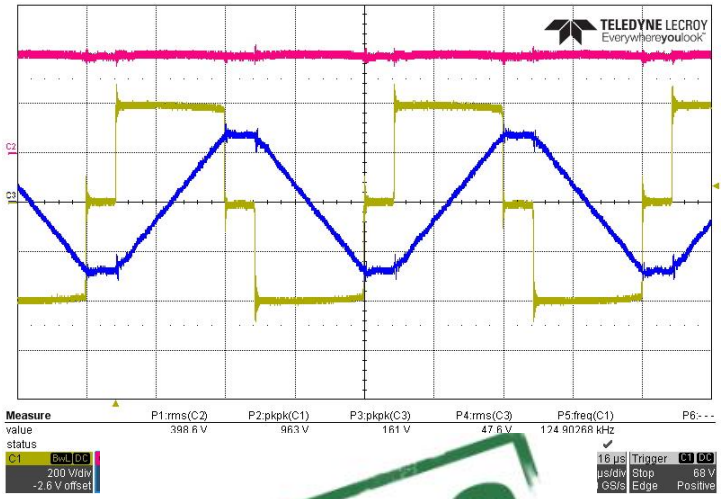
~~**Exotic packaged Si (HSOF-8): $5!**~~

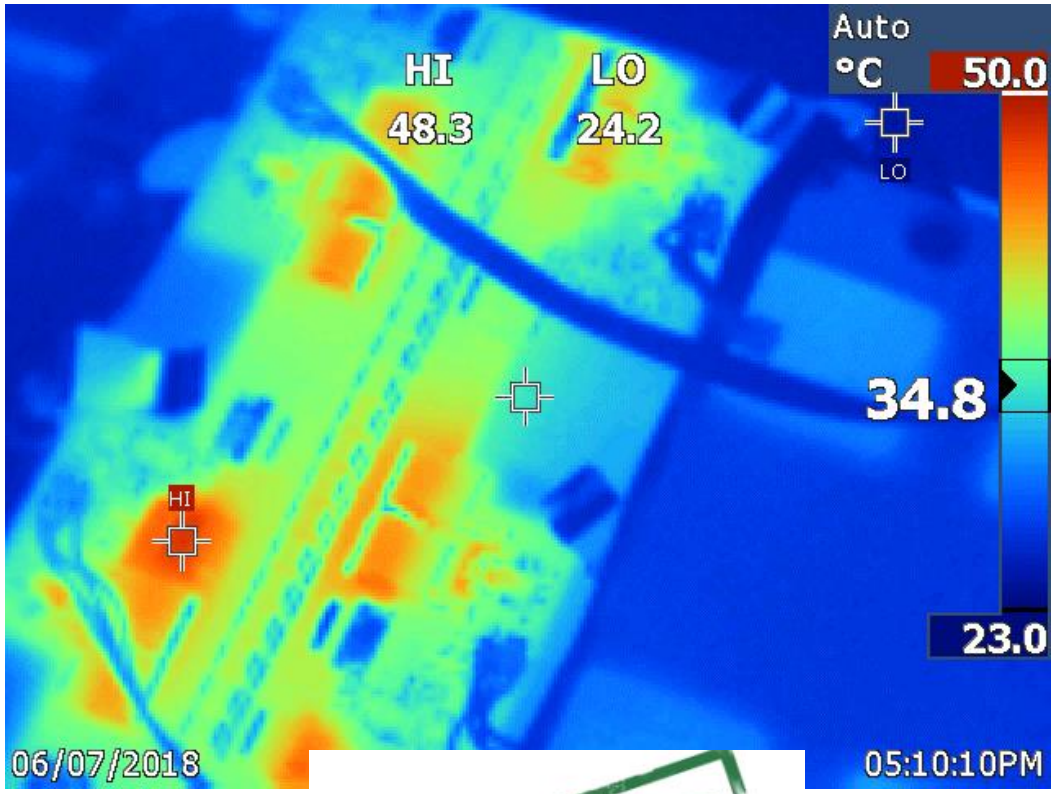
~~**Delay Chip: $1.**~~

D^2Pak Si: $3 (-$3*2*8*3=-$144)

Liyan Zhu and **Hua Bai**, “Transient Analysis in Gate-Drive Loops of GaN+Si Hybrid Switches", IEEE 6th Workshop on Wide Bandgap Power Devices & Applications, 2018;

