DC AS A SERVICE APPROACH TO HIGH POWER COMMERCIAL VEHICLE CHARGING SYSTEMS FROM KILLAWATTS TO MEGAWATTS

Complicated power distribution infrastructure (AC vs DC)

THEODORE BOHN
Principal Electrical Engineer
Argonne National Laboratory
tbohn@anl.gov, 630-816-7382

February 8th, 2023
12:00-1:00pm CST;
IEEE PES Chicago Section Meeting

This work is supported by DOE-Vehicle Technology Office, Lee Slezak program manager

PRESENTATION TOPICS

- Focus is on