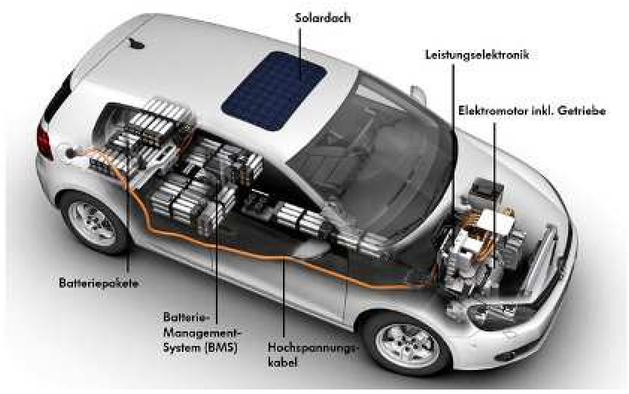
Load measurements on on-board power supply systems of electrical vehicles

Imagine you are a proud owner of a pure electrical vehicle and you spent two great days skiing in the Austrian Alps. The next morning, you leave your hotel to free your car from last night's snowfall. At sub-zero temperatures, the vehicle battery cannot provide its full power, but you're lucky: the vehicle starts and the heating function does its best to warm you up while you carefully drive down wintery roads to the valley.

Approaching a hairpin bend, you decelerate and your dashboard lights up like a Christmas tree. When trying to steer into the curve you realize it's almost impossible to turn the steering wheel. While uncontrollably sliding straight forward you thank God for letting you hit a huge pile of snow instead of an upcoming vehicle.
This is what might have happened meanwhile in your car; not exactly but close:

ABS: *"Anti-lock Braking System calling Power Distribution System! I have kind of an urgent issue down here."*
PDS: *"Sorry, I'm busy supplying heating and radio with power. What's up?"*
ABS: *"Driver stepped on the brakes and we're not slowing down…I could need some additional power."*
PDS: *"Roger that. You know you're my top priority."*
ESC: *"Hey PDS, this is Electronic Stability Control. It looks like we're on ice. Me and my buddy ABS are in charge of controllability here. Counting on your support."*
PDS: *"I copy. I'm kind of low on energy, but I'll cut off heating and radio so you should be fine."*
ESC: *"Appreciate that."*
EPS: *"This is Electrical Power Steering. Sorry to interrupt you guys but, believe it or not, that guy wants to steer now too! Kindly requesting power for steering support."*
PDS: *"Negative. All available power is distributed to higher priority systems. Please wait until resources are available again."*
EPS: *"Are you kidding me? How do you expect our driver to get two tons around the corner?... Hello, anyone there?... Alright, I'm outta here."*
…Moments of silence while the car inevitably crashes into a pile of snow…
PDS: *"Darn. I guess we messed that up…"*

Especially (but not only!) electrical vehicles are prone to such critical situations, where limited resources must be able cover the power requirements of vital systems. This is a big challenge for PDS developers and one thing is to design the PDS for theoretical, i.e. calculated loads, but another thing is to test and measure the load under real conditions (like low temperatures, critical driving situations, additional payloads etc.).
Such measurements were recently conducted by VW in Germany and I would like to deliver insight into what equipment they used, how the test were done, which challenges they had and – last but not least – some interesting results.



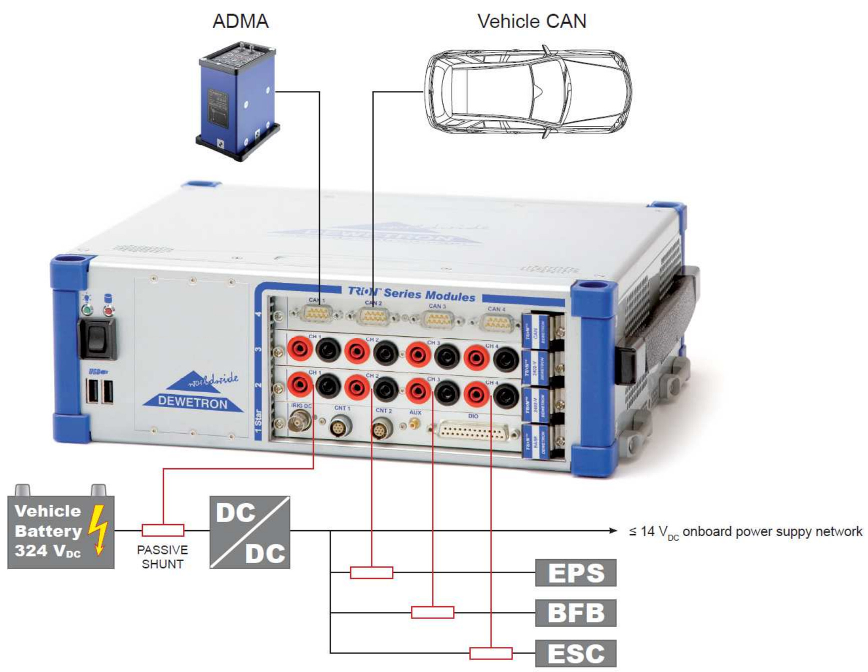
The vehicle under test was the new VW E-Golf which was presented during the IAA 2013 in Frankfurt. The task was to measure the total current on the main battery side (Li-Ion with 24 kWh capacity and 324 VDC system voltage) as well as specific currents on the consumer side for:

- EPS – Electronic Power Steering
- ABS – Anti-lock Braking System
- ESC – Electronic Stability Control

Additionally acquired were vehicle CAN bus data and vehicle movement data like position, acceleration, rotational velocity and speed measured by an inertial sensor (ADMA).