Hybrid Switch





fs= 1 I_k = 80A T_{GaN} ≈ 50° ≈ 15°C

PASS

PASS

Challenges

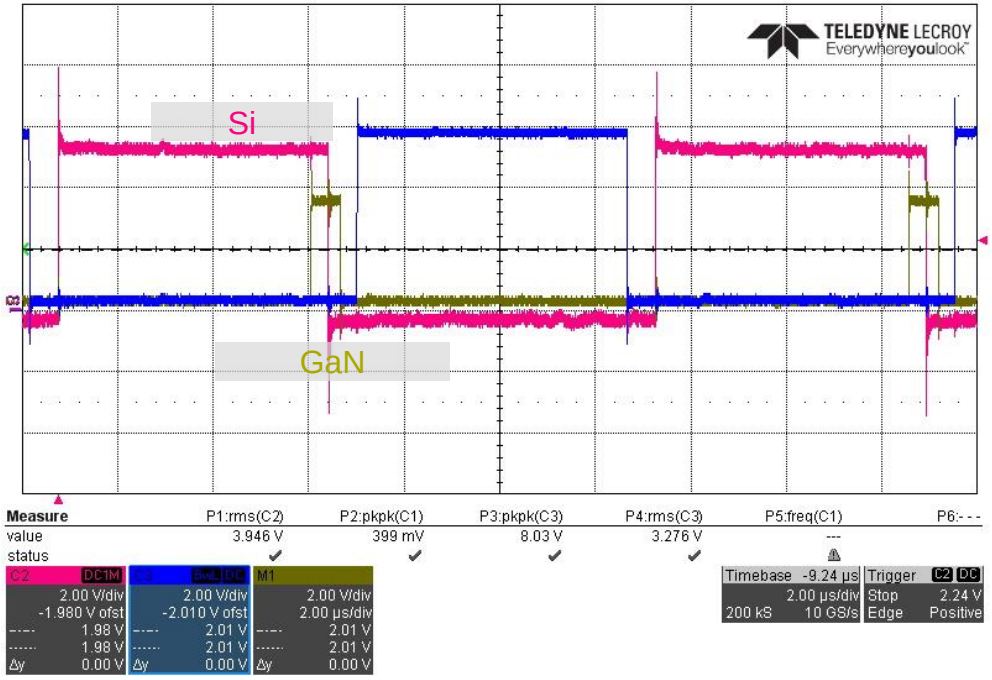
PowerAmerica

3. Can we save more?

GaN HEMTs: $6

D²Pak Si: $3

1 GaN + 2 Si: ~~$(3*2+6)*8*3=$288~~



Liyan Zhu and **Hua Bai**, “Transient Analysis in Gate-Drive Loops of GaN+Si Hybrid Switches", IEEE 6th Workshop on Wide Bandgap Power Devices & Applications, 2018;

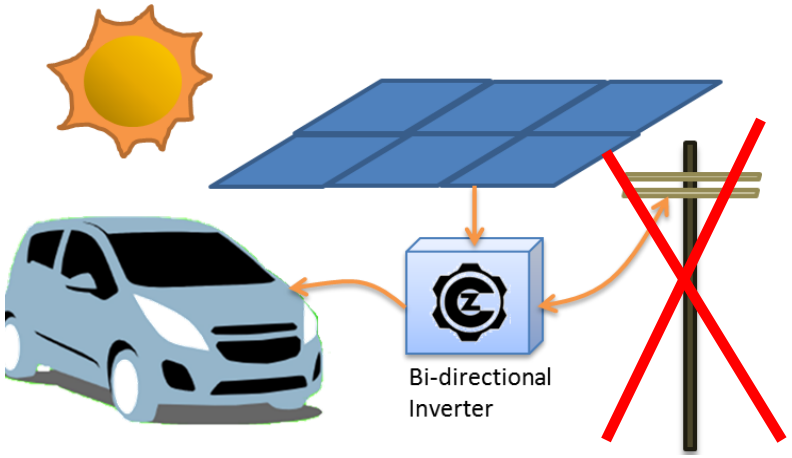
Agenda

- Reducing the cost;

