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Joint Research Centre

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Stand-by power consumption, efficiency under operational load and EMC of DC chargers for EVs

Performed by the *European Centre for Interoperability of Electric Vehicles and Smart Grids*,

European Commission, Joint Research Centre (Directorate General)

Speaker: Dr.-Ing. Harald W. Scholz,

Project Leader Interoperability Smart Grids, Electric Vehicle and Smart Homes

Work presented has been undertaken in large parts *for* and *in collaboration with*: *European Project NCE-FastEvNet, No. 2015-SK-TM-0320-S (Fast Charger implementation in Poland and Slovakia) of DG MOVE – INEA. EMC work on chargers was supported by the Exploratory Research Project "Do Not Disturb" of the EC's Joint Research Centre*

Expert Workshop on Energy Efficiency of EVSE,

IEA Research Cooperation and Austrian **bmvit**, Vienna, 28 September 2017

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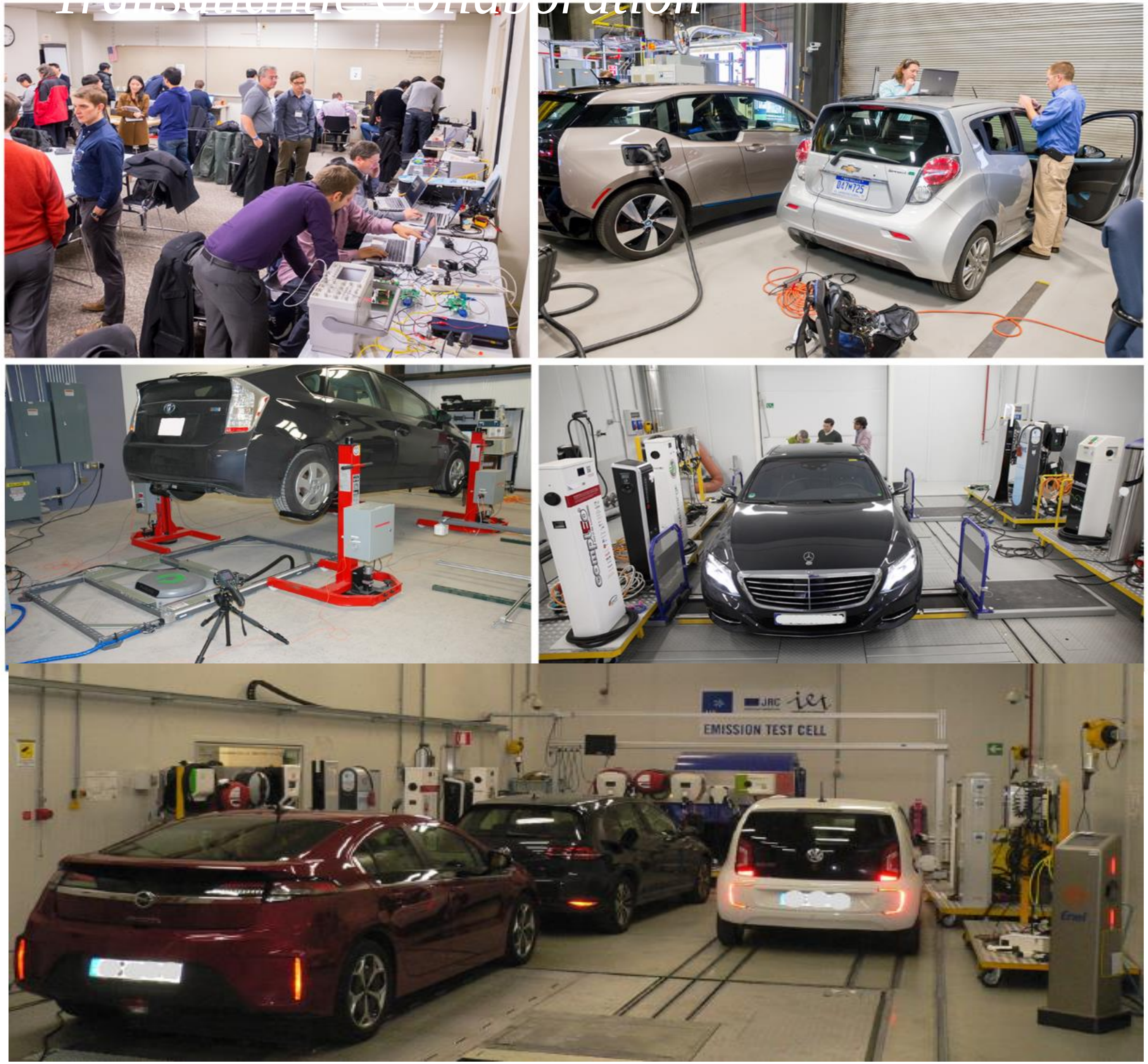
Transatlantic Collaboration



JOINT RESEARCH CENTRE
The European Commission's in-house science service

Argonne NATIONAL LABORATORY

- Underpinning global standards with applied research
- address interoperability issues between electric vehicles, smart grids and recharging systems
- focus on common goals with complementary capacities

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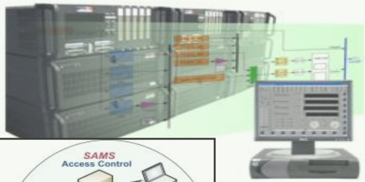
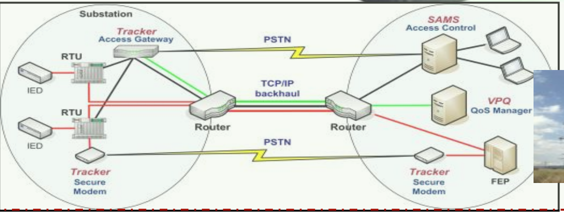
EU/US common approach for global standardization of EVs and EVSEs

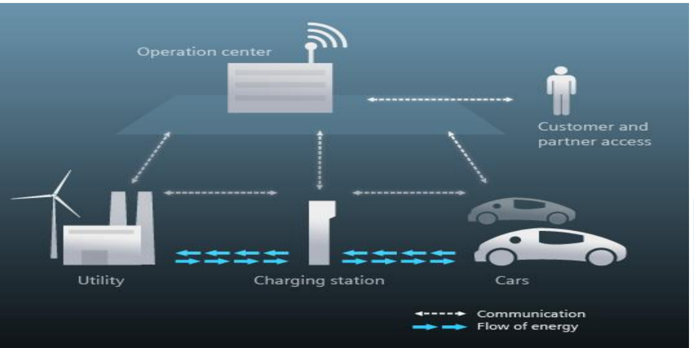
Petten, The Netherlands

Battery Research

Smart Grid Research

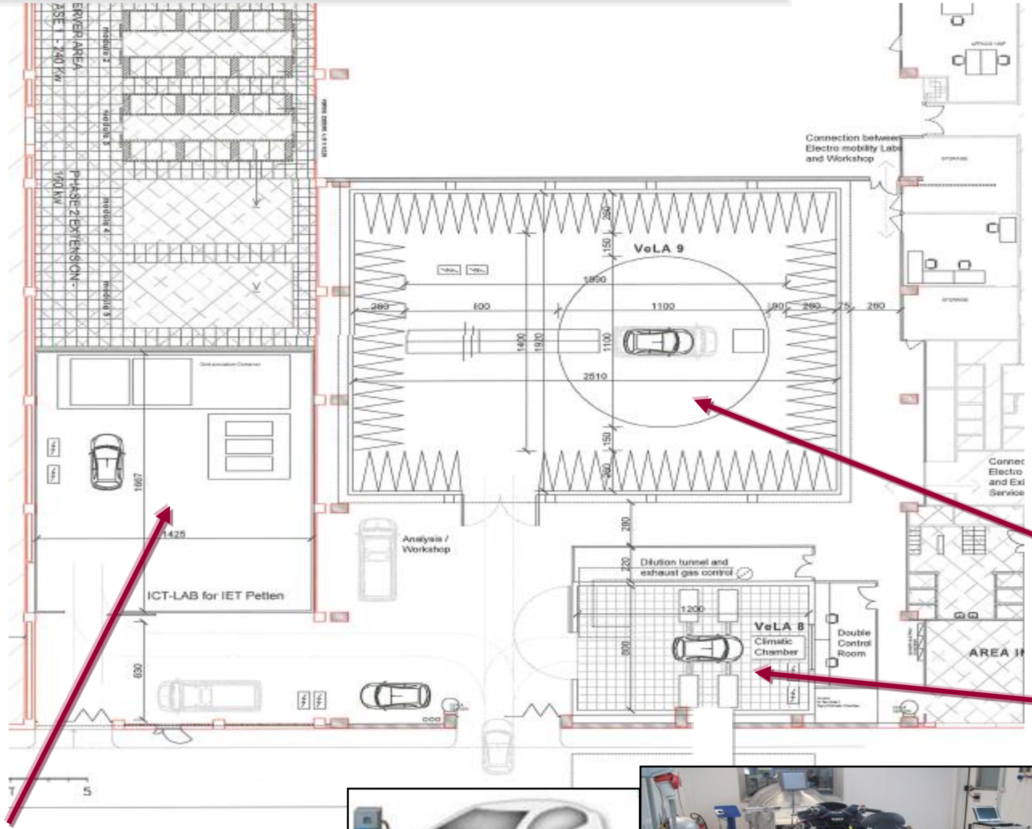


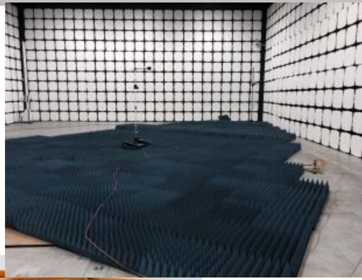


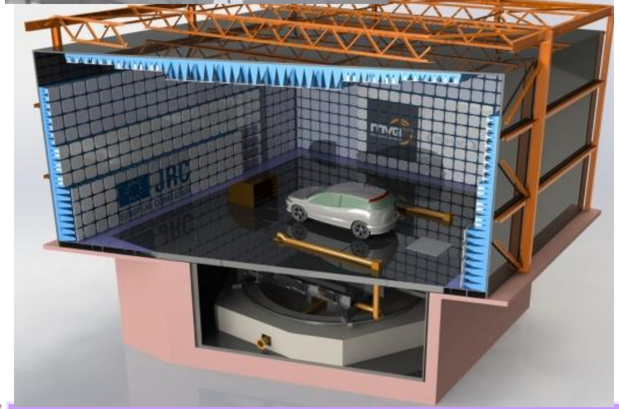


2015: Inauguration of New Interoperability Centre in JRC Ispra

Ispra, Italy

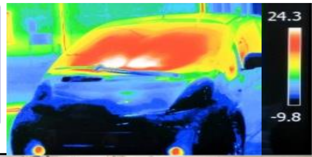






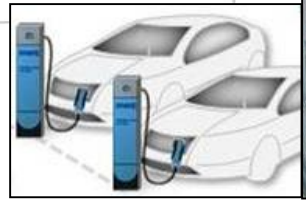
EMC testing under load

Vehicle charging and -performance under varied temperatures



Vehicle-to-Grid Interoperability

+ Smart Grids for EVs



INTRODUCTION

The Joint Research Centre (JRC) of the European Commission has tested charging column candidates for the implementation of the European Project NCE-FastEvNet, **No. 2015-SK-TM-0320-S in Poland and Slovakia**, as well as further DC-Multichargers arrived later. This project gives aids to the installation of multi-type Fast-Charging columns at TEN-T corridors.

Our testing plan concentrated primarily on the aspects of:

- **energy efficiency of the candidate devices in CCS and CHAdeMO ,Fast Charging modes**
- **stand-by power consumption of DC-Multichargers (up to 50kW, ca. 400V dc)**
- **influence of ambient temperature on the above described**
- readability of display HMI, and usability of candidate devices at various temperatures, ranging from -25°C to +40°C
- interoperability of the devices with various CCS and CHAdeMO chargeable electric vehicles
- OCPP back-end communication tests
- **Electromagnetic emissions from these candidate devices when being switched on, and when charging various EVs.**

Introduction cont’d

The tests were planned to take place during April and May 2017, at our European Interoperability Centre for Electric Vehicles and Smart Grids, situated within the JRC site of Ispra, Lombardy, Northern Italy. **Three quarters of the columns came with delays, respectively substantial delays to the JRC laboratory, such that a real testing period from May until August 2017 had to be arranged.**

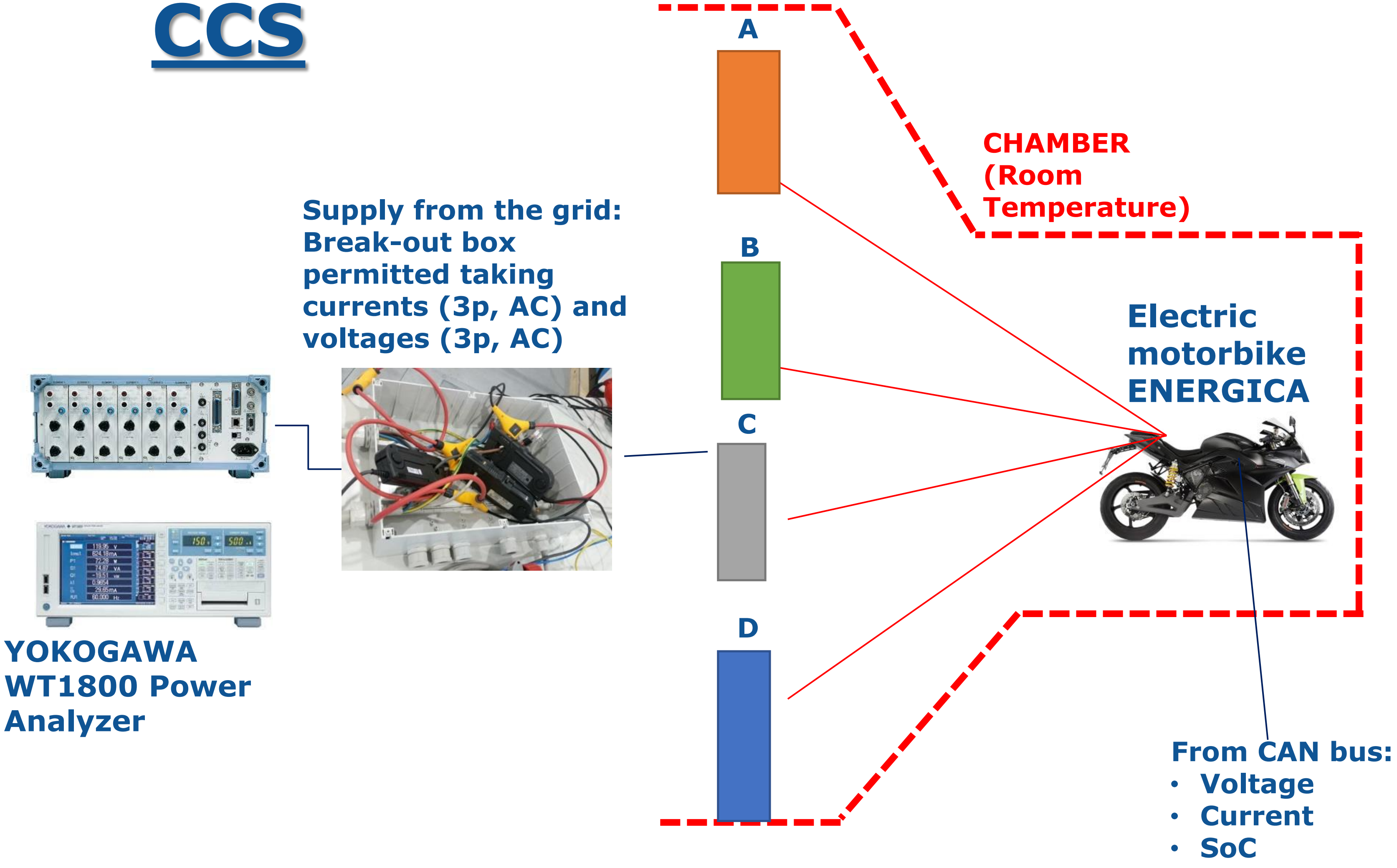
This testing activity aimed to support the electro-mobility infrastructure policy of DG MOVE and it's INEA agency, and is has been performed therefore free of charge. The improvement of methodologic approaches for charger quality and notably efficiency measurement tests was a welcome side-effect of the project, and will lead to a scientific publication with anonymised charging column candidates.

