Challenging Questions for Power Electronics Engineers/Researchers in Vehicle Electrification

Ford Model T 1908
www.thehenryford.org

APEC 2015
Industry Session

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Ford Escape Hybrid 2005

XEV Line-Up *

Hybrid

Fusion Hybrid

C-Max Hybrid

Plug-in Hybrid

Fusion Hybrid Energi

C-Max Energi

Battery Electric

Focus Electric

* as of Mar. 2015

After 10 years, we have many challenges.

Cost!

http://www.showroom.ford.com/

Weight

- directly affects MPG.

Volume

- limited space

(esp. for HEV: both ICE + gas tank and E-Machines + PE + Battery)

Quality

- no compromise is tolerated.

After 10 years, we have many challenging questions, e.g.

Active components:

Is Si device improvement really getting saturated?

Will WBG power devices really take over the role of Si devices? If "Yes", when? [1, 2]

[1] Chingchi Chen and Ming Su, The Opportunities and Challenges of Wide-Band-Gap Technologies for Automotive Applications, The 2nd IEEE Workshop on Wide Bandgap Power Devices and Applications, Oct. 13-15, 2014, Knoxville, Tennessee

[2] Ming Su and Chingchi Chen, Can SiC or GaN power the next-generation hybrid electric vehicle drive systems?, CS International Conference 2014, Mar. 17-18, 2014, Frankfurt am Main, Germany

Active components and peripherals:

How small can parasitic L be in a switching device commutation path?

How to make active and passive go hand-in-hand, e.g. for high-temp operation?

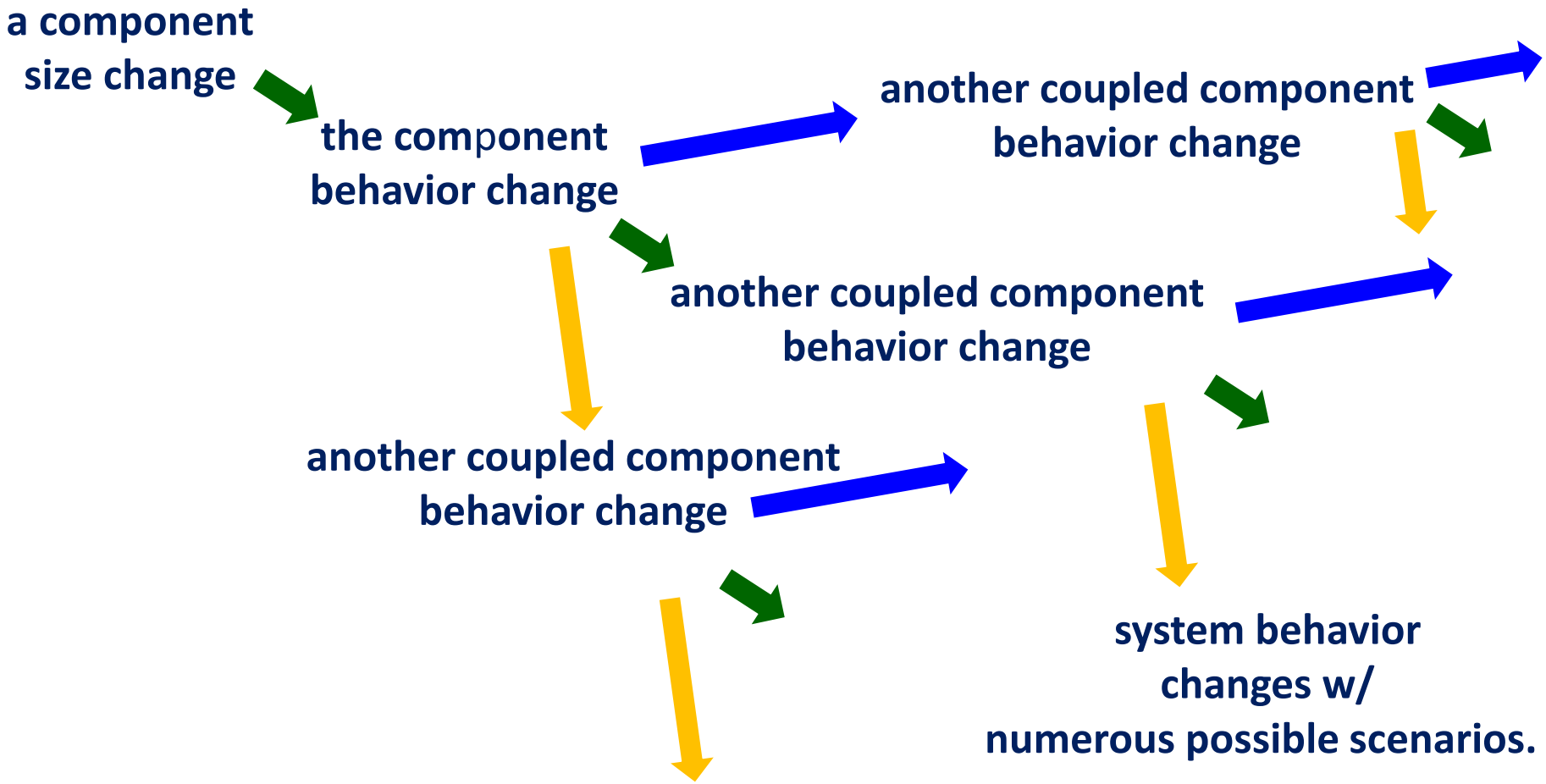
Passive components:

How small can they be?

On batteries (from PE viewpoint) :

What is the maximum tolerable ripple current for HEV/EV traction batteries?

They are all cross-coupled, e.g.



How to fully utilize every component to meet cost, weight and volume reduction without quality compromise?

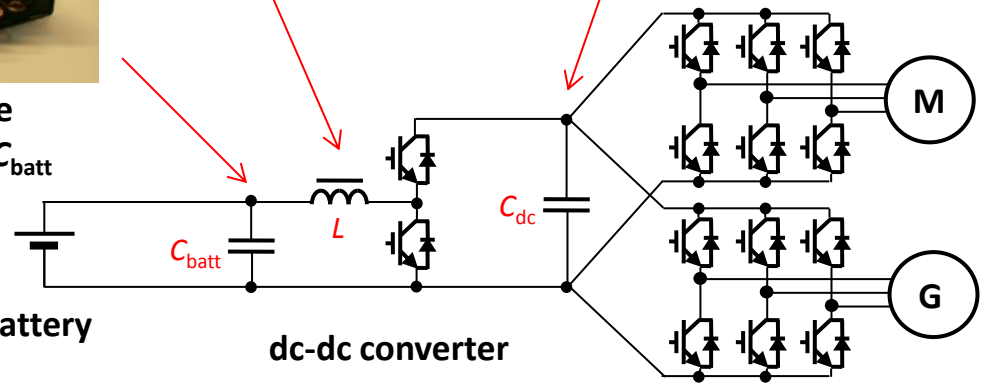
Brief case studies for HEV e-drive passive components

dc-bus capacitor: C_{dc}

dc-dc converter inductor: L

battery side capacitor: C_{batt}

generator drive



battery

dc-dc converter

motor drive

HEV e-drive power electronics subsystem

HEV dc-bus capacitor has been driven to smaller and smaller.

capacitance

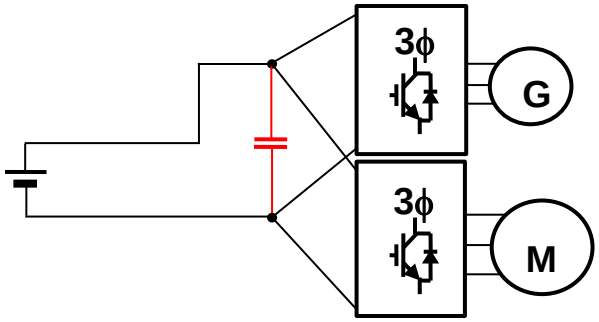
material choice

topology choice

smaller and smaller

Escape Hybrid 2005 ~
1500uF x 3 parallel
= **4500uF**

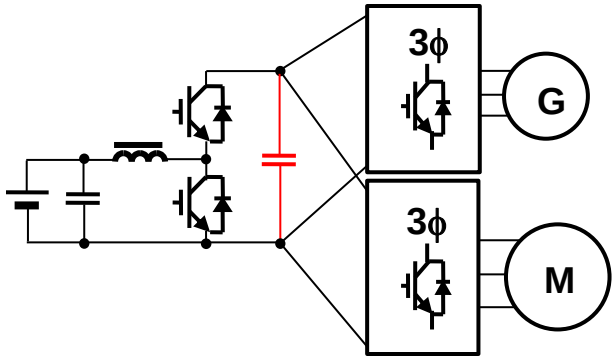
electrolytic



Fusion Hybrid 2010 ~
2200uF

film (PP)