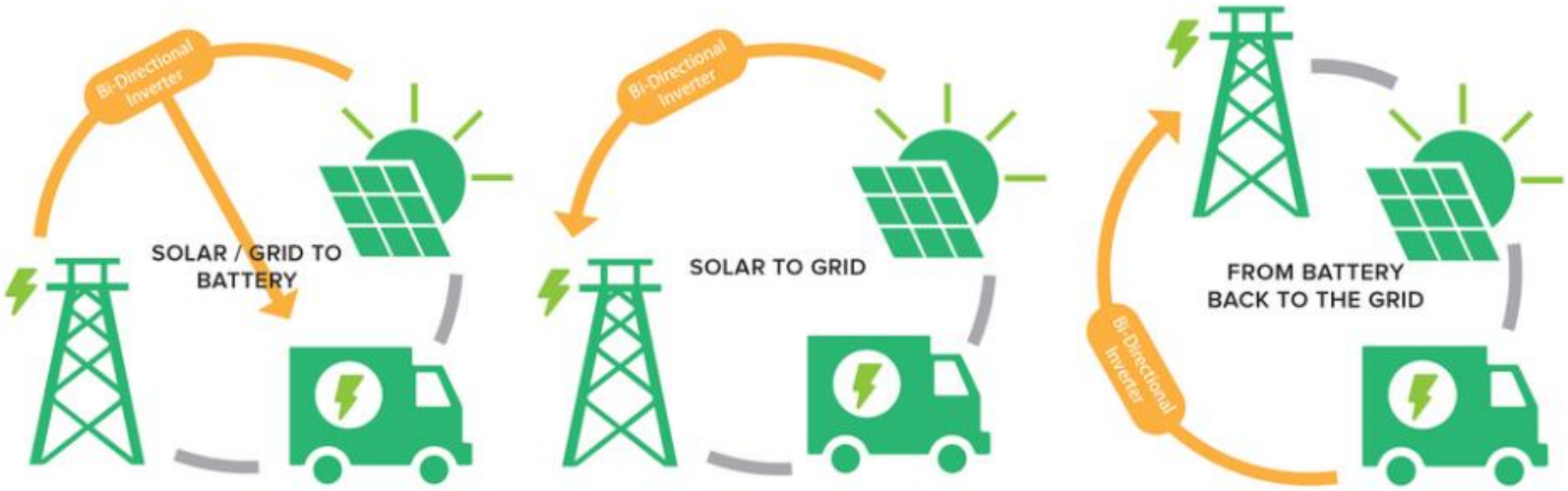
- Differentiation Design.

EV Charger

CZAR-POWER
CARBON ZERO ADVANCED RESEARCH



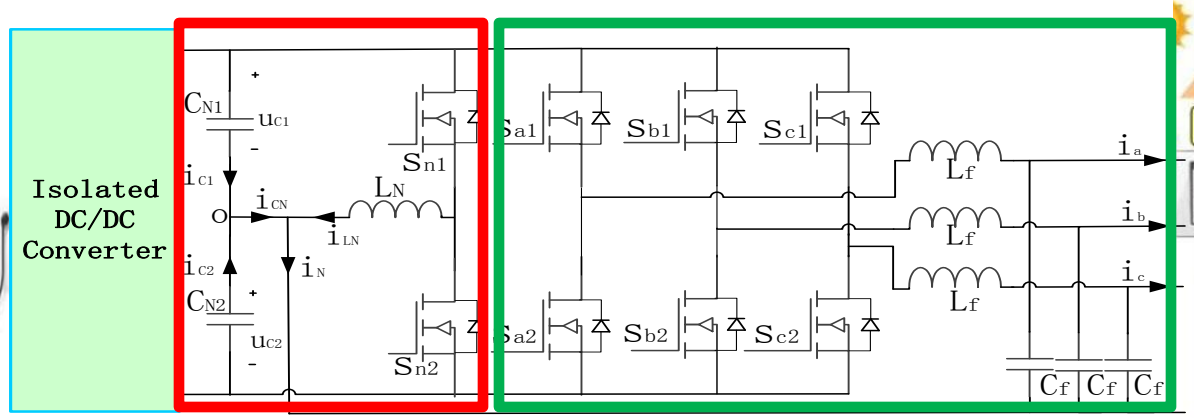
Can we create our own grid?

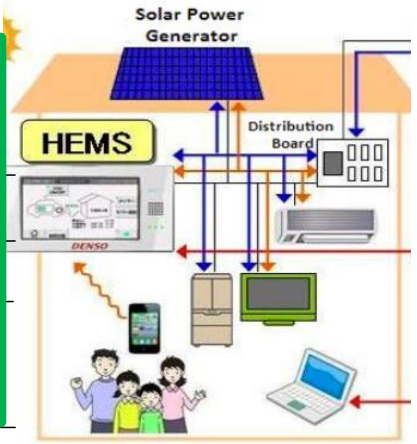


Solar+ G2V | **Solar to Grid** | **V2G**

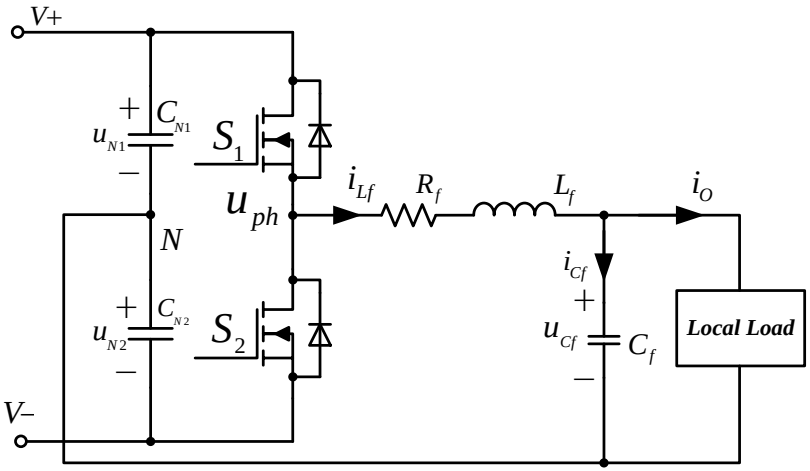
Chenguang Jiang, **Hua Bai*,** et al, "The Power-Loss Analysis and Efficiency Maximization of A Silicon-Carbide MOSFET Based Three-phase 10kW Bi-directional EV Charger Using Variable-DC-Bus Control", Journal of Emerging and Selected Topics in Power Electronics, vol.4, no.3, 2016, pp. 880 – 892.

