Challenging Questions for Power Electronics Engineers/Researchers in Vehicle Electrification

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Industry Session

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Ford Model T 1908
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Ford Escape Hybrid 2005
XEV Line-Up *

Hybrid

Ford Fusion Hybrid

Ford C-Max Hybrid

Plug-in Hybrid

Ford Fusion Hybrid Energi

Ford C-Max Energi

Battery Electric

Ford Focus Electric

* as of Mar. 2015
After 10 years, we have many challenges.

Cost!

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]


[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.

- a component size change
- another coupled component behavior change
- another coupled component behavior change
- another coupled component behavior change
- another coupled component behavior change
- system behavior changes w/ numerous possible scenarios.

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

HEV e-drive power electronics subsystem
HEV dc-bus capacitor has been driven to smaller and smaller.

- **Capacitance**
  - Escape Hybrid 2005 ~ 1500uF x 3 parallel = 4500uF
  - Fusion Hybrid 2010 ~ 2200uF
  - Fusion Hybrid 2013 ~ C-Max 2013 ~ 1100uF

- **Material choice**
  - Electrolytic
  - Film (PP)

- **Topology choice**
$C_{dc}$ size affects:

- Cost
- Weight
- Volume
- System stability
  multi-power converter interaction: Please, visit poster presentation D12-10
- 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

\[ i_{\text{ripple\_batt}} = \frac{Z_{C\_batt}}{Z_{\text{batt}} + Z_{\text{cable}}} \times i_{\text{ripple}} + Z_{C\_batt} \]

- Battery pack
- Battery cable
- Battery cable as ripple current source
- DC-DC converter
- Generator drive inverter
- Motor drive inverter
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 $C_{\text{batt}}$.

Note) The resonant frequency is not for $C_{\text{batt}}$ and dc-dc converter $L$, but for $C_{\text{batt}}$ 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?
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.]