Fusion Hybrid 2013 ~
C-Max 2013 ~
1100uF



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C_{dc} size affects:

- Cost
- Weight
- Volume

- System stability
  - multi-power converter interaction: ***Please, visit poster presentation D12-10***

Jun Kikuchi, "Stability Modeling of HEV/EV Electric Drives as a Small-Scale Distributed Power System, " APEC 2015

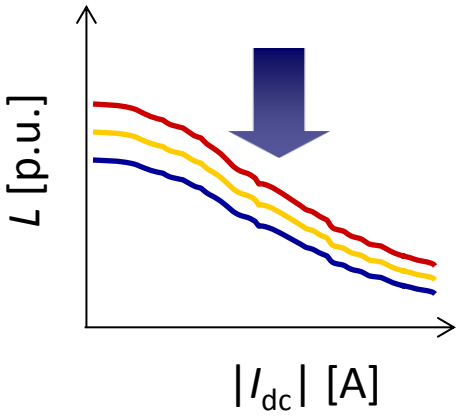
- Dc-bus voltage transient behavior
  - controller tuning
- ESR & ESL
- Bus structure
  - parasitic L, parasitic R, thermal behavior
- Current sharing among C cells
  - esp. for high switching frequency operation

- Steady-state voltage ripples
- etc.

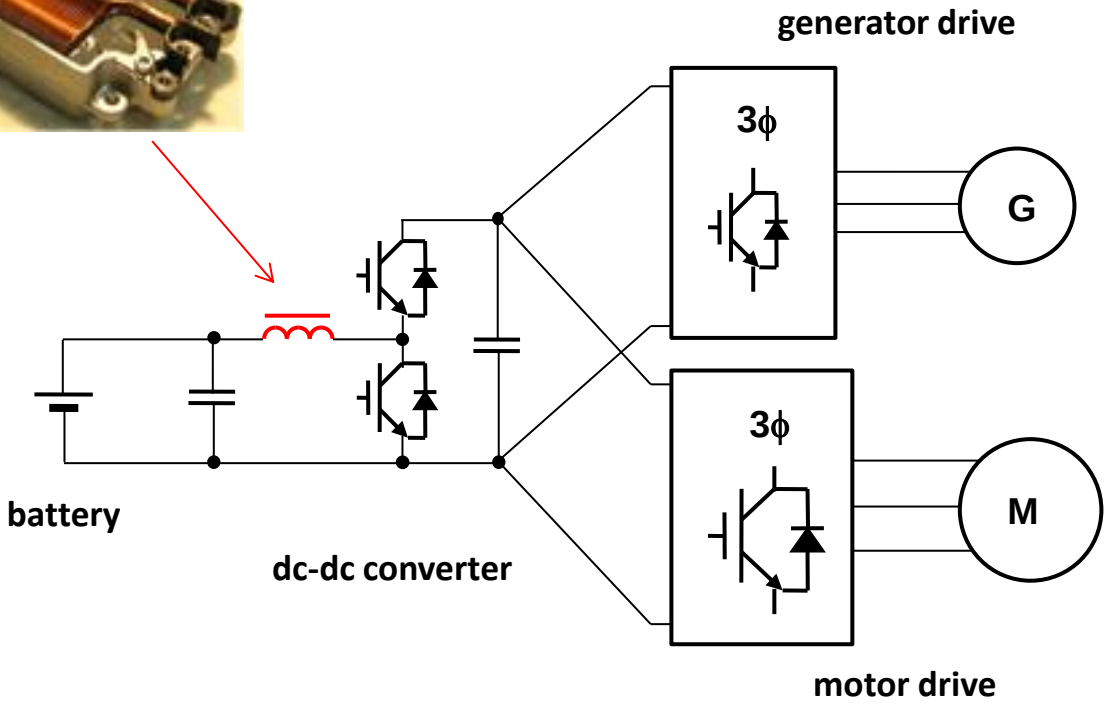
Note) Unlike stationary applications, voltage-sag ride through capability is not an issue.