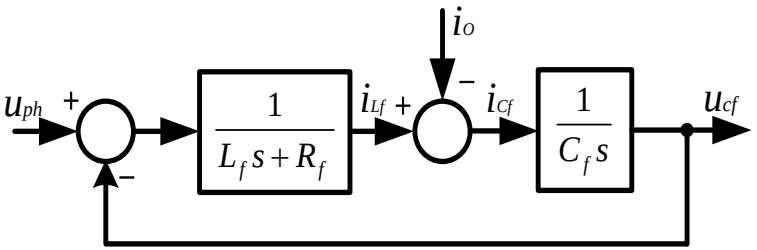
V2L Charger





Creating stable N **Creating stable 3Φ**



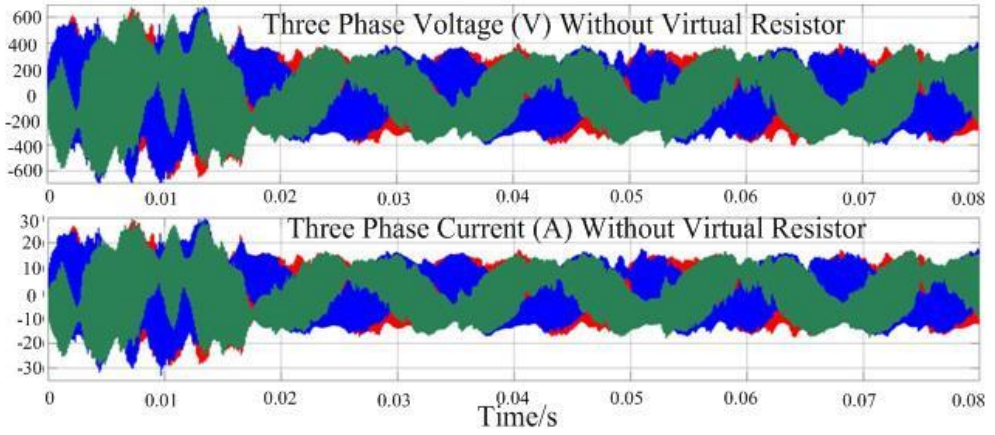


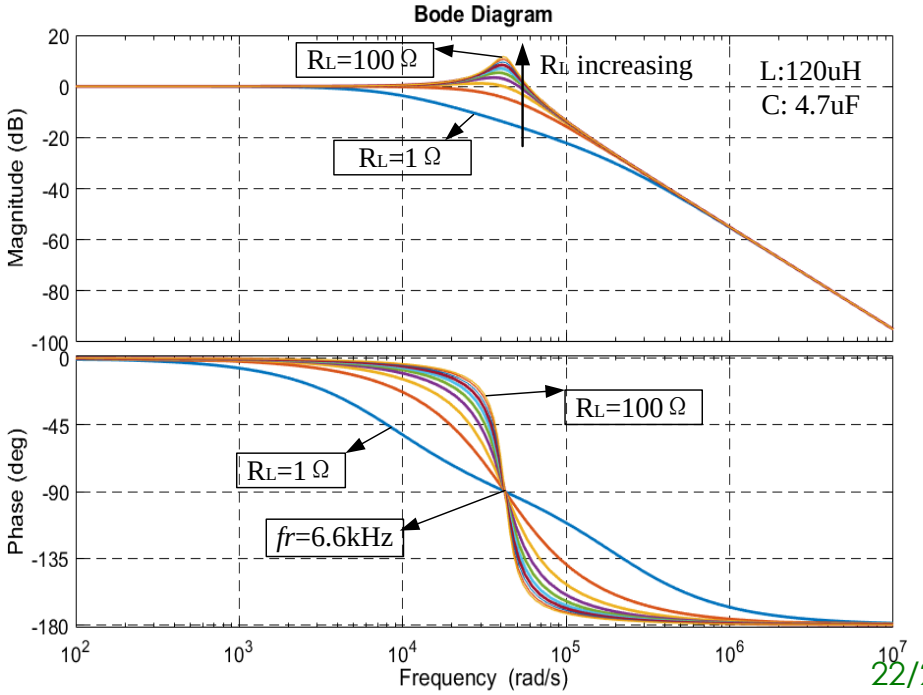
V2L Charger

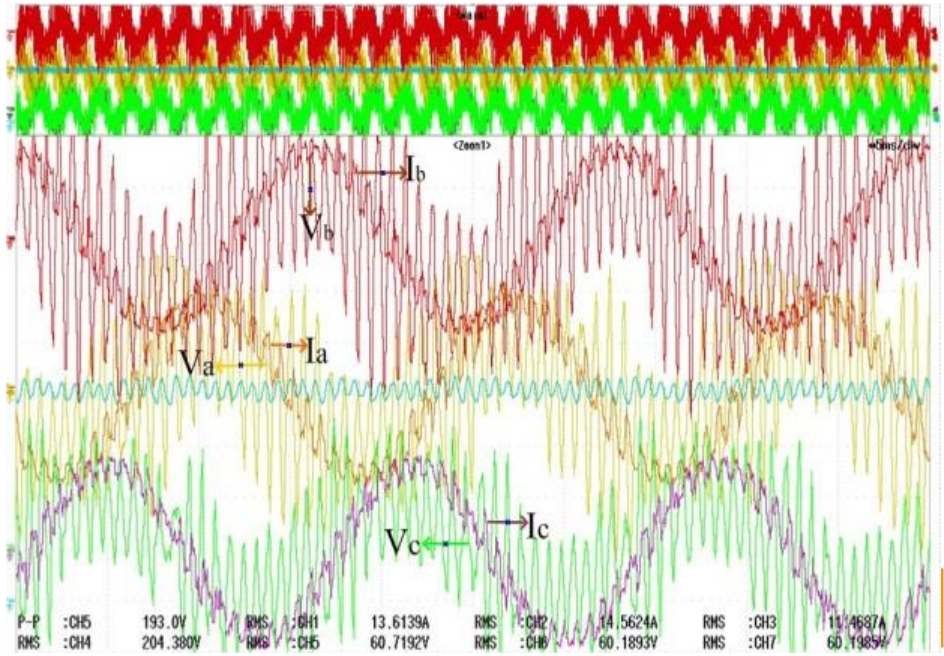
$$u_{spwm} = \left[\left(\frac{1}{j*\omega*C}//R_L\right) + j*\omega*L\right] * i_L(t)$$

$$\begin{cases} \dfrac{i_L}{u_{spwm}}(s) = \dfrac{R_L*C*s+1}{L*C*R_L*s^2+L*s+R_L} \\ \dfrac{u_c}{i_L}(s) = \dfrac{R_L}{R_L*C*s+1} \end{cases}$$