Massive interest of EU-, U.S. ad Australian industry lead to a continuation of the work for broadening the result matrices

EU- and non-EU products were tested

Fast Charging Columns Efficiency Measurement Set Up

CCS



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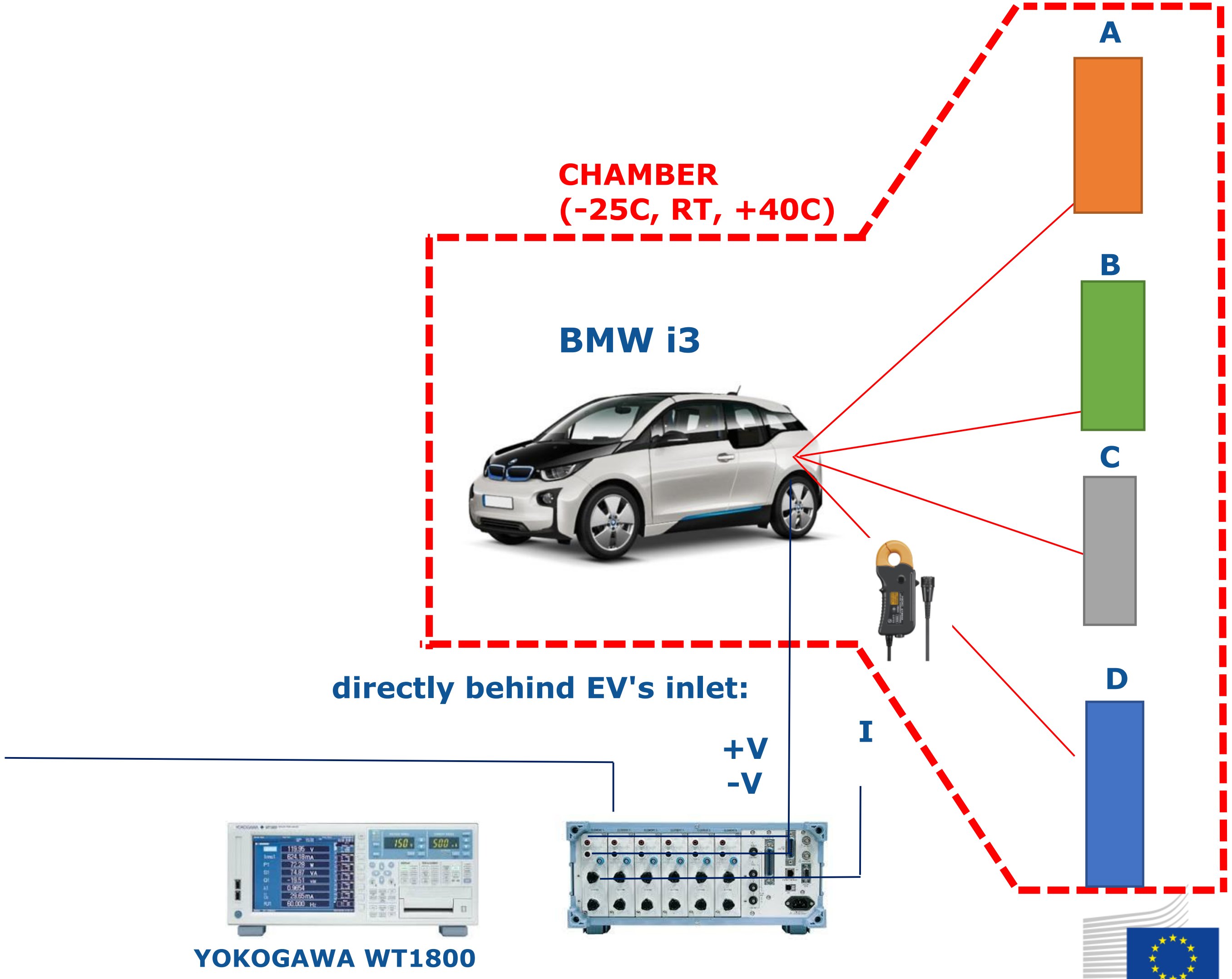
Fast Charging Columns Efficiency Measurement Set Up

CCS

Supply from the grid: Break-out box permitted taking currents (3p, AC) and voltages (3p, AC)



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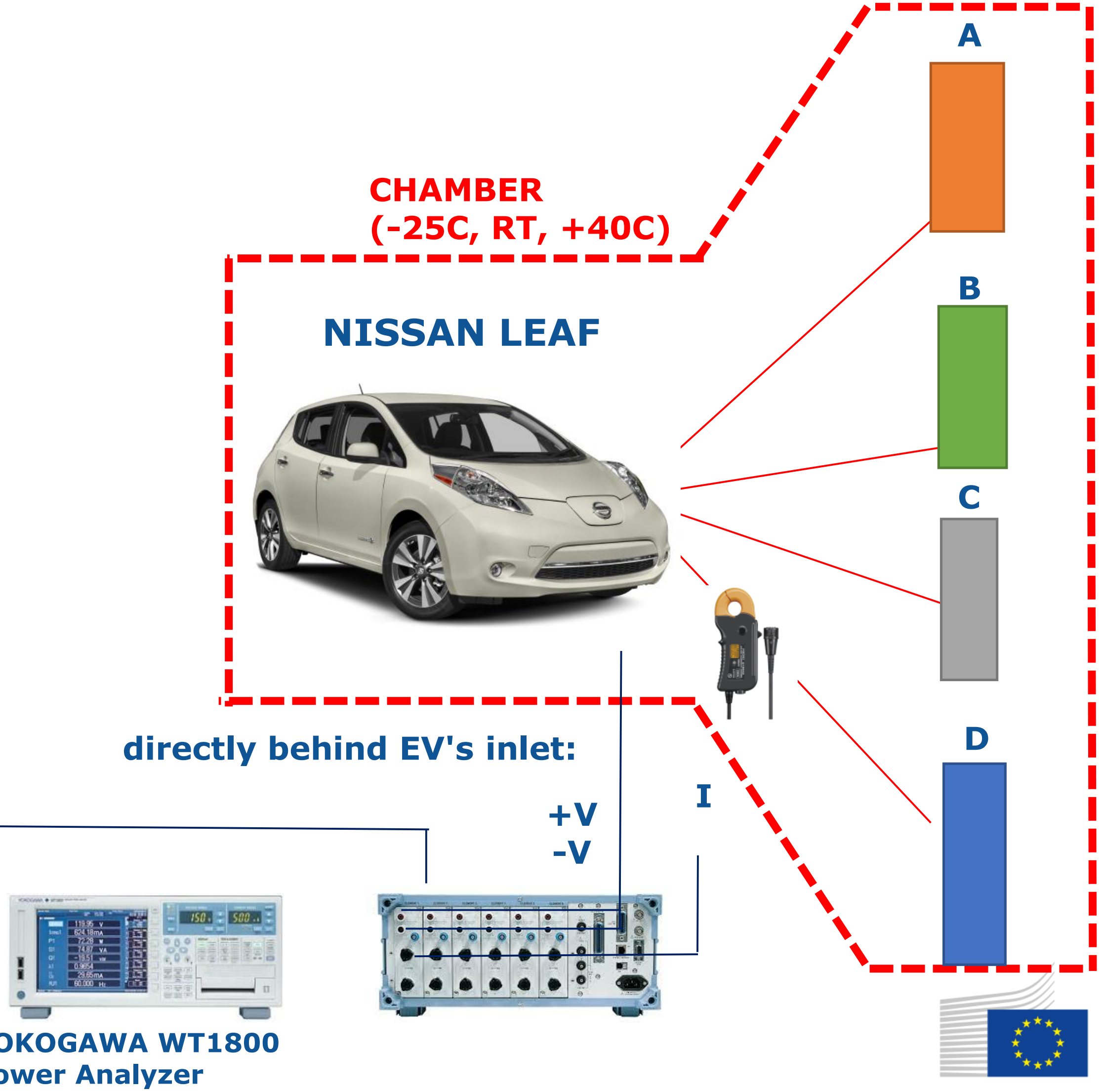
Fast Charging Columns Efficiency Measurement Set Up

CHAdeMO

From the grid

directly behind EV's inlet:



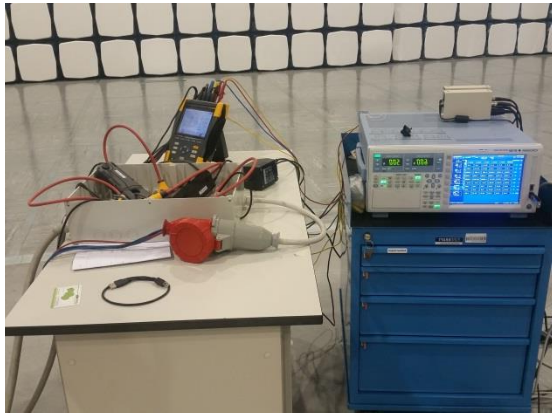
Instrumentation

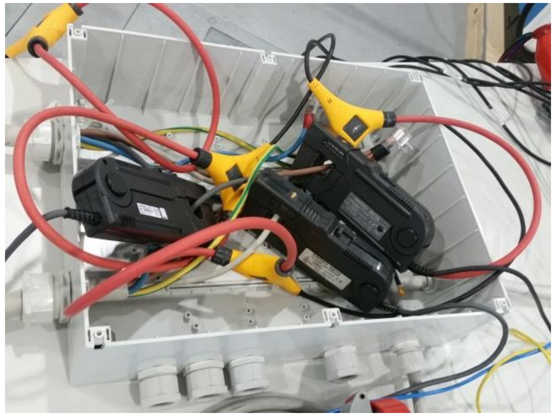
Grid side: *for comparison, two instruments were used:*

Fluke 437 with clamps i430-Flexi-TF-II

and also

Yokogawa WT1800 with clamps HIOKI 9278, 3275





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Operational tests – at Room Temperature

- testing of real columns (EVSEs) against EV simulators, in order to test conformity to critical issues in standards, like control pilot PWM, and as applicable, HLC (high-level communication), SLAC (Signal Level Attenuation Characterization), etc. This is done for AC and CCS connectors.
- testing of real columns against some real EVs, for interoperability proofs in product matrices (EV vs. EVSE), check of DC voltage steering compatibility between EV and DC-columns, HLC "man-in-the-middle analysis", grid interrupt ("black-out") - behaviour, etc.
- power distribution in time during whole charging session (10-80% SoC of car battery)
- analysis of conducted harmonic distortions stemming from the EVSEs back to the 3-phase AC-grid with FLUKE equipment, embedding results into a comparison base of columns tested before (anonymized producers). Includes comparison of results to applicable standards in EU. This is done for CHAdeMO and CCS connectors.

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Preliminary Standby Power Measurements (**apparent power**) of charging columns

Chargers	25C	40C	-15C	-25C
A	740.14VA	703.38VA	708VA	(722.54VA)*
B**	134VA	177VA	Not tested	161VA
C**	150VA	177VA	164VA	(983VA)*
D	952.2VA	919.26VA	Not tested	966.9VA
E	822VA	To be tested	To be tested	To be tested
F	To be tested	To be tested	755VA	761VA
G	To be tested	To be tested	1176VA	1205VA
H	To be tested	To be tested	180VA	167VA

*Charging column out of order or in faulty conditions.

** Standby powers between 130 and 180 VA, distributed inharmoniously between the three phases, partly encountered on only one phase, were at the limit of setup's measurement capability.

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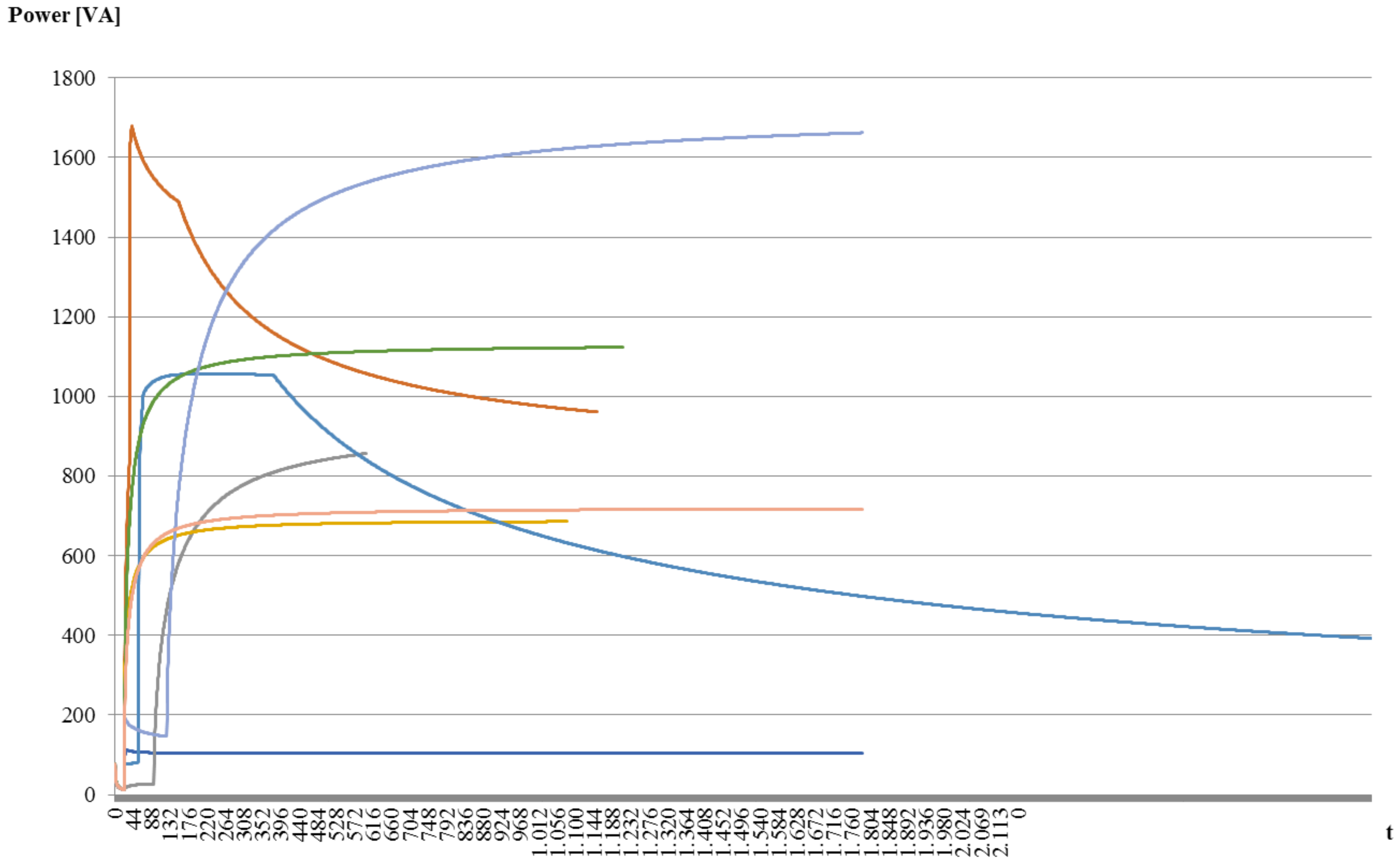
Automated, apparent Standby Power Measurements of 8 different DC -chargers



Stand-By power MUST be measured for at least 15minutes, better 30 minutes.