Dc-dc converter inductor

Size reduction needs are there, but it doesn't appear as dramatic as C_{dc} size reduction.



The *L* vs. I_{dc}| profiles are those of typical examples.



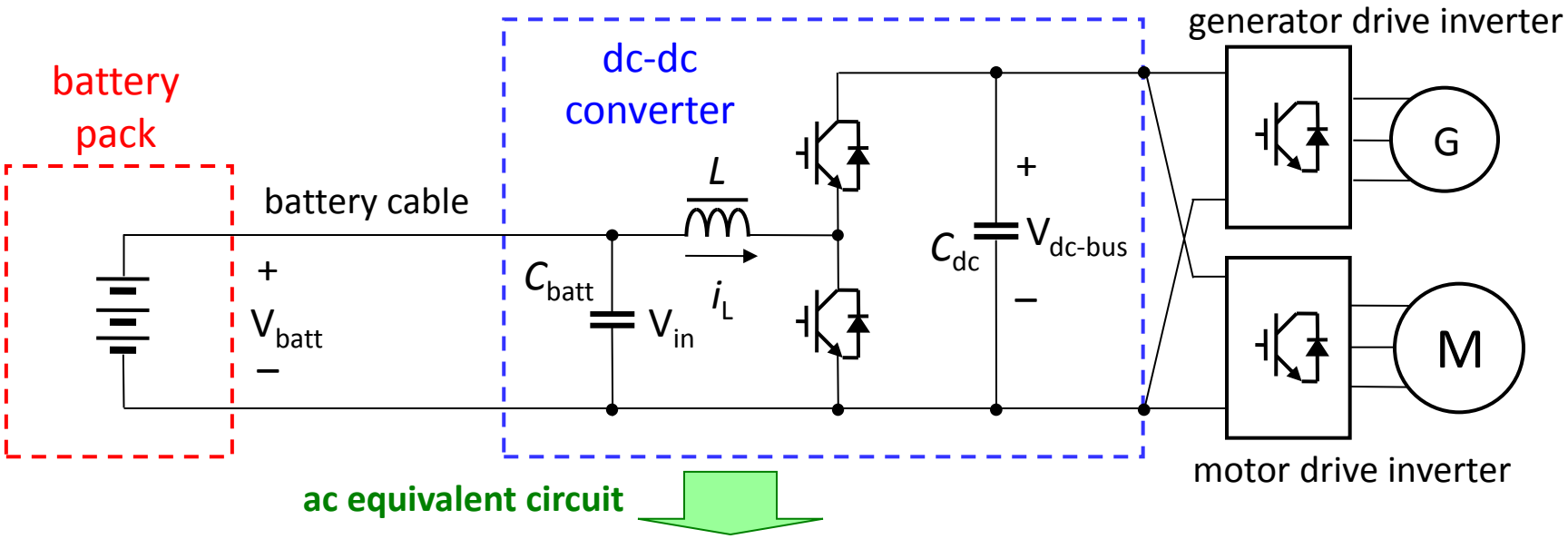
Dc-dc converter *L* size affects:

- Cost
- Weight
- Volume

- Dc-dc converter stability
  - dc-dc converter controller tuning
  - eventually multi-power converter interaction
- Dc-dc converter *L* ripple current
  - winding ac loss
  - core loss
  - thermal design
  - dc-dc converter device repetitive peak current
- Battery side capacitor sizing
- Battery branch ripple current

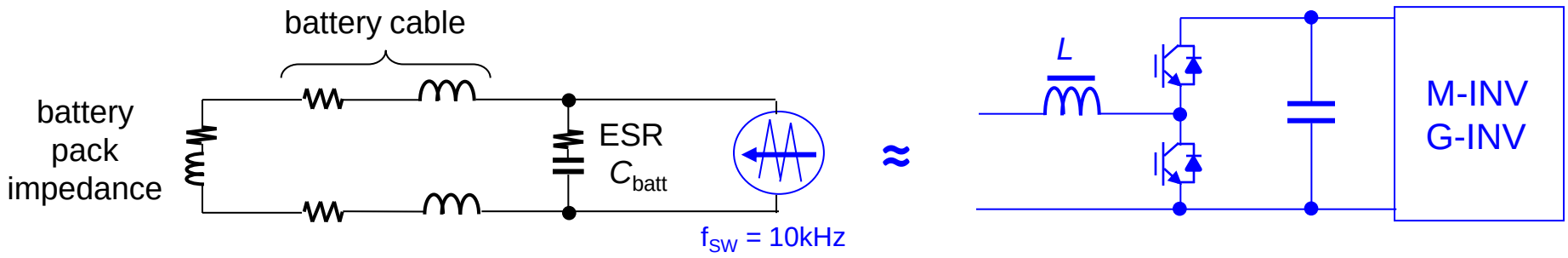
- etc.