The output of this test can be broken down to a few significant parameters that are of interest for the PDS developers:

- Which circumstances provoke critical power demands?
- Current maxima – How much power does each vital system need at max?
- Current gradients – How fast is it needed?



"Whatever can go wrong, will go wrong"
[Edward A. Murphy, 1949]

In the first trials, a DEWE2-M4 was equipped with TRION-CAN-4D for vehicle CAN and ADMA data and a TRION-2402-dACC module to measure the currents of specific consumers via active shunts from CSM[1]. This setup caused problems on two sides:

1. The measured currents were implausible in terms of maxima and gradients: instead of short peaks, that should have been there according to PDS developers, the measured signal showed damped amplitudes and lower frequencies than expected. This was tracked down to the threshold frequency of the active shunts of 1.4 kHz.
   Solution → Passive shunts (0.1 mΩ, ~0.1 mV/A)

   NOTE: By switching to passive shunts, the engineers could now tap the full potential of their DEWETRON measurement system and acquire data with a sample rate of 50 kHz. This way they could see effects they have not seen before, especially the very high gradients!

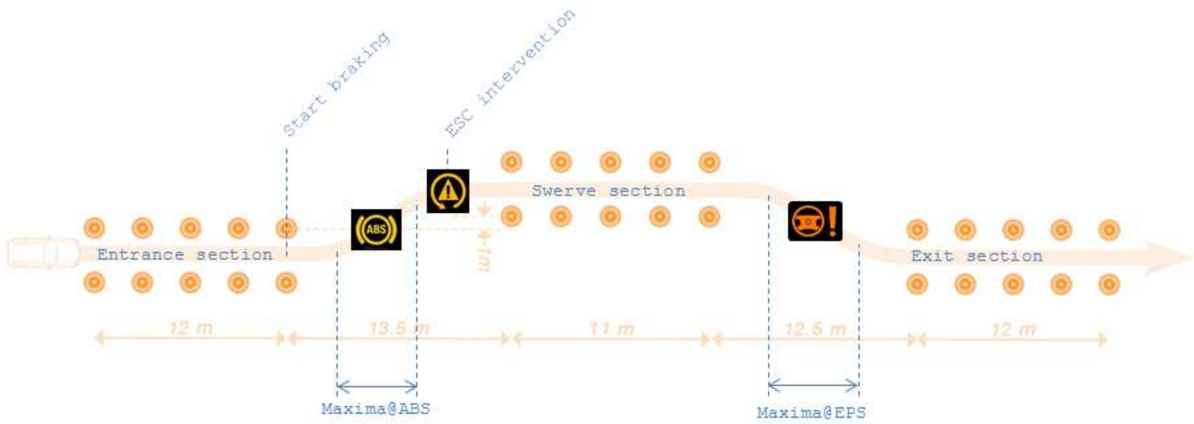
2. After exchanging active for passive shunts, the engineers set the dACC inputs to a ±30 mV input range because the voltage-drop on the shunts is small. However, this led to channel overloads due to the low common mode voltage of ±12 VDC. Switching to input ranges with higher CMV (input range > 10 V) didn't solve that either because the low input voltage is just too noisy in the bigger input ranges.
   Solution → Isolated inputs from TRION-2402-V-x-B

   NOTE: They were extremely happy with the performance of our isolated modules and decided to immediately buy a TRION-2402-V-4-B and a TRION-2402-V-8-B module for upcoming measurements!

If that weren't enough, the power supply of the steering robot which was used to reproducibly drive the test manoeuvre, also caused problems. The robot needs 24 VDC supply voltage. For obvious reasons you don't want to supply it from the vehicle battery, so in the first stage power was taken from a separate 12 V battery and DC/DC converter. The latter caused strong disturbances on the measurement signals, and was removed in the final stage. The robot was then supplied directly from a 24 V truck battery. Problem solved.

[1] http://www.csm.de/images/beitragsbilder/PDF/Messtechnik/CSMshunt_DS_0231_ENG.pdf

Now that everything works as expected let's have a look at the manoeuvre: the VDA lane change[2] a.k.a. "Elch test".



1. Entrance section: the vehicle enters with constant speed and steering wheel angle.
2. Braking point: from this point on, until the end of the manoeuvre, the driver manually brakes. A brake robot is an option here, but this would have been way more effort rigging up and does not significantly improve repeatability.
3. Between entrance and swerve section the ABS wants to quickly increase brake pressure which is why you would see maxima of 150 A and gradients greater than 20.000 A/s in the data at this moment.
4. Swerve section: when the steering robot steers back into the swerve lane, ABS should have reached the required brake pressure (unless you drove faster) and needs less power now. However, the ESC light warns you with bells and whistles that it's active and tries to counteract vehicle over-steering.
5. With ESC still active, the robot steers out of swerve lane towards exit lane. In this phase the EPS requests a lot of power due to higher steering forces caused by load-cycle changes.
6. In exit lane, the driver is still braking. Depending on the initial speed, this might be the last time in this manoeuvre for the ESC to intervene.

Unfortunately the data is not fully analyzed yet and even if this was the case, we couldn't publish it here. But knowing that maxima of 190 A (theoretically even 270 A if all consumers were to request power at the same time) and gradients of up to 140.000 A/s were measured, it's pretty clear that PDS developers have challenging work to do: P=I*U. With the power being limited by the battery and current being variably drawn from different sources, the parameter to be tuned is voltage in order to provide the required current. However, the voltage is also limited because if it drops below 6.5 V the on-board power grid breaks down.

After a week of intense testing, the measurement engineers were more than happy to deliver perfect data with new insights to their PDS developers and we're curios what's coming up next!

[2] http://www.vda.de/en/verband/fachabteilungen/technik/infos/vda-spurwechseltest.html