Dramatic differences stem from topology of design and also from more or less switch-gear investment to switch on coils only when the customer is really triggering a DC-charge

Conclusions from Stand-by power Tests:

- We need to better develop our measurement protocols for precise measurement of unbalanced Stand-by power consumption
- In order to precisely make sound judgements on the portion of real power (*Wirkleistung*) with the apparent power.
- WE HAVE MEASURED A COLUMN TO CONSUME ca. 65W of real Power, but 1100W of total apparent power in stand-by.
- The producer claimed, this would be a welcomed effect to the grid of his countries' grid operator, but this may depend on regional situations.
- There are countries in EU, who make industrial operators pay for reactive power (*Blindleistung*)

CCS Energica electric motorcycle: Room Temperature Test

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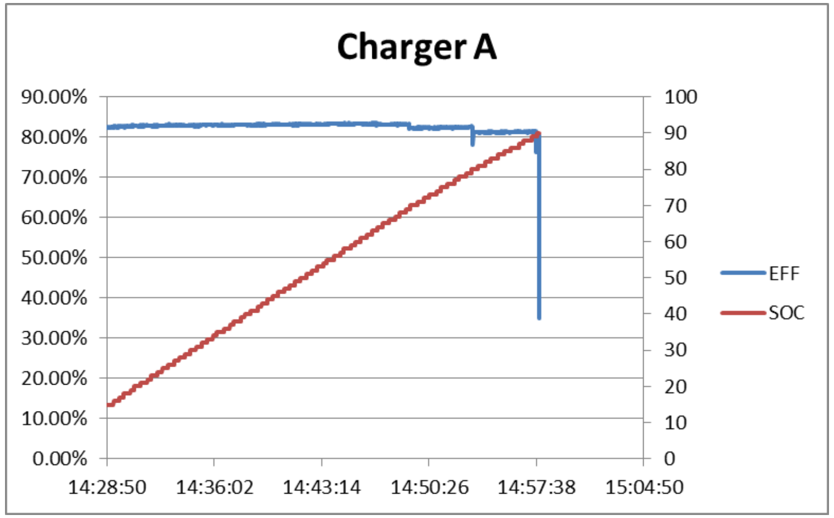
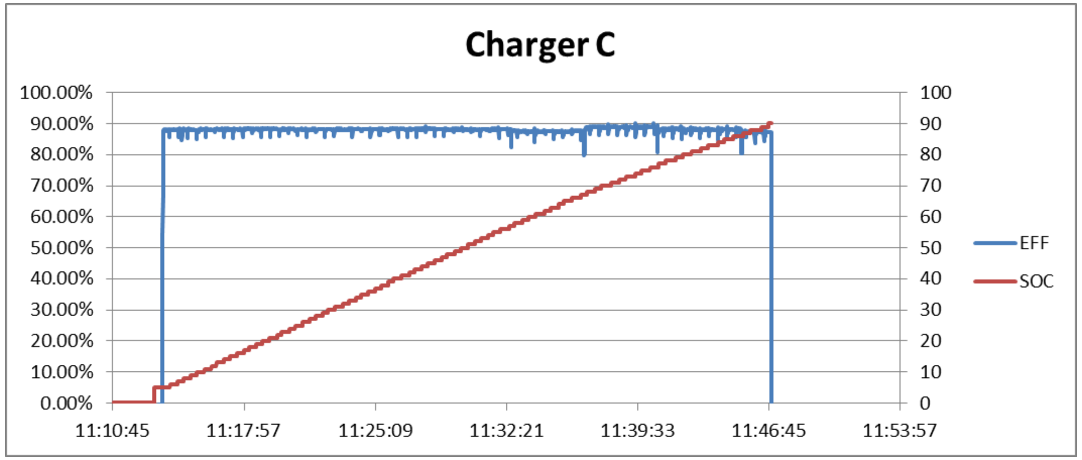
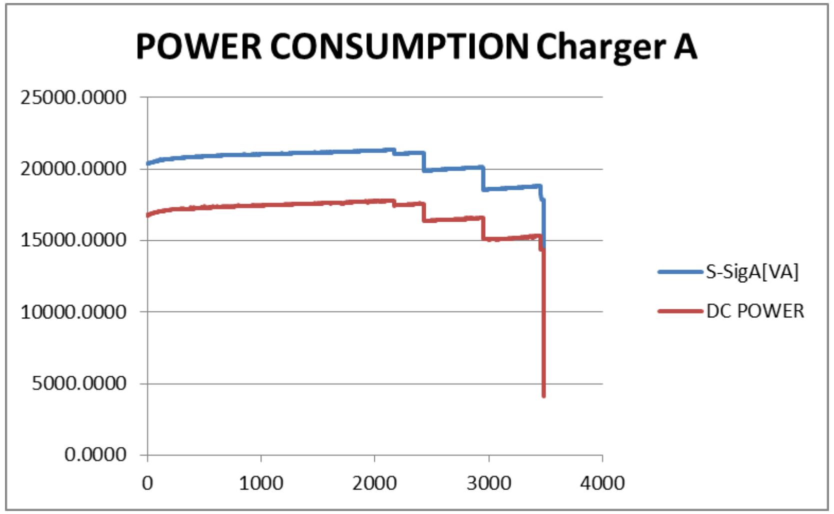
CCS Energica electric motorcycle: Charging columns efficiency measurements

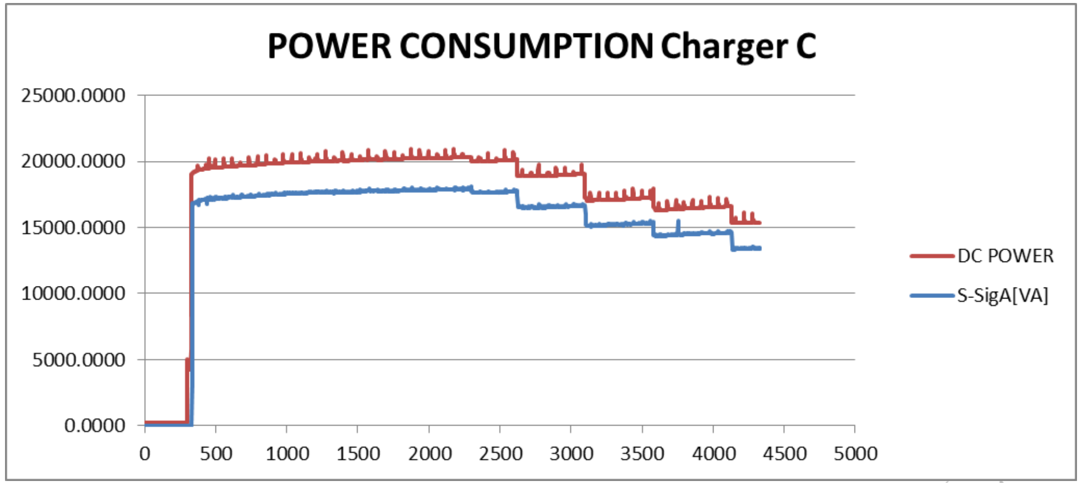
Chargers	25°C Average efficiency of charging column (S.o.C. 10-80%)	
A	82.90%	17.28kW
B	EV not compatible	EV not compatible
C	88.06%	16.98kW
D	87.39%	14.18kW

Results Chargers A and C

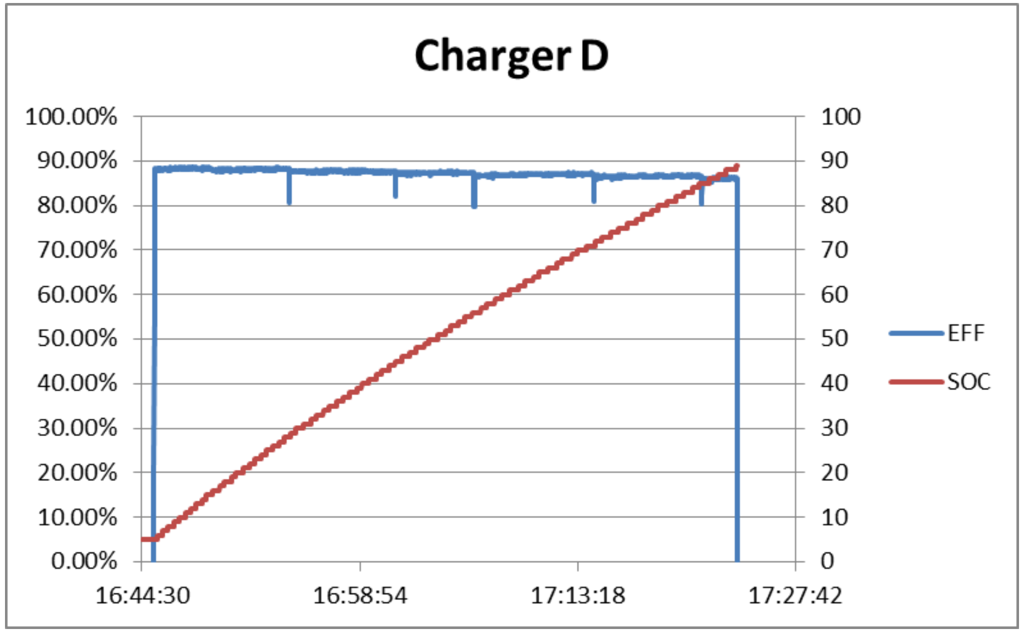


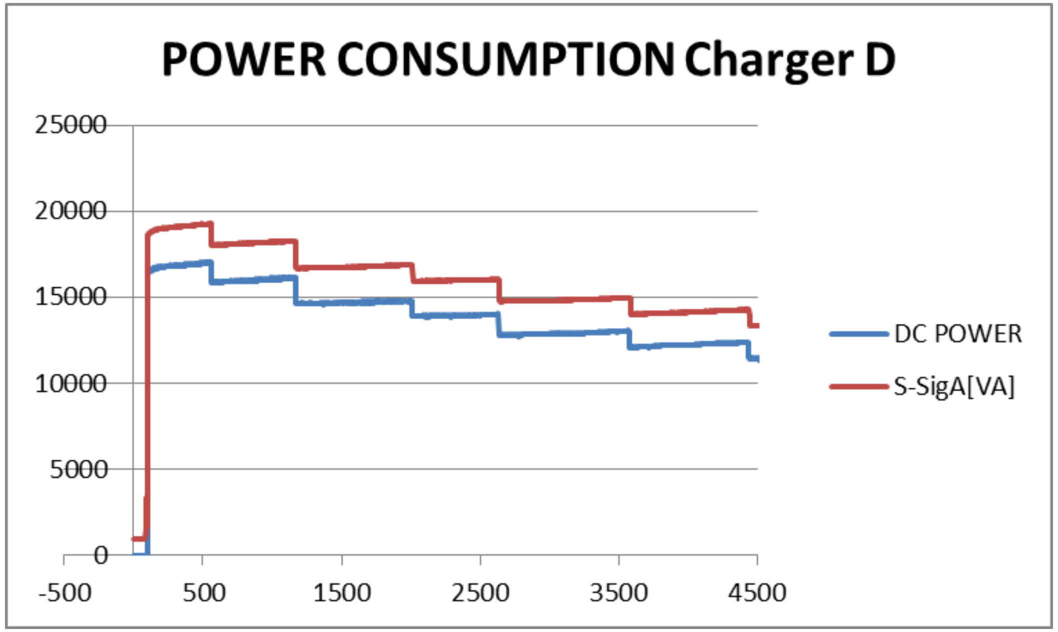






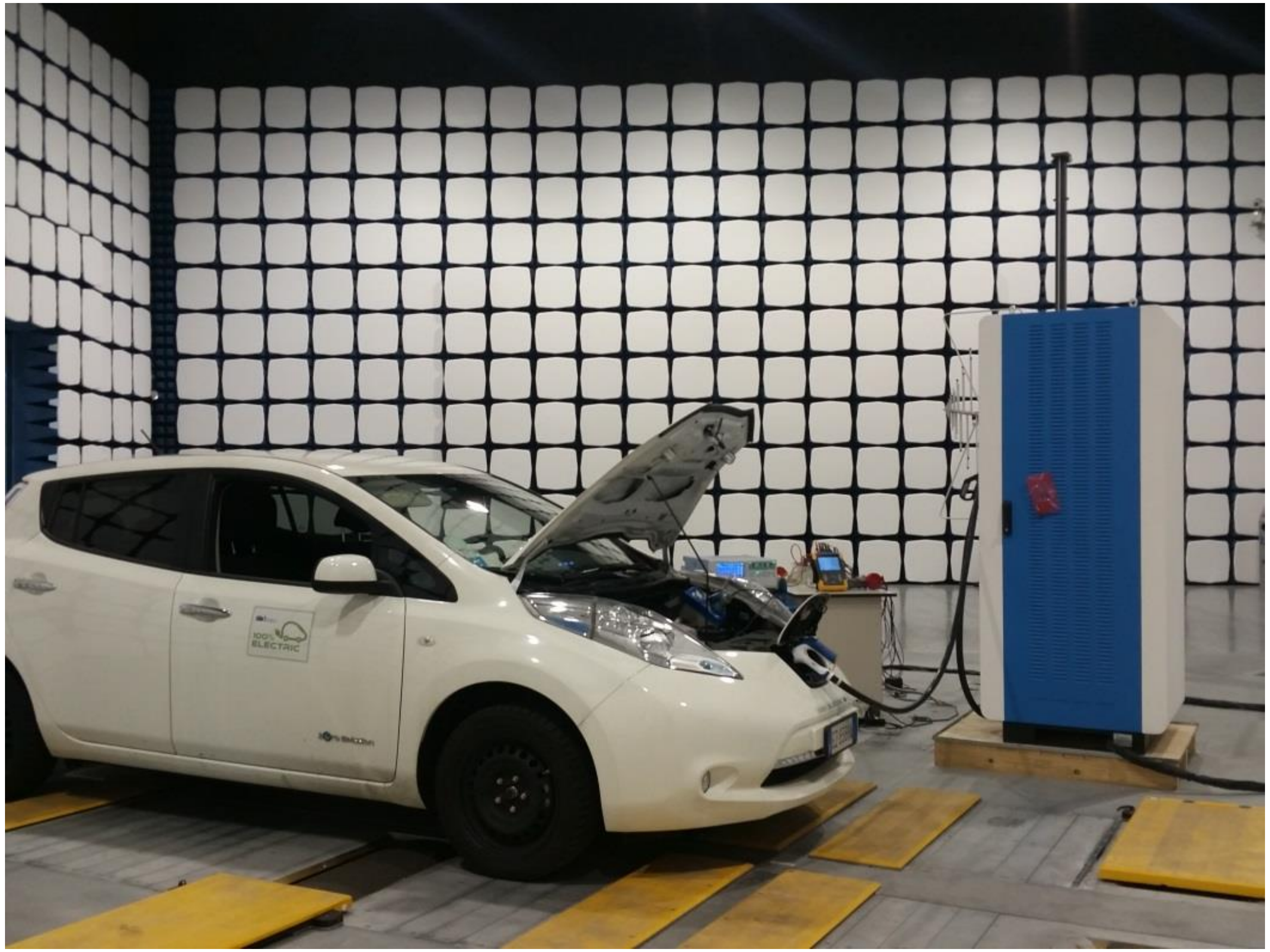
Results Charger D

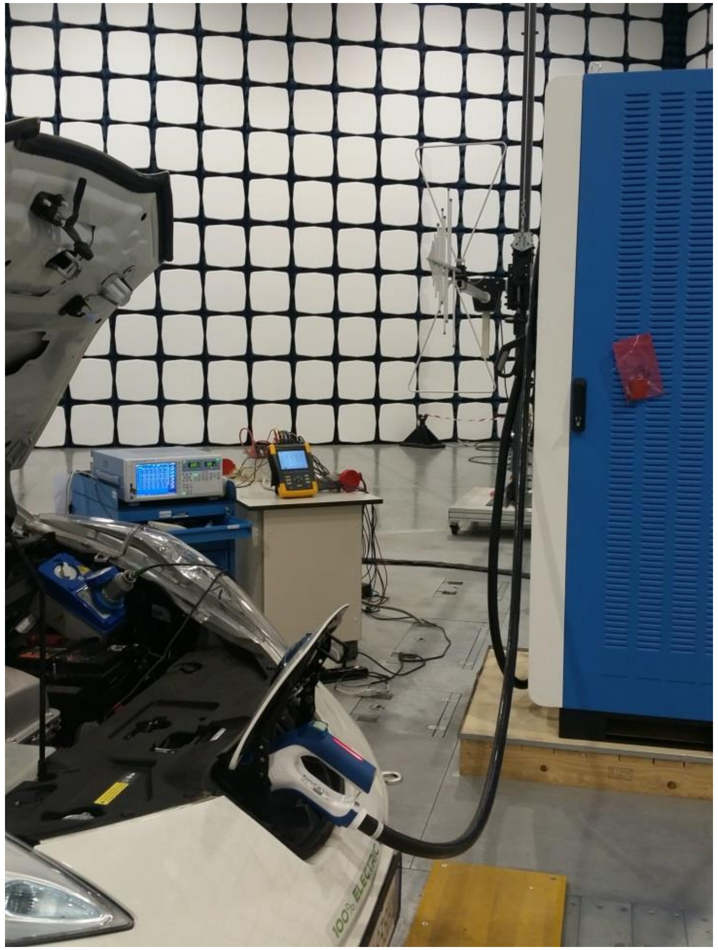




CHAdeMO DC side

Yokogawa WT1800 power analyzer
with clamps HIOKI CT6844





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EXTREME TEMPERATURE FUNCTIONALITY TESTS

- cold tests at -25°C
- warm tests at +45 °C
- Other tested features: charging functionality, readability of the display of the column, etc.