$$\frac{u_c}{u_{spwm}}(s) = \frac{R_L}{R_L*L*C*s^2+L*s+R_L}$$

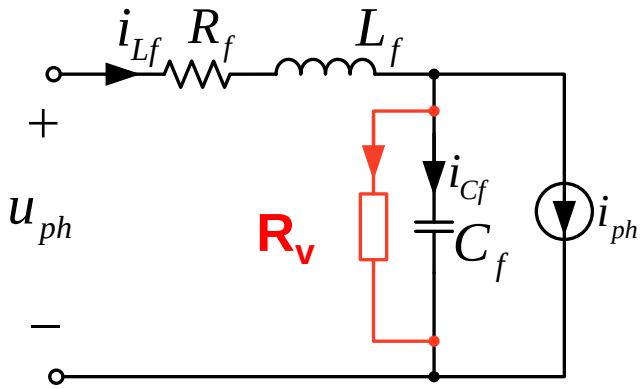




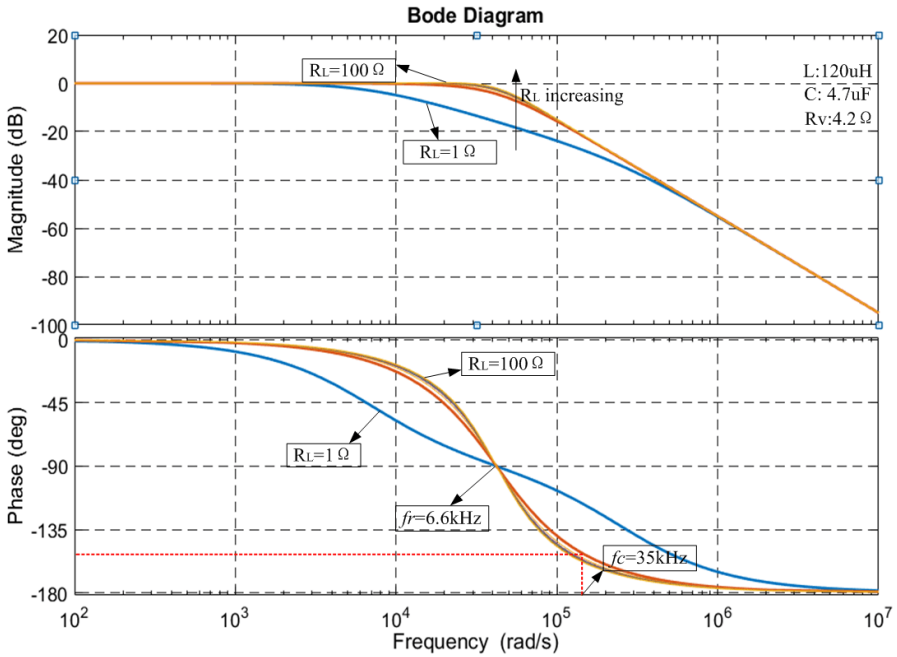


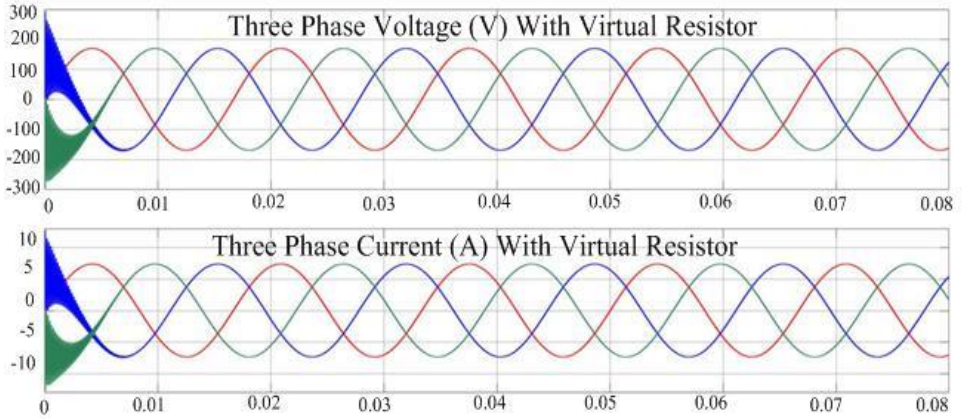
V2L Charger

$$R'_L = \frac{R_L * R_v}{R_L + R_v}$$ ← Virtual Resistance



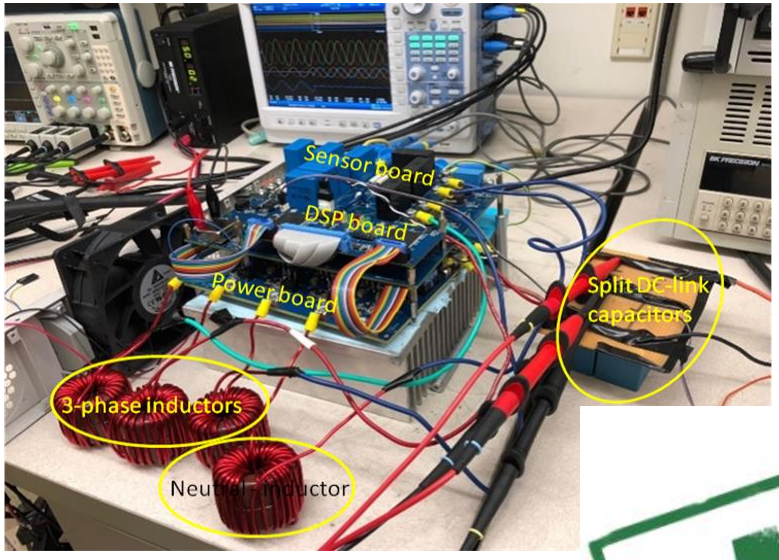
$$\frac{u_{c\_v}}{u_{spwm\_v}}(s) = \frac{R_v}{R_v * L * C * s^2 + \left(\frac{R_v}{R_L} + 1\right) * L * s + R_v}$$