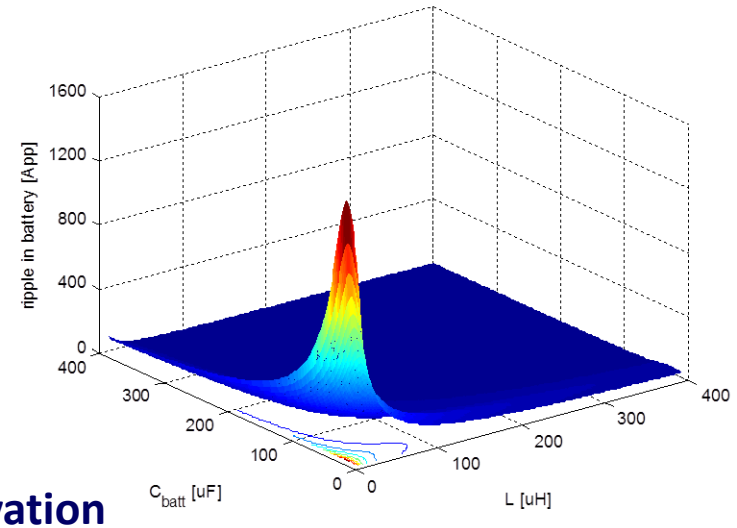
A rough estimation of battery branch ripple current

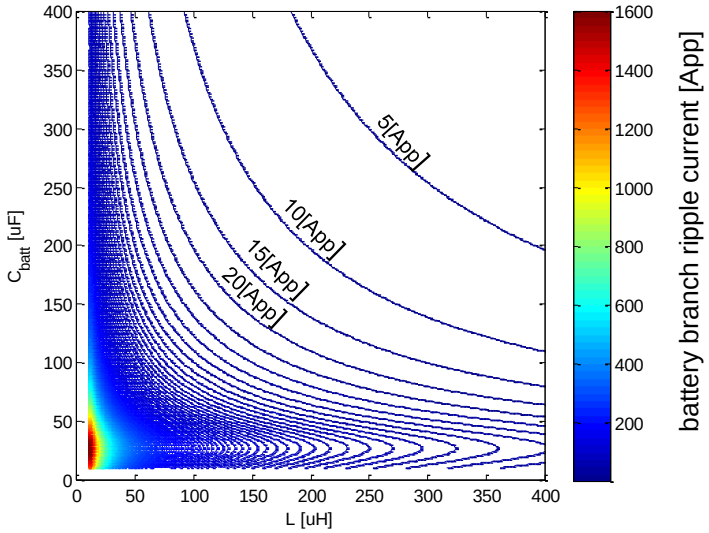


$$i_{ripple\_batt} = \frac{Z_{C\_batt}}{(Z_{batt} + Z_{cable}) + Z_{C\_batt}} \times i_{ripple}$$

Landscape of battery ripple current @f_{sw} on C_{batt}– L plane







Observation

- The *L*-*C* tank resonance can cause larger battery branch ripple current than the injected ripple current.
- Staying sufficiently away from the resonant frequency may eventually determine the minimum C_{batt}.

Note) The resonant frequency is not for C_{batt} and dc-dc converter L, but for C_{batt} and parasitic L on the battery branch including battery cable.

Summary

1. We need to fully utilize each component in order to tackle the challenges to reduce cost, weight, volume and to maintain high quality.

2. We need to answer many challenging questions in order to fully utilize each component and to overcome the challenges.

3. We need not only component focused studies but also system level studies to answer the challenging questions.

Go further question:
How does this impact on Power Electronics beyond vehicle electrification?

Thank you!

Georg Cantor 1845 ~ 1918

In mathematics the art of asking questions is more valuable than solving problems.

In re mathematica ars proponendi quaestionem pluris facienda est quam solvendi.