POWER MEASUREMENTS

- Efficiency measured at -25°C, 25°C, 45°C
- Standby power consumption measured at -25°C, 25°C, 45°C

CHAdeMO extreme temperature set-up

CHAdeMO NISSAN LEAF: Efficiency measurements of charging columns

Chargers	25°C		40°C		-15°C		-25°C	
	Efficiency…	…@ Power	Efficiency…	…@ Power	Efficiency…	…@ Power	Efficiency…	…@ Power
A	90.8%	40.37kW	91.18%	40.2kW	36.26%	4.18kW	Out of order	Out of order
B	91.47%	48.24kW	89.13%	47.35kW	Not tested	Not tested	56.65%	4.1kW
C	91.76%	37.61kW	92.4%	37.36kW	89.5%	21.21kW	Out of order	Out of order
D	92%	47.09kW	91.21%	45.9kW	Not tested	Not tested	72.83%	4.42kW
E	92.1%	45.77kW	to be tested		to be tested		to be tested	
F	to be tested		to be tested		84.15%	22.95kW	51.5%	5.15kW
G	90.48%	45.45kW	to be tested		Out of order	Out of order	Out of order	Out of order

Values obtained from the median of the maximum stable charging conditions.

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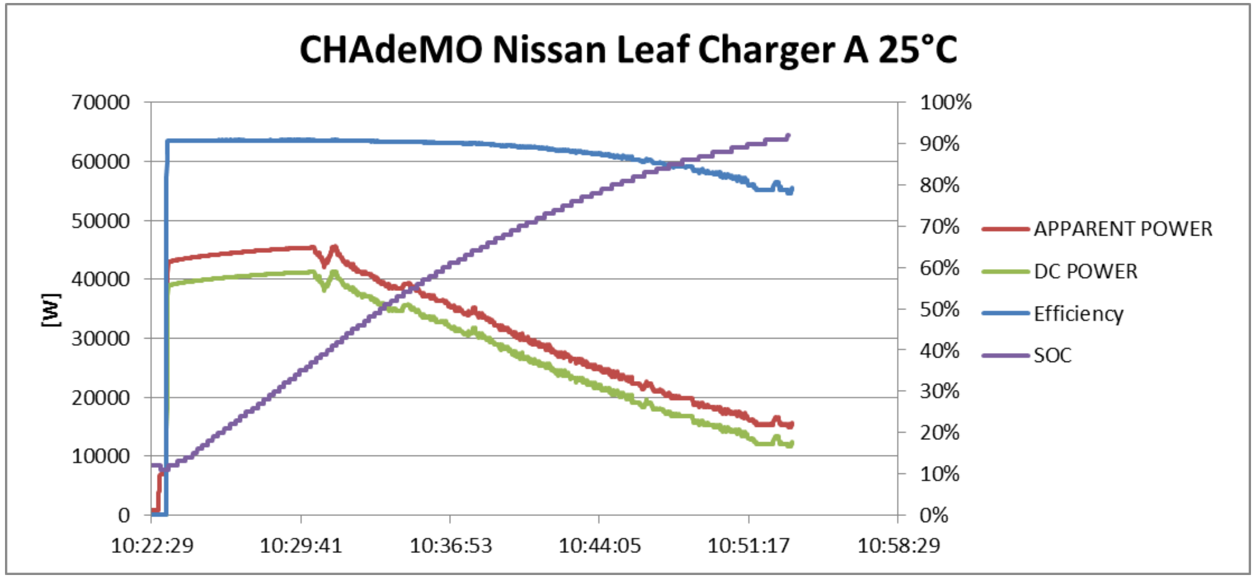
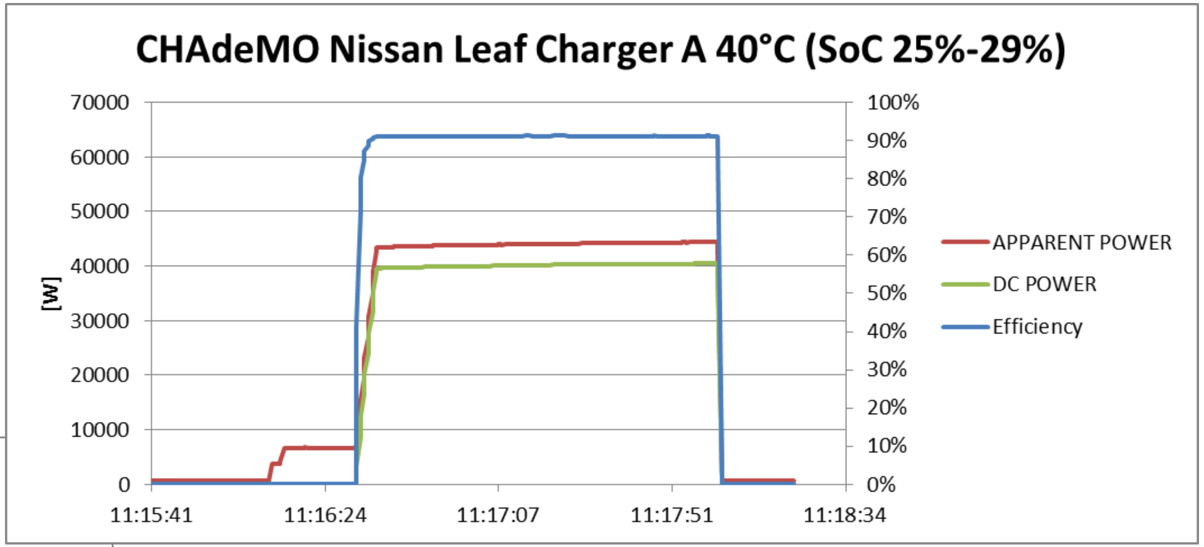
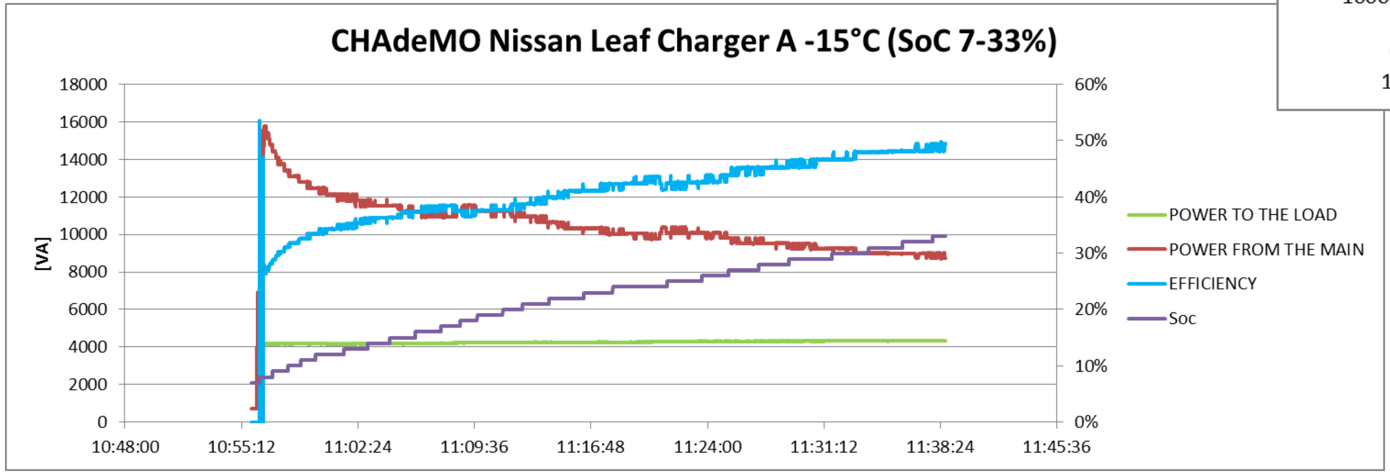
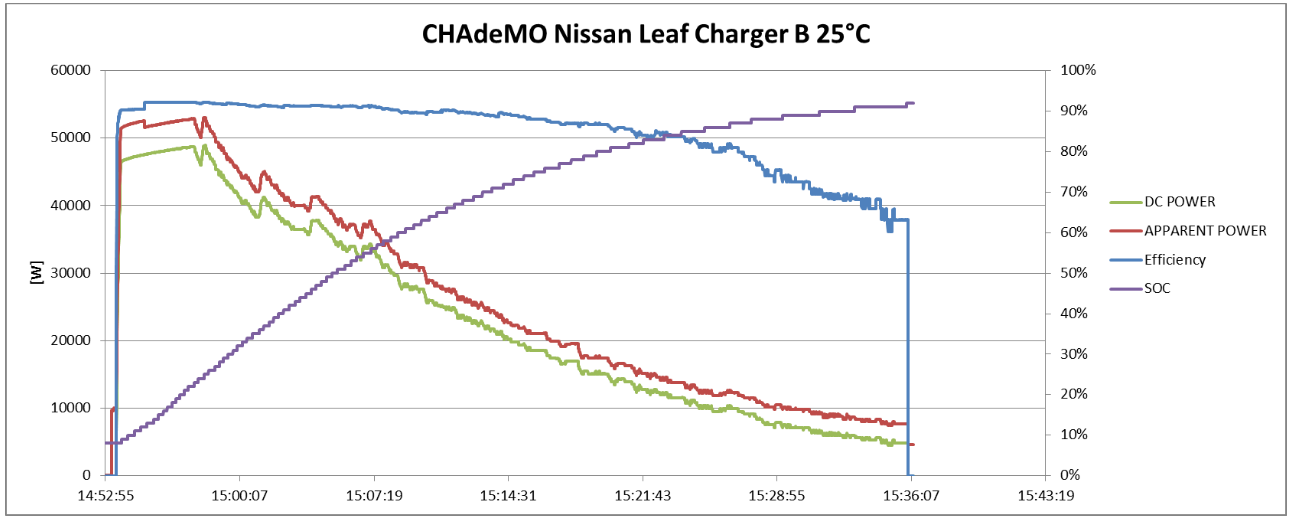
Results Charger A

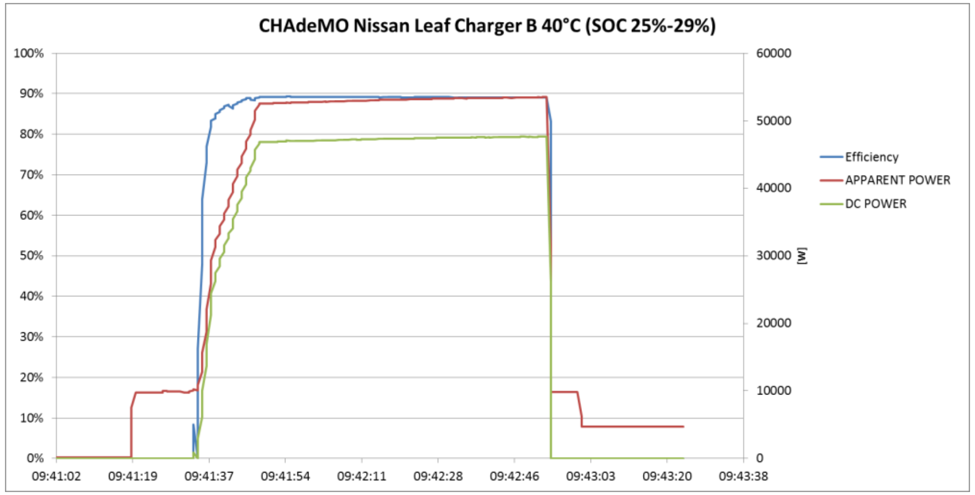


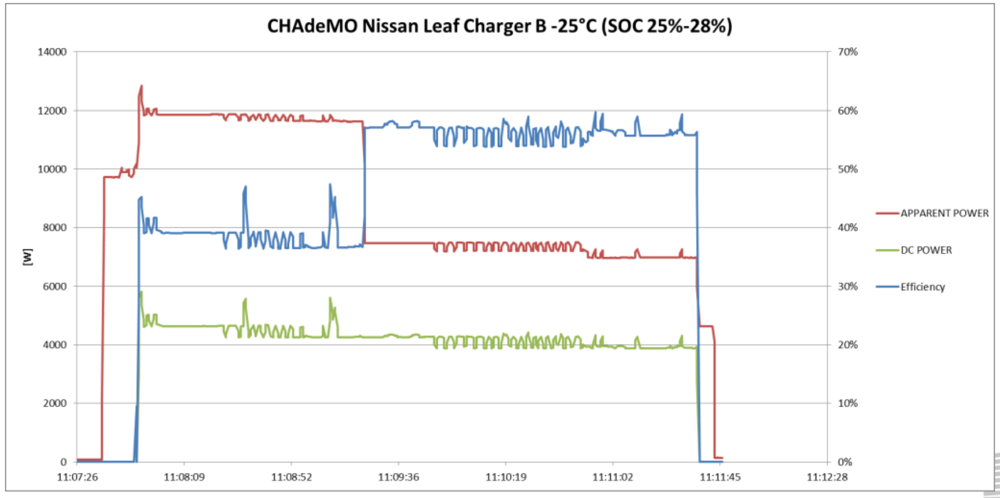




Results Charger B







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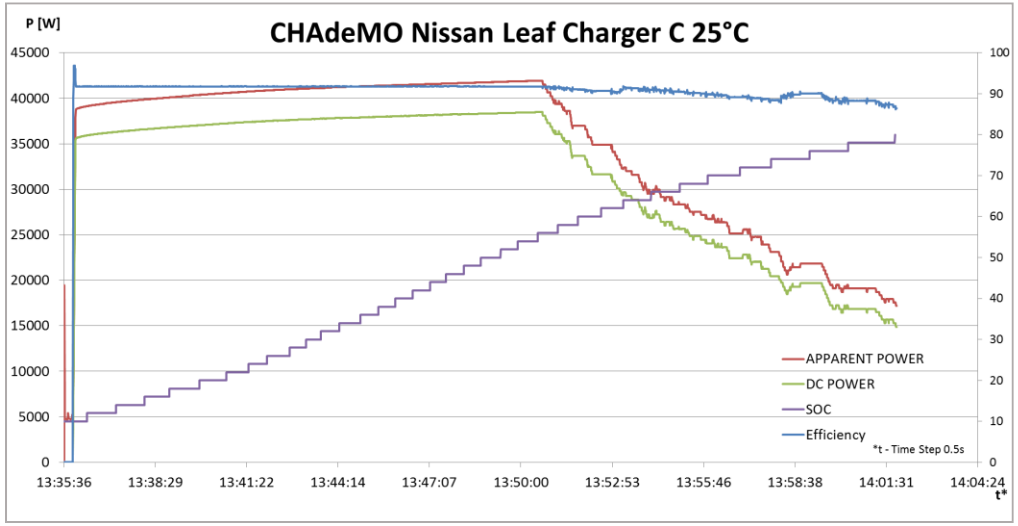
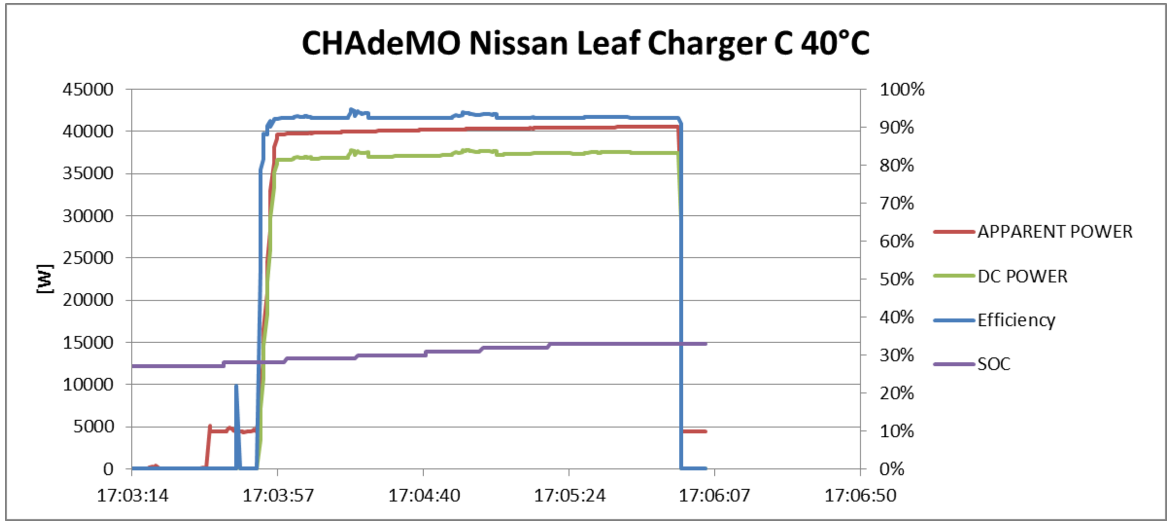
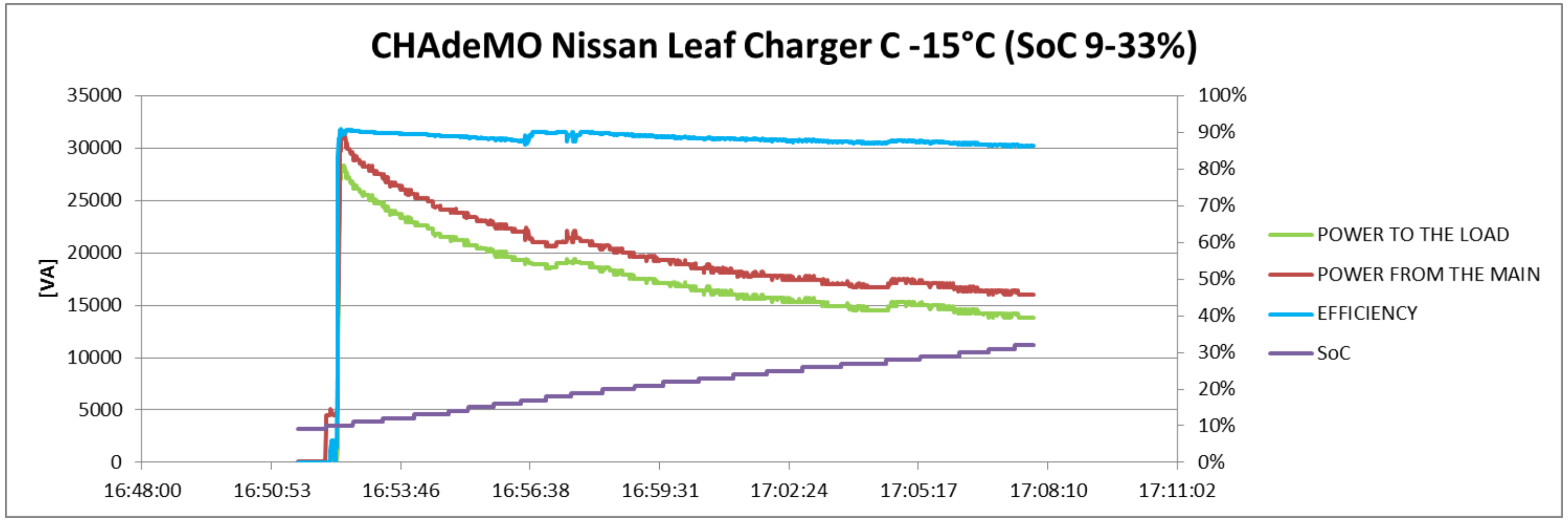
Results Charger C