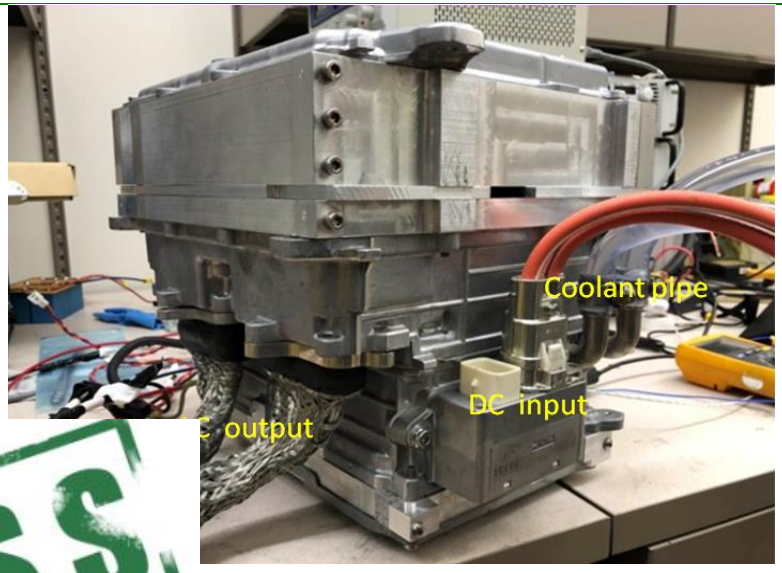




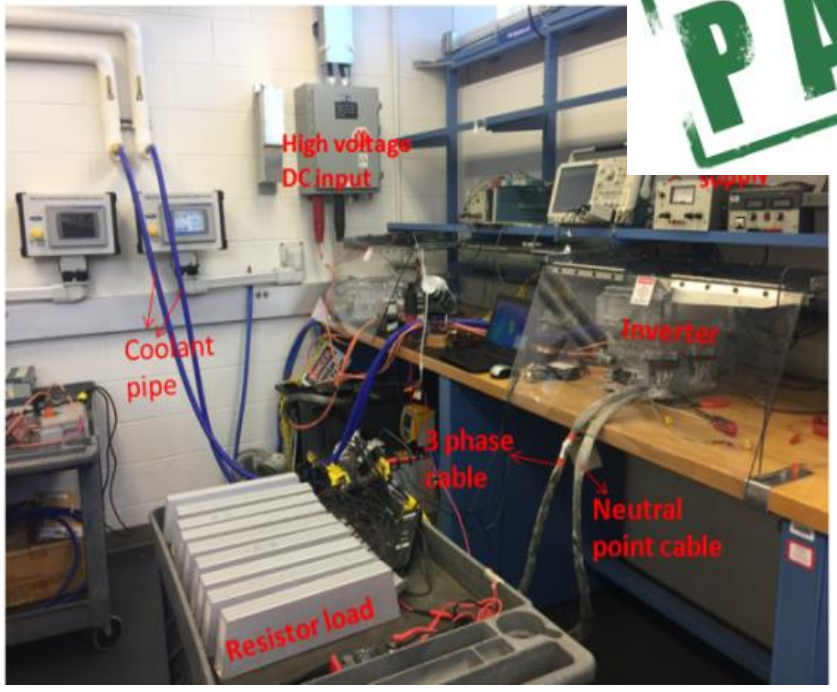
Yongsheng Fu, Yang Huang, **Hua Bai**, et al, "A High-Efficiency SiC Three-Phase Four-Wire Inverter with Virtual Resistor Control Strategy Running at V2H Mode", IEEE 6th Workshop on Wide Bandgap Power Devices & Applications, 2018;