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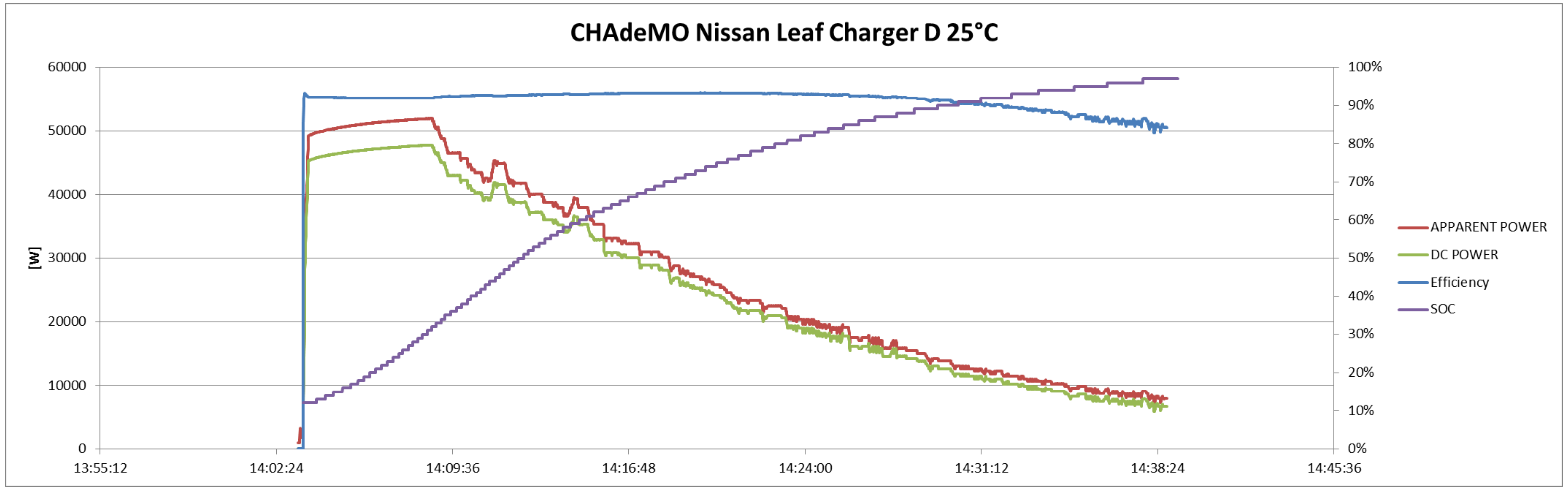
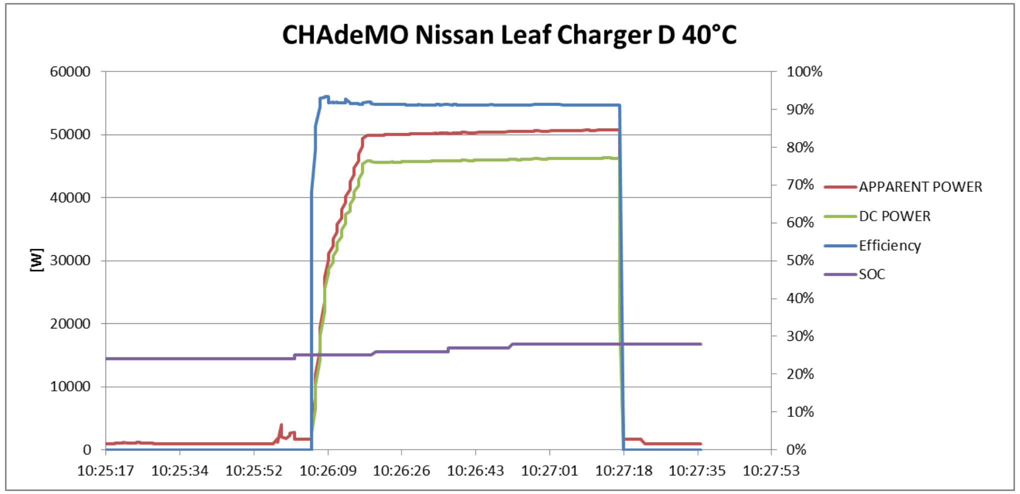
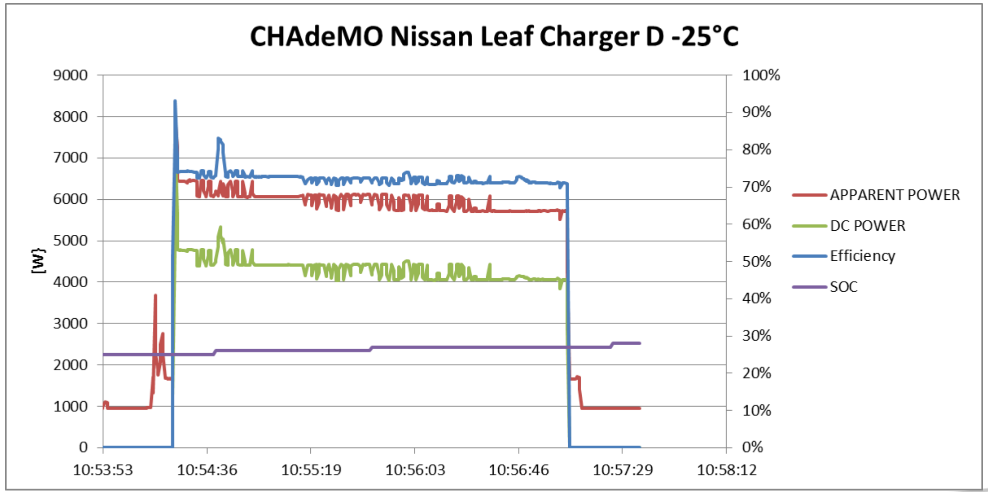
Results Charger D







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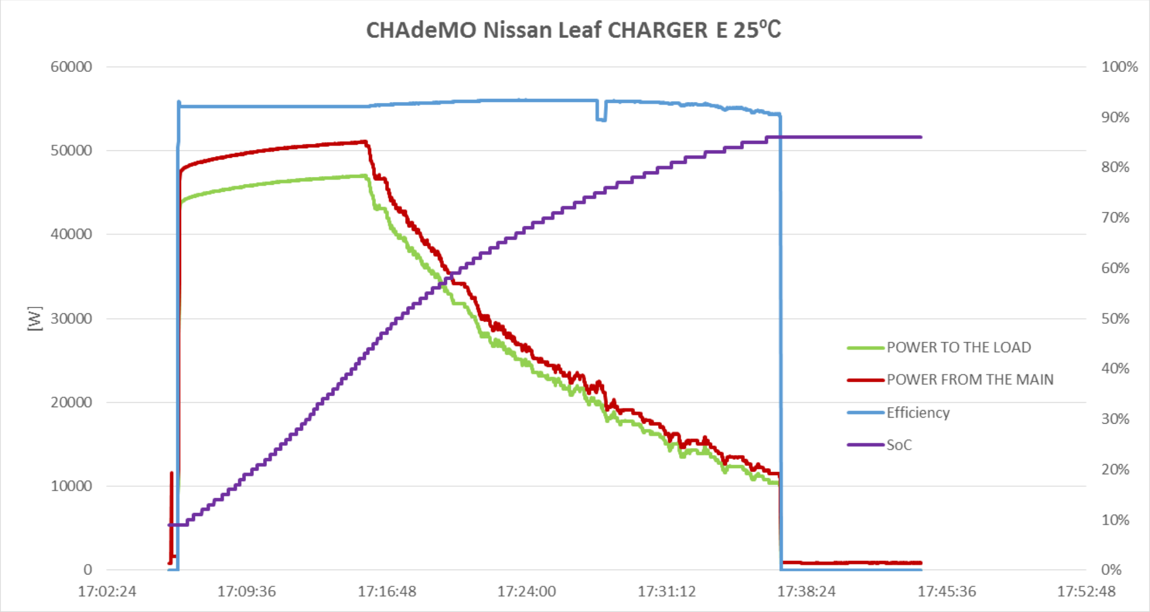
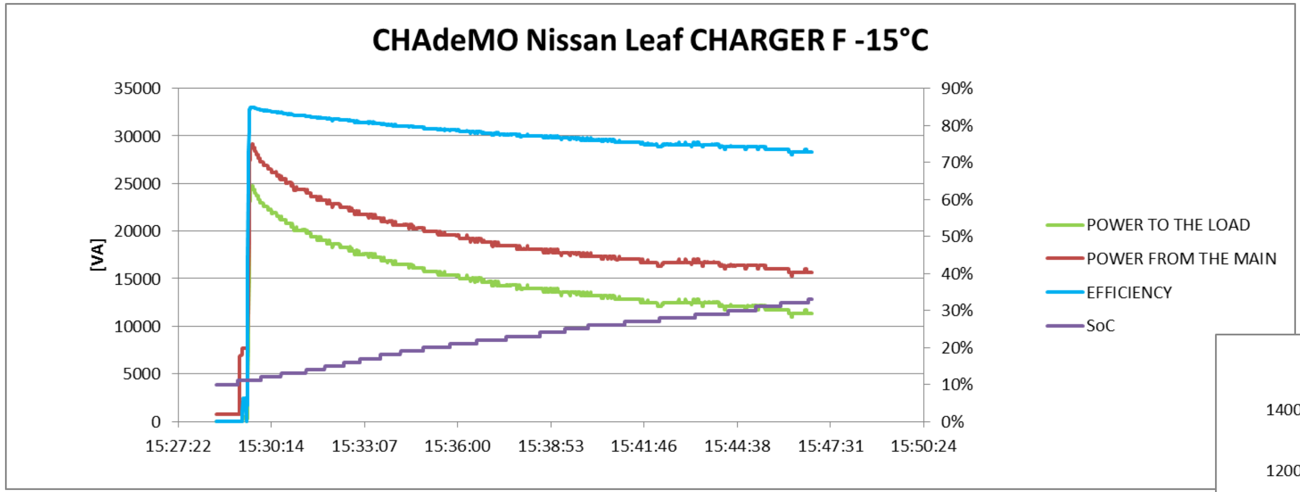
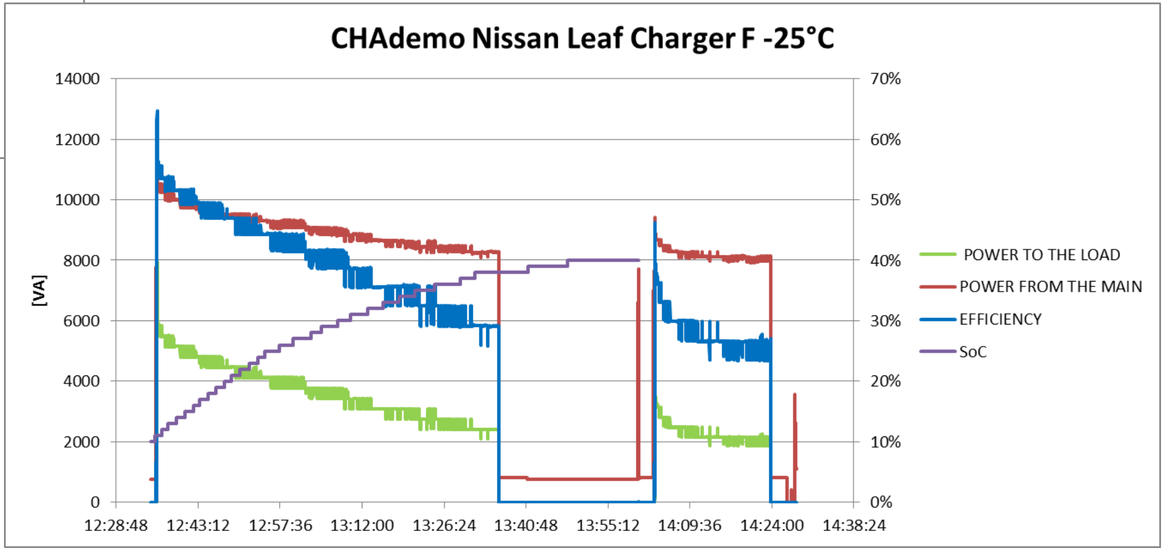
Results Charger E



Results Charger F





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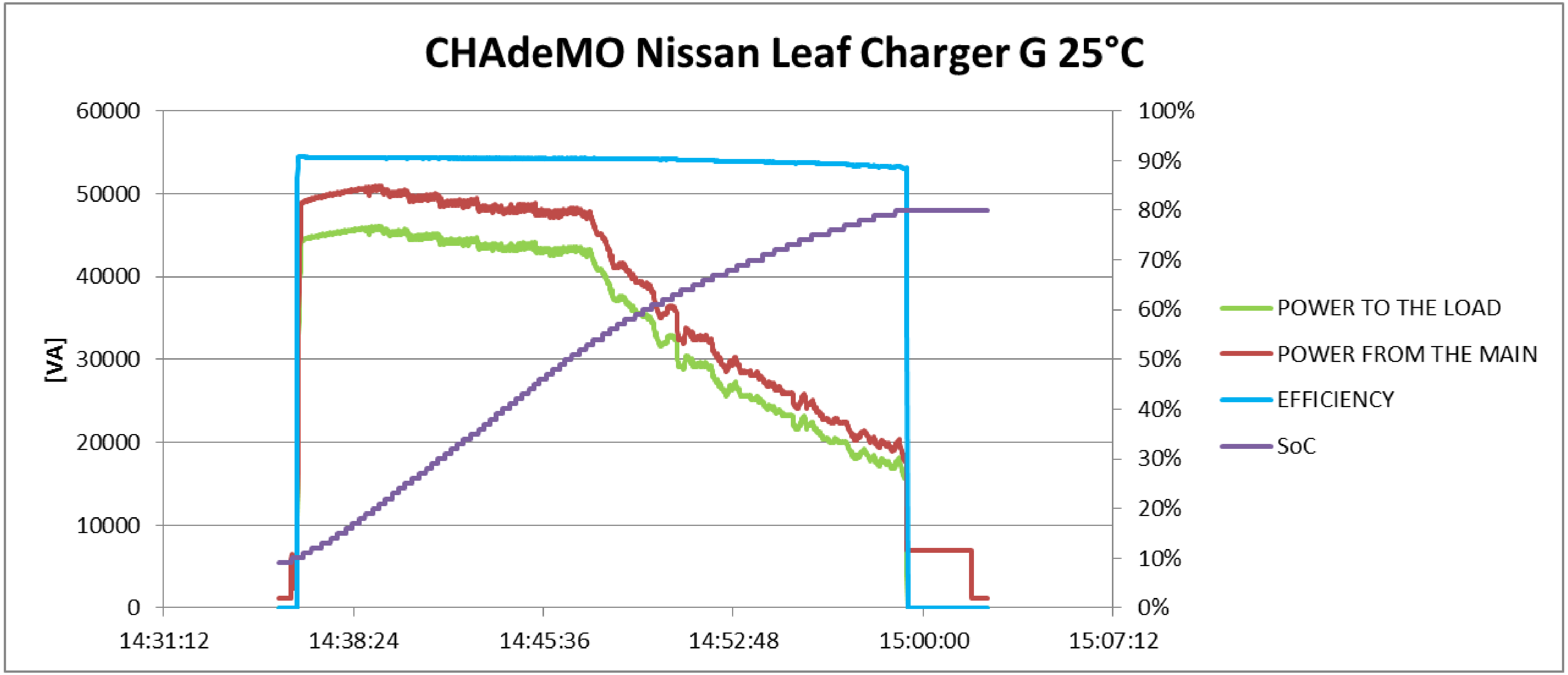
Results Charger G



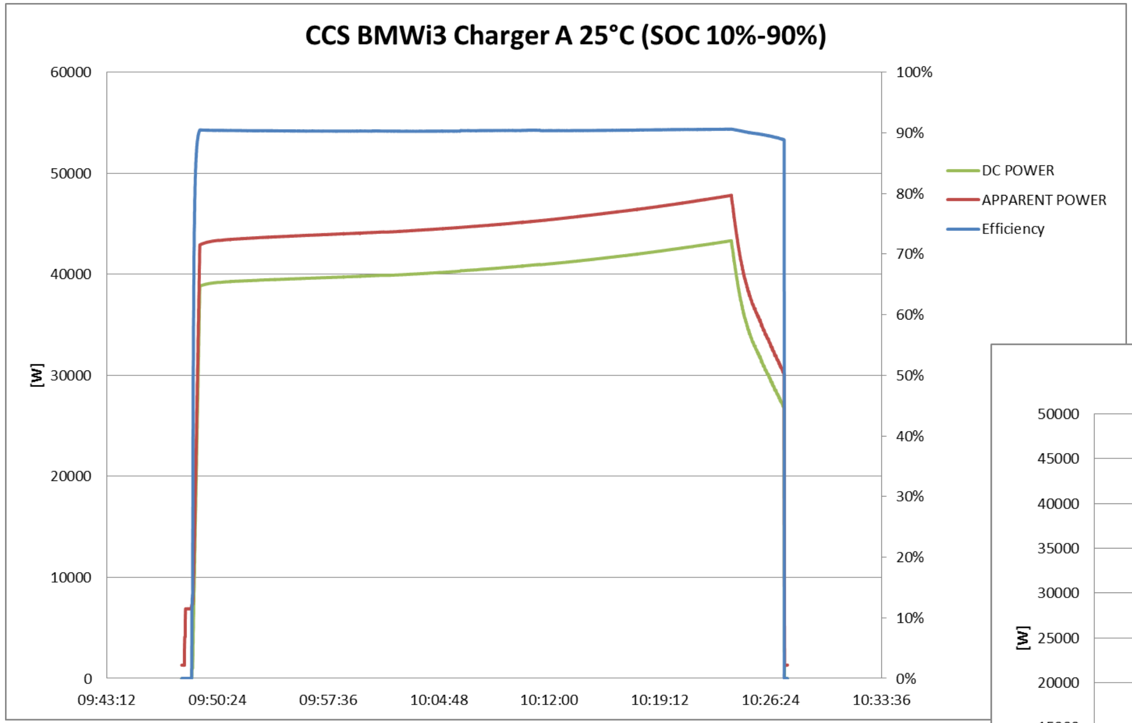
CCS extreme temperature set-up

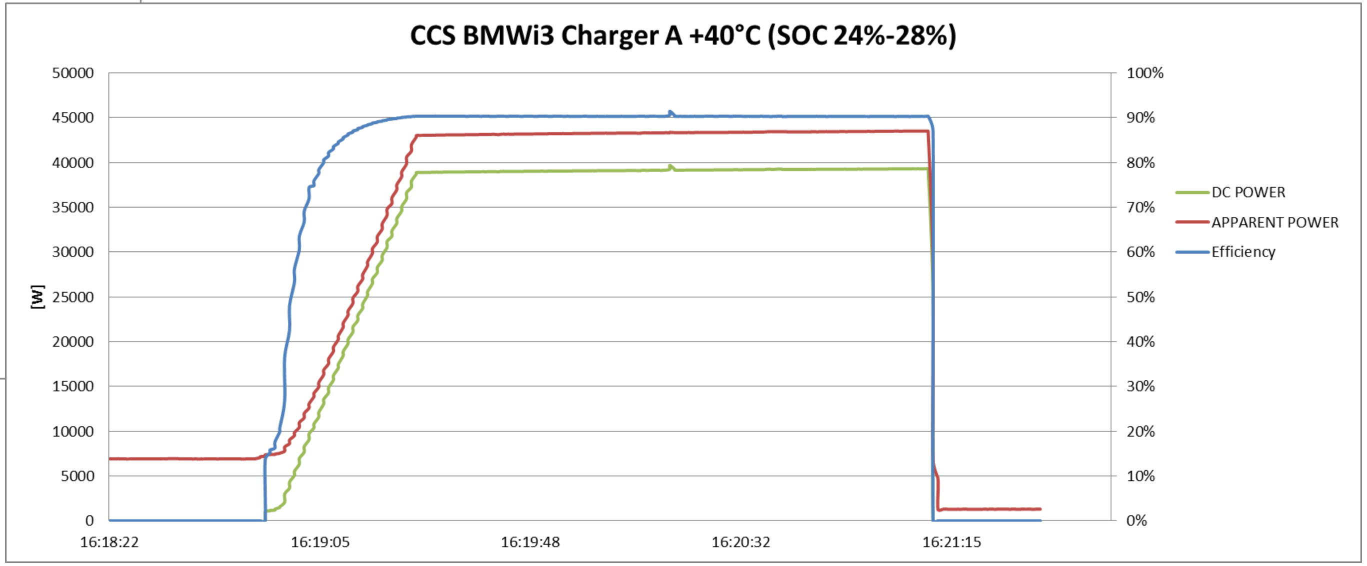
CCS BMW i3:
Efficiency measurements of charging columns

Chargers	25°C		40°C		-20°C	
	Efficiency	Power	Efficiency	Power	Efficiency	Power
A	90.38%	40.3kW	90.35%	39.15kW	Out of order	
B	89.84%	44.47kW	89.87%	42.2kW	64.51%	6.52kW
C	Not tested: column out of order					
D	90.56%	46.40kW	90.89%	45.06kW	78.84%	7.55kW

Values obtained from the median of the stable charging conditions.

Results Charger A





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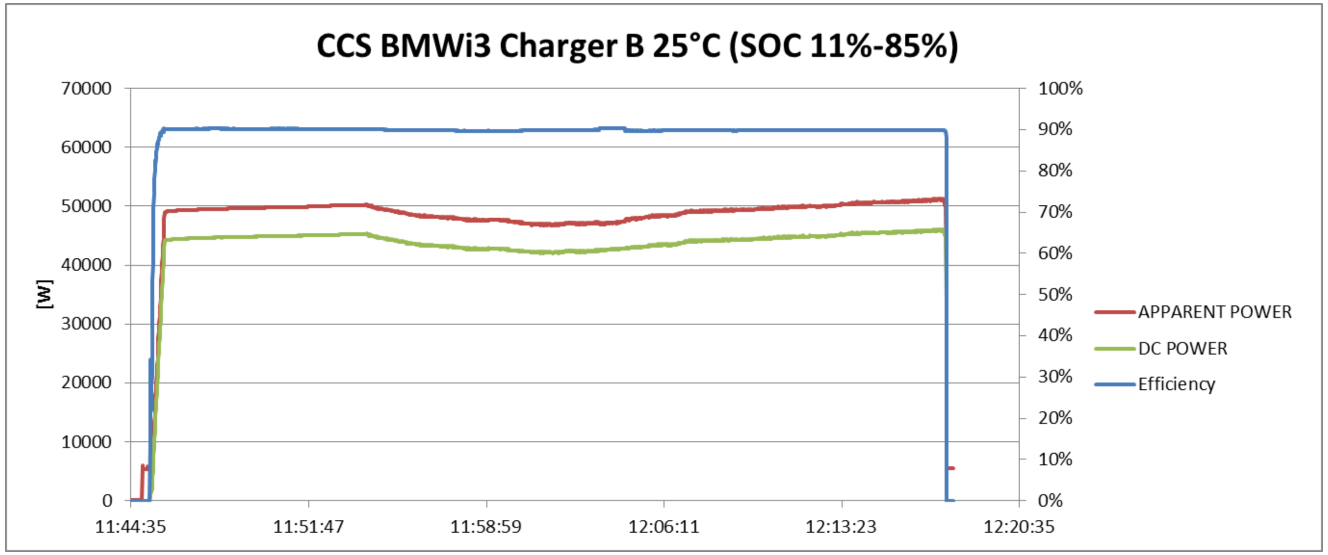
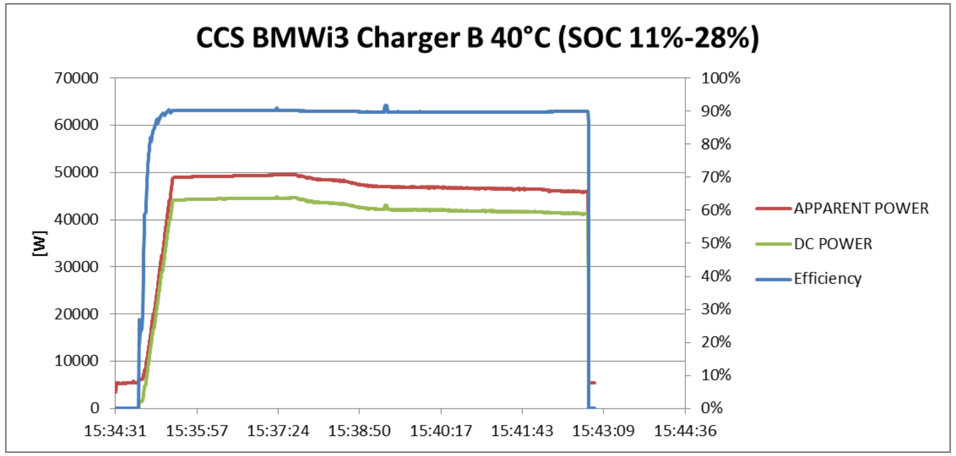
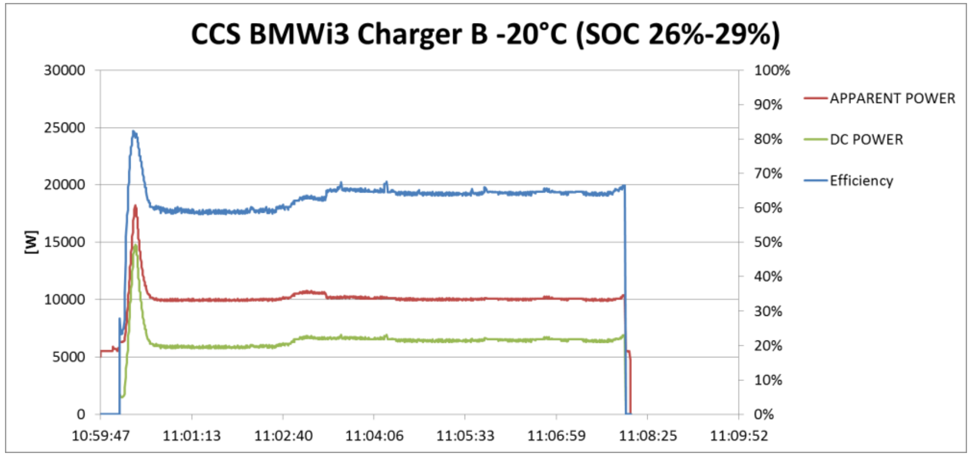
Results Charger B







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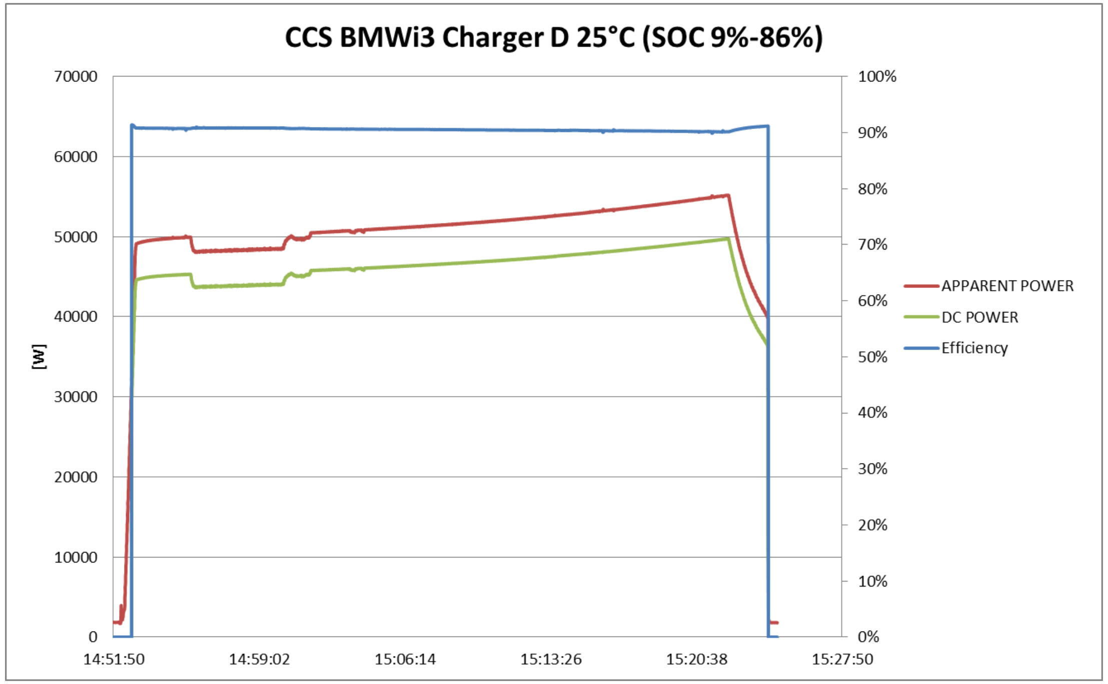
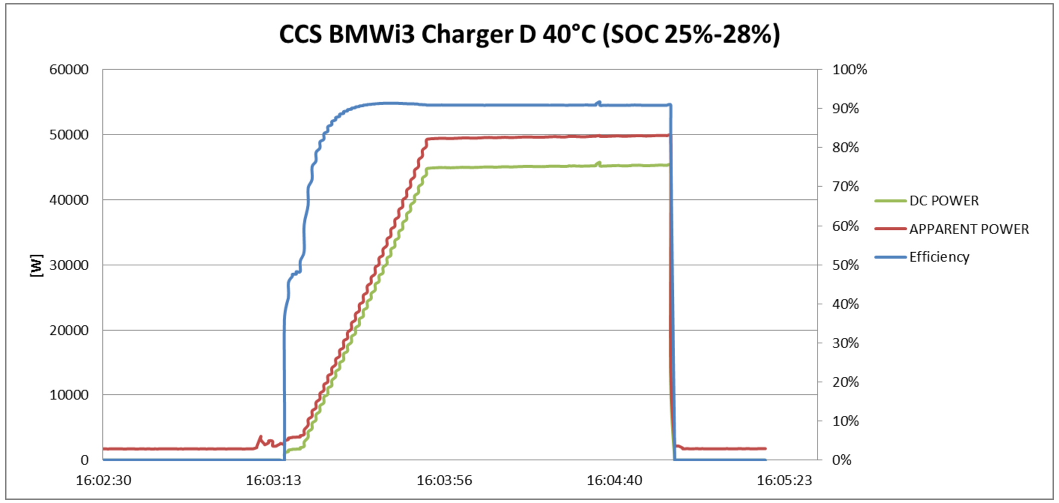
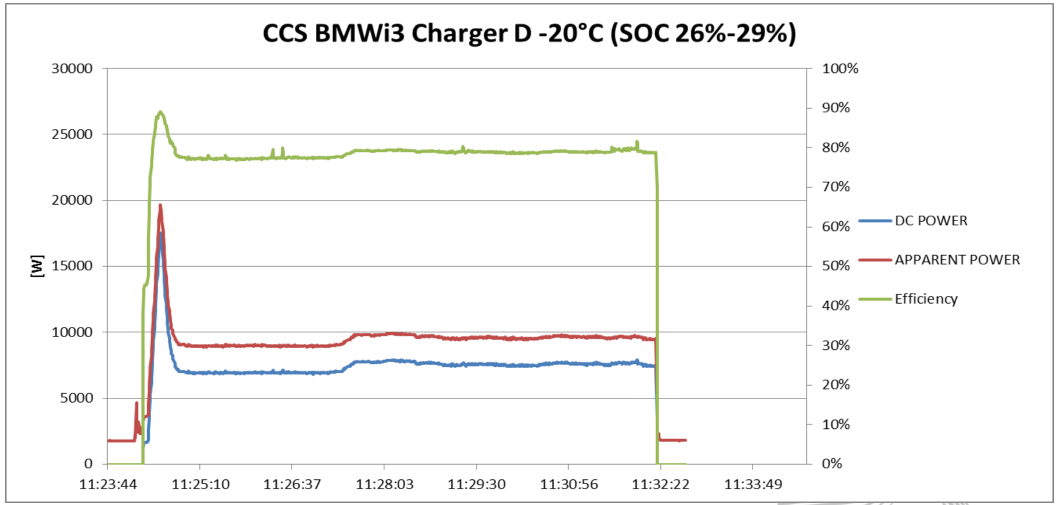
Results Charger D