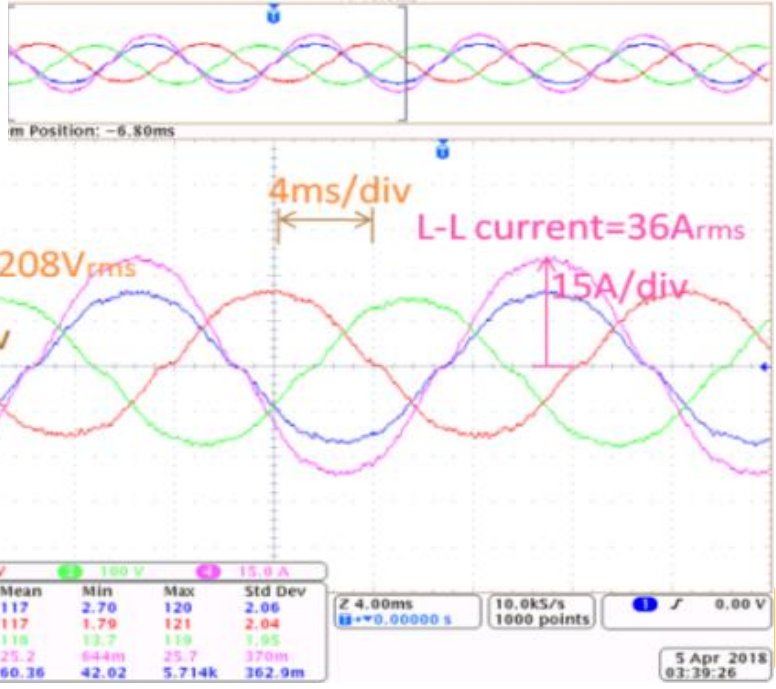
V2L Charger



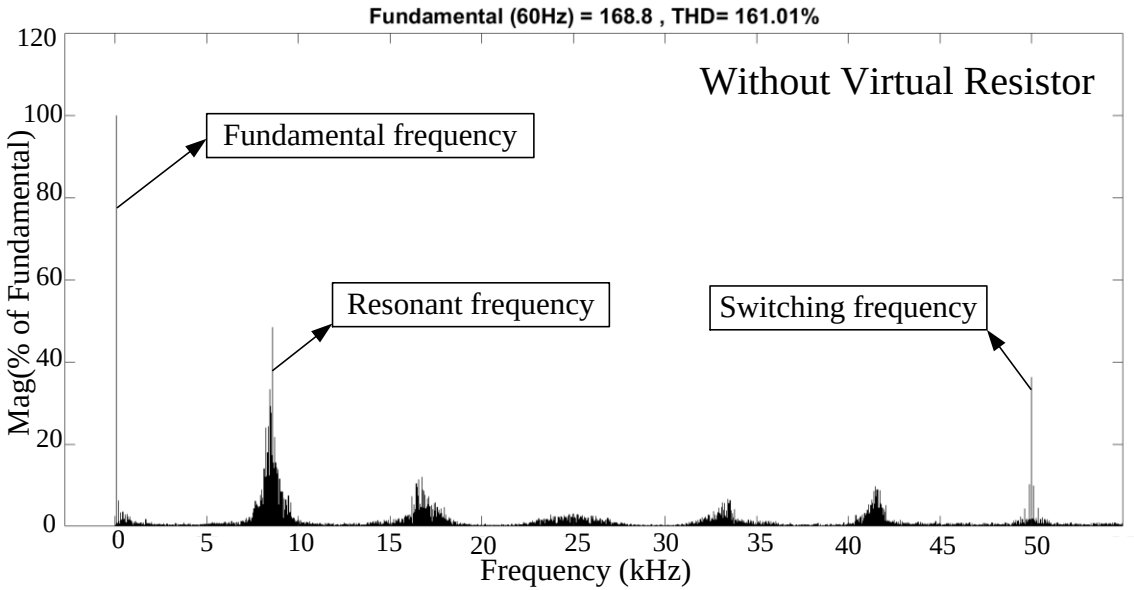


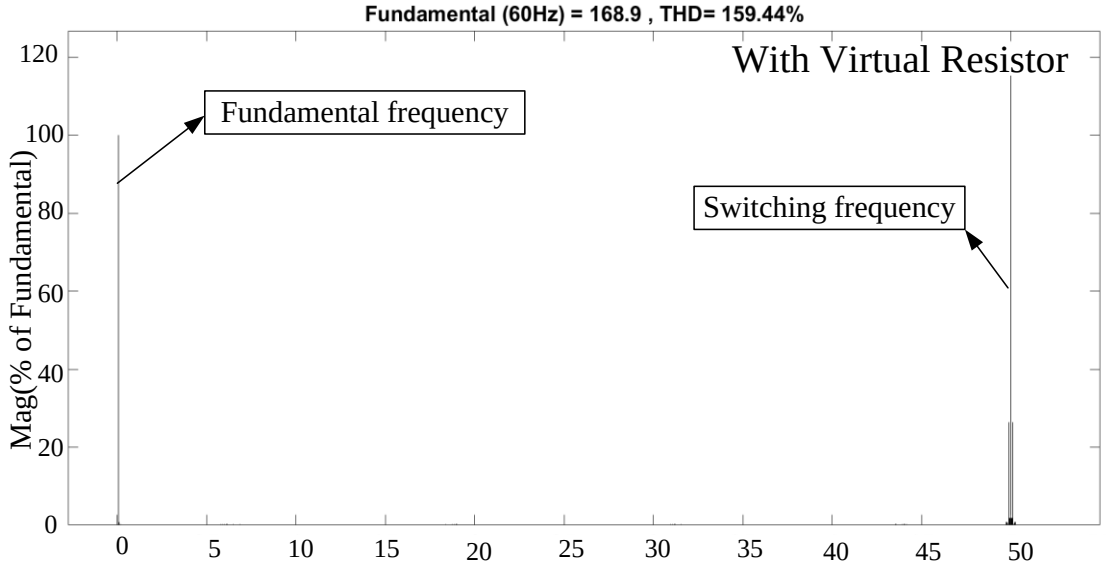
PASS





V2L Charger


Fundamental (60Hz) = 168.8 , THD= 161.01%
Without Virtual Resistor
Fundamental frequency
Resonant frequency
Switching frequency
Mag(% of Fundamental)
Frequency (kHz)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
35
40
45
50


Fundamental (60Hz) = 168.9 , THD= 159.44%
With Virtual Resistor
Fundamental frequency
Switching frequency
Mag(% of Fundamental)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
35
40
45
50

Summary

- Academia: efficiency > size > cost;
- Automotive OEMs: cost ≈ reliability > size > efficiency;
- Hybrid-switch solution is a intermediate solution;
- V2L and V2H functions will be emphasized more;
- What's the next for the EV charger?

Acknowledgement

EV OEM

Tier-I

Tier-2

Entrepreneur

Government

Acknowledgement

Invitation of CURENT;

Students: Yang Huang, Liyan Zhu
Philip Mike Johnson, Allan Taylor
Guanliang Liu, Juncheng Lu, etc.

Thank you!

Questions?