Total Harmonic Distortion Analysis

Measures \ Chargers	B		D		A		C	
ChaDemo EV (Nissan Leaf)	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]
25 Degrees	77.5	5.7%	79.6	10.6%	68.9	7.10%	61.8	7.80%
40 Degrees	81.2	8.2%	77.4	11.2%	68	6.10%	61.5	8.70%
-25 Degrees	17.7	15.8%	9.4	39.8%	EVSE out of Order		EVSE out of Order	
CCS-BMW - THDi | Current (ϕ1)	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]
25 Degrees	74.9	6.80%	80	10.70%	71.5	5.80%	test ongoing	test ongoing
40 Degrees	74.4	6.80%	75.5	11.70%	67.5	6.10%	EVSE out of Order	
-25 Degrees	test ongoing	test ongoing	test ongoing	test ongoing	test ongoing	test ongoing	EVSE out of Order	
CCS-Energica - THDi | Current (ϕ1	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]	at a current level of... [A]	THD *I* (current ϕ1) [%]
25 Degrees	*EV is incompatible*		29	21%	31.2	11.40%	30.7	9.90%

* Voltage related, THD *v* where always observed to be under 3%. Uncritical and thus not reported here.

** At ambient temperature charging cycles were performed from 10% to 80% of SoC
at extreme temperature, measurements were taken from approx. 25% to 28% of SoC

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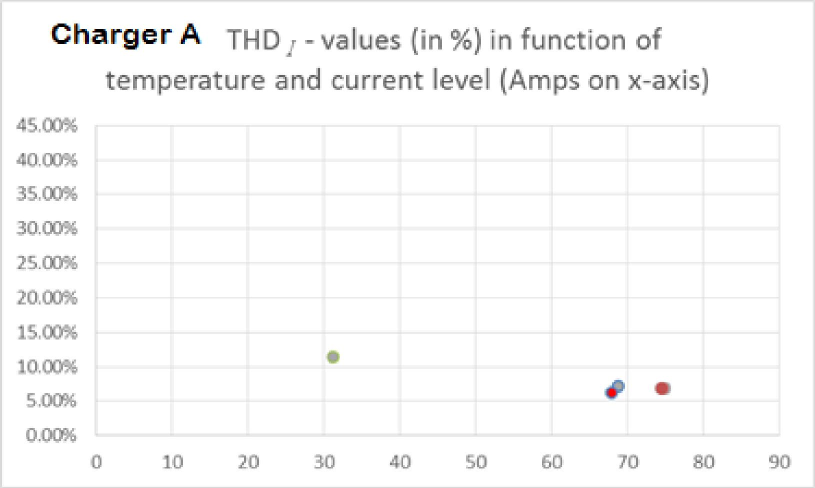
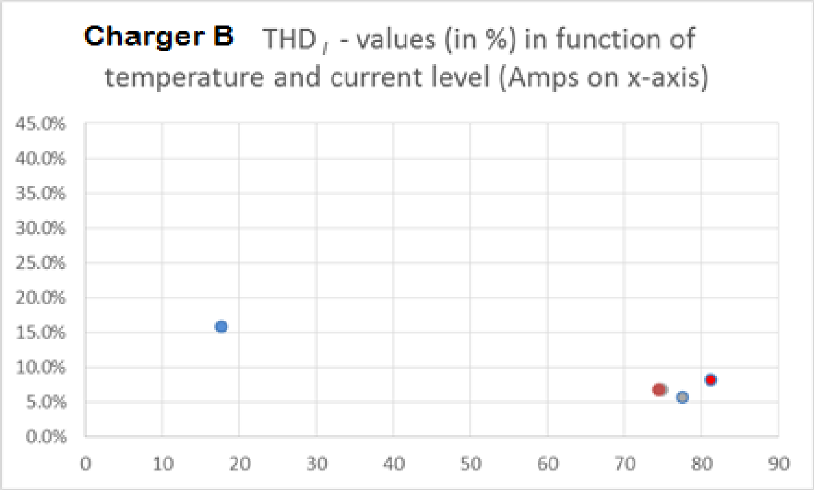
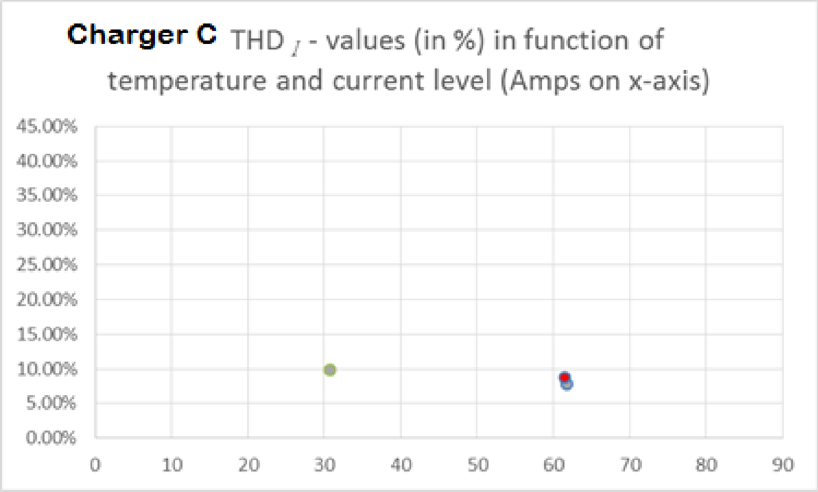
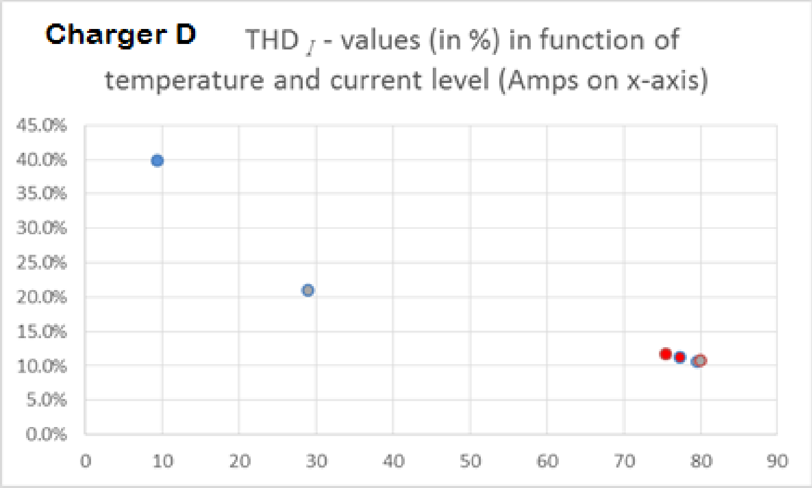
Total Harmonic Distortion Analysis









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Preliminary conclusions from Tests:

- Today's energy efficiency of typical market participating DC-Multi-charger are around 89..92 %, >92% is already good.
- But such efficiency-values can easily deteriorate massively, if the delivered power is only a fraction of the nominal load of the Multi-charger
- Such lower power requests in CCS or CHAdeMO fast-charging can have various reasons: temperature conditions, charging history of EV (trying to prolong its battery life-time), size of EV
- Extrapolations of EVSE population energy use must take into account, that non every charge will be a 50kW charge
- This aspect may be even stronger in future 150kWand 350kW HPC

Preliminary conclusions from Tests:

- The relatively good efficiency of Charger D seems to be «bought in» by significantly worse THD characteristics, notably very high THD values when using it in partial load.
- Charger B features good results, and is not «guilty» with regard to ENERGICA Interop problems.
- Charger A is the least efficient. Its user Interface (software) gives rise to some critical comments: the screen returned often into its "mother tongue", even after explicit change to other languages.
- Charger C suffered dysfunctions from extreme temperatures, limiting even our CCS test programme on it. Was it extended modularly to 50kW by the producer's technician correctly? (to clarify)

But: *We found an issue to solve*

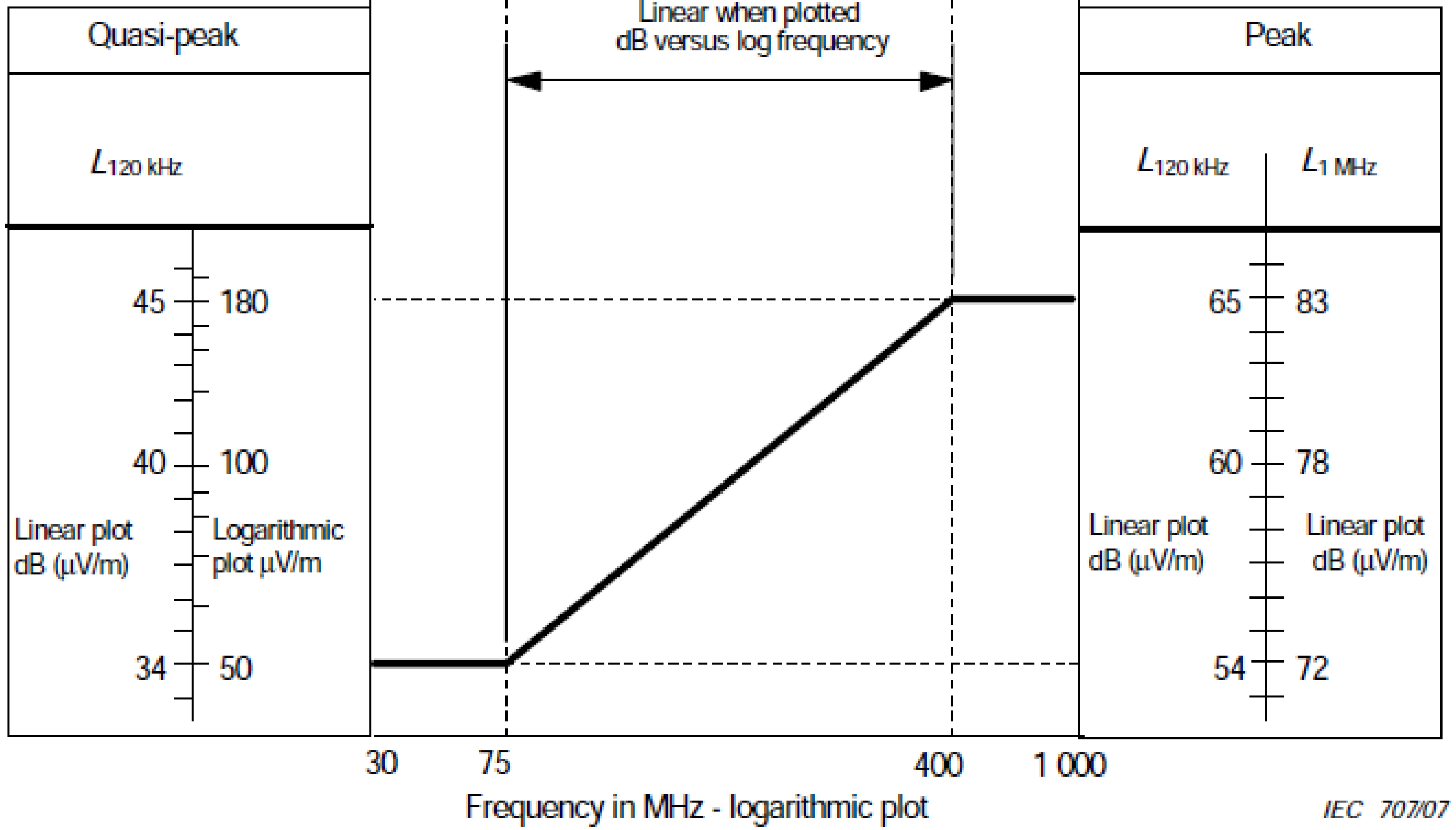
- EVSE with a favourably low stand-by power consumption do have additional switch gears built in, which however add another spike of electro-magnetic emission, notably in the regulated frequency range from 30MHz upwards (regarding radiative emissions).

CISPR 12
Limits (for 10m antenna distance)

Planned limits for IEC 61851-21-2 are even 2dB lower, in harmony with UN-ECE R10 limits for EVs

Limit L_{bw} in dB (µV/m) as a function of bandwidth, detector and frequency f in MHz

L_{bw}	30-75 MHz	75-400 MHz	400-1000 MHz	Measurement type
$L_{120\,kHz}$	34	$34 + 15{,}13 \lg (f/75)$	45	Quasi-peak
$L_{120\,kHz}$	54	$54 + 15{,}13 \lg (f/75)$	65	Peak
$L_{1\,MHz}$	72	$72 + 15{,}13 \lg (f/75)$	83	Peak



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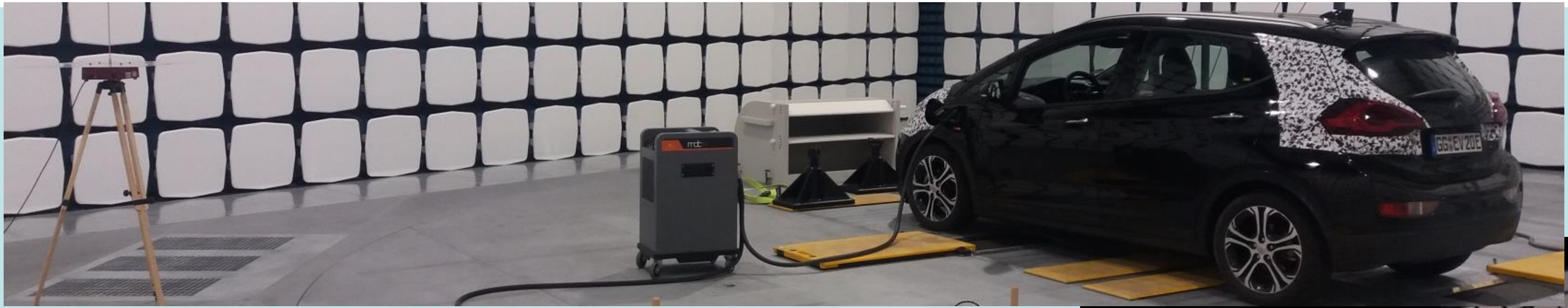
One of the EV Charging Columns with NISSAN Leaf

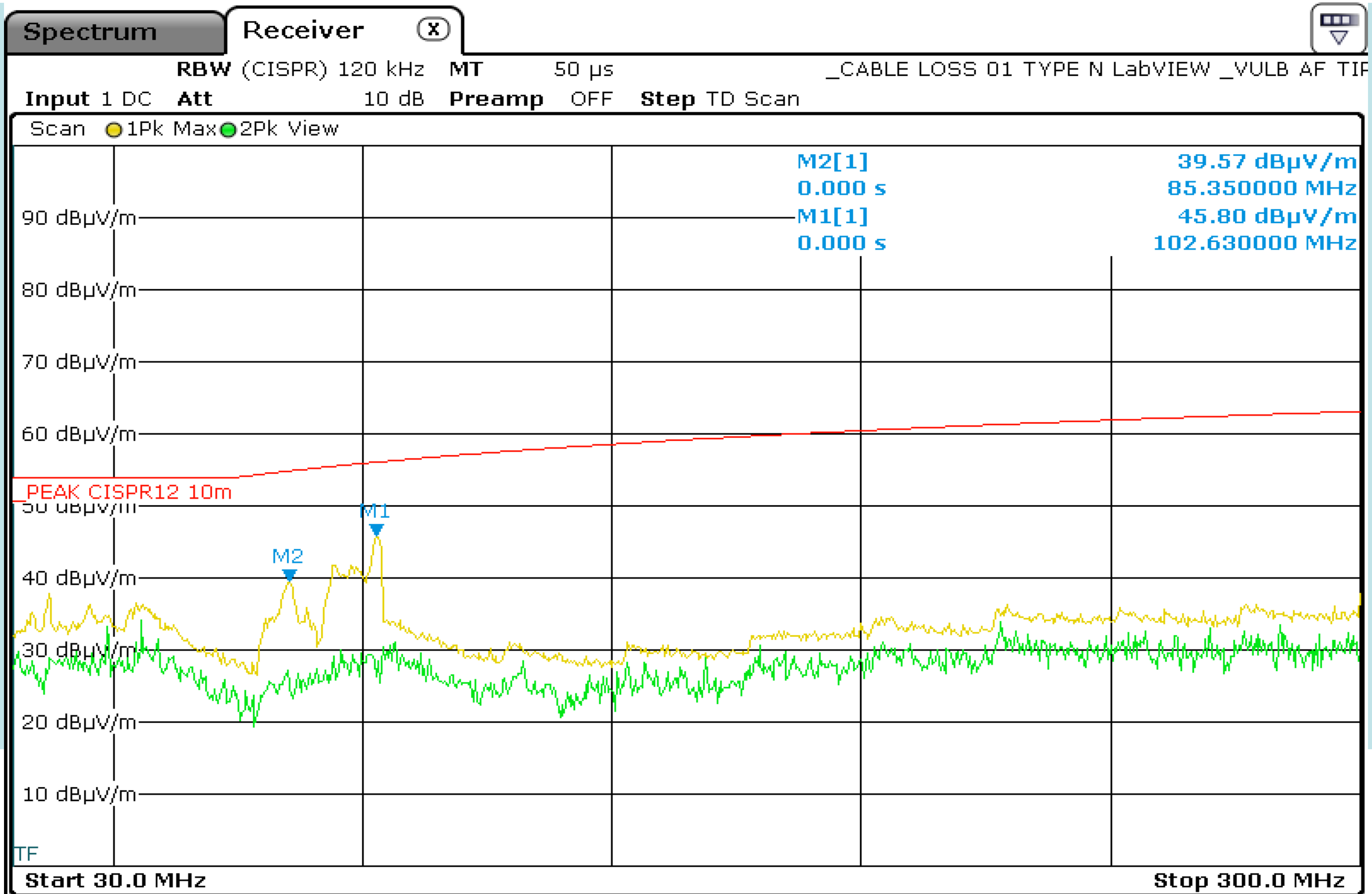
Antenna config.: 10m away from EV and 3m high (CISPR-12), V-polarization

Many more DC Fast Charging columns tested in 10m and 3m distances, and various polarizations:



Example: EV Charging Column 'C' with NISSAN Leaf

Antenna config.: 10m away from EV and 3m high (CISPR-12), V-polarization



Frequency domain:

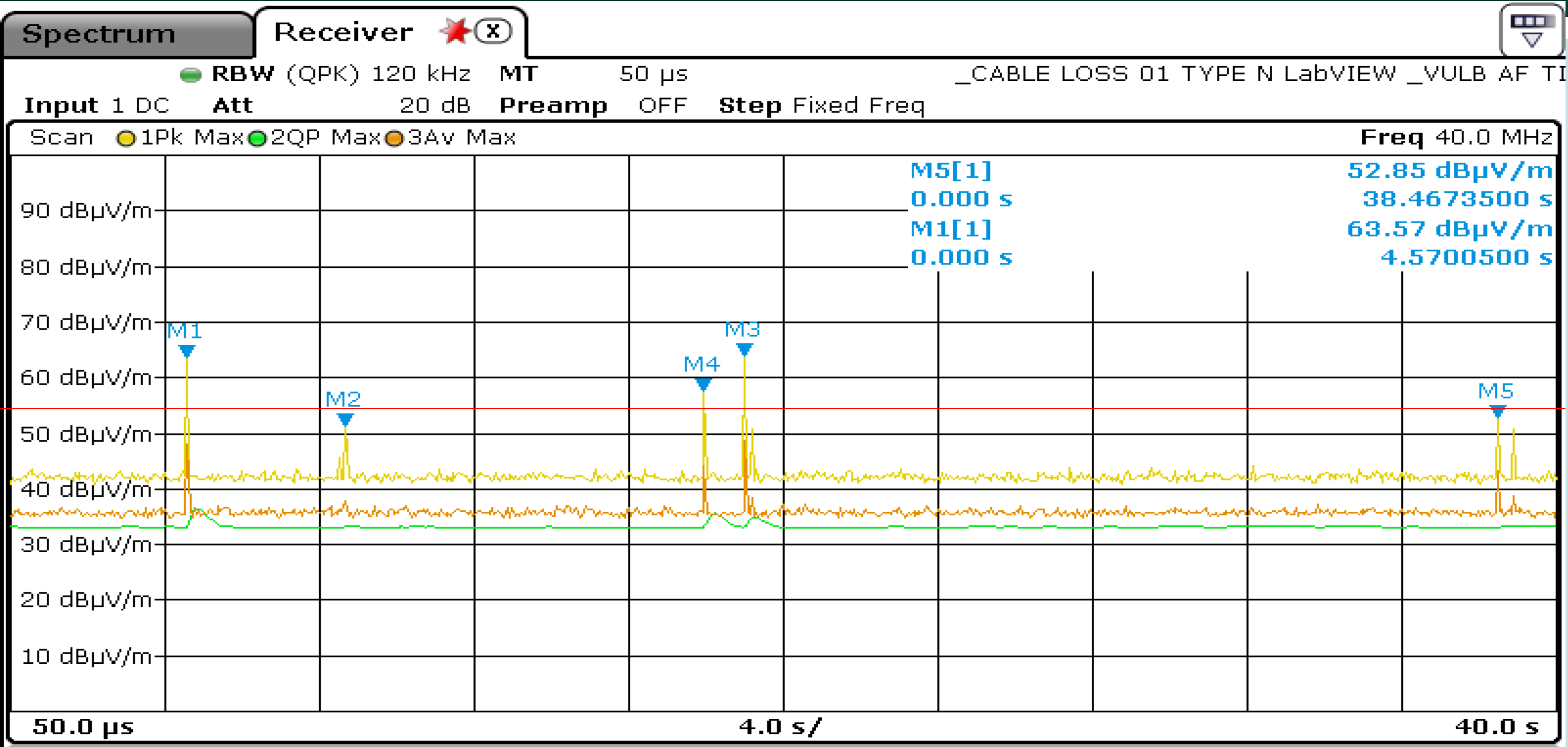
Understanding **where to look** in the spectrum

(depends on EV-EVSE combination)

Example: EV Charging Column ‘C’ with NISSAN Leaf

Antenna config.: 10m away from EV and 3m high (CISPR-12), V-polarization

Side orientation as per draft standard IEC 61851-21-2



Marker

Diagr	Type	Ref	Trc	Stimulus	Response	Function	Function Result
Scan	N1		1	4.6 s	63.57 dBµV/m		
Scan	N2		1	8.7 s	51.39 dBµV/m		
Scan	N3		1	19.0 s	63.91 dBµV/m		
Scan	N4		1	17.9 s	57.58 dBµV/m		
Scan	N5		1	38.5 s	52.85 dBµV/m		

time domain:

Measuring current in-rush induced EM-peaks in time-domain, with 50µs of time resolution

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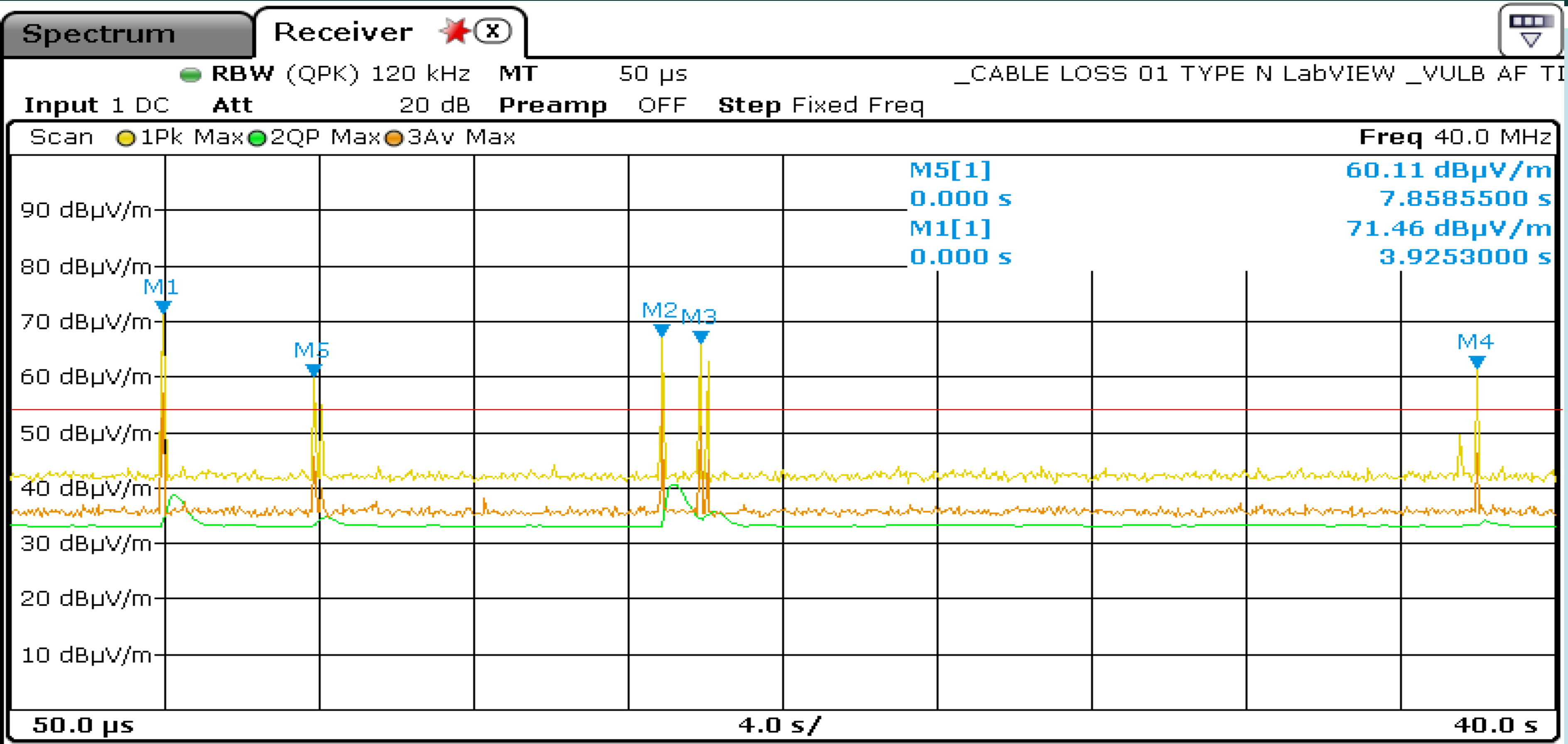
EV Charging Column ‘C’ with NISSAN Leaf

Antenna config.: 10m away from EV and 3m high (CISPR-12), V-polarization

Antenna orientation now versus maximum charge cable exposition



Marker

Diagr	Type	Ref	Trc	Stimulus	Response	Function	Function Result
Scan	N1		1	3.9 s	71.46 dBµV/m		
Scan	N2		1	16.8 s	67.16 dBµV/m		
Scan	N3		1	17.9 s	66.16 dBµV/m		
Scan	N4		1	38.0 s	61.42 dBµV/m		
Scan	N5		1	7.9 s	60.11 dBµV/m		

time domain:

Resolving current in-rush induced EM-peaks with 50µs of time resolution

Much higher peaks, if the antenna "sees" directly most of the EVSE-to-EV charge-cable

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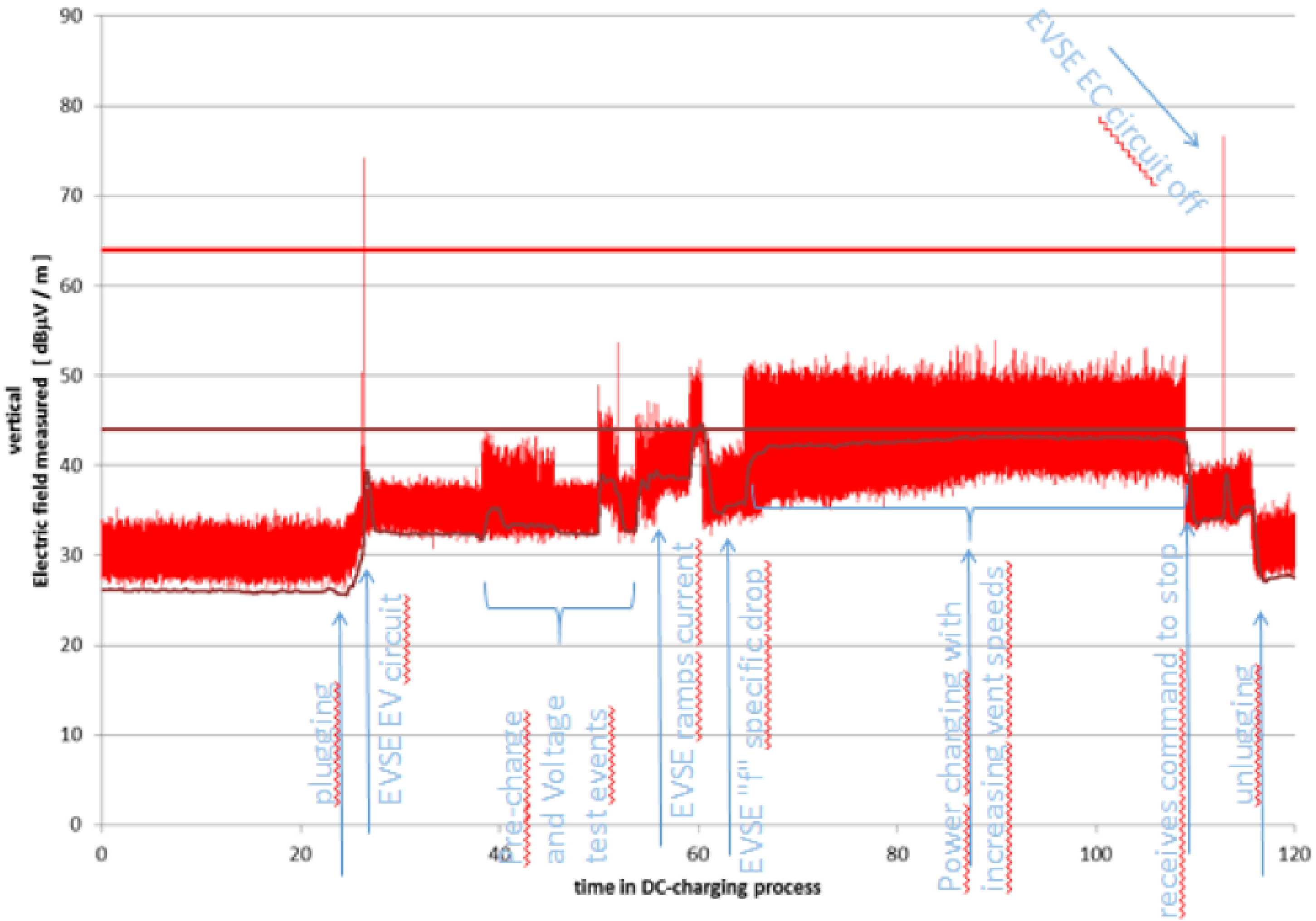
Critical results also for some of the CCS charging: relais switch induced spikes and current ramp induced breachings of the field strength limits

50kW DC-chargeable EV (no. 3) on charger "f" (CCS)



Result example, we follow the whole charging process for two minutes; e.g., 40MHz was critical with one of the DC-Multi-chargers

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Conclusions for improving IEC 61851-21-2

- EV and each respective charging column (EVSE) must be tested together, in a real world, combined approach
- EV and EVSE only together, synergistically, create the in-rush currents, notably in the DC-charge-cables, which can induce EM fields, that in turn breach the foreseen field strength limits.
- If either the EV or EVSE are artificially filtered and/or shielded in the intent to "purely" measure the disturbance of one of the two, the actual real world EMC issue gets lost.
- The IEC 61851-21-1 & -2 draft standards should be improved on the basis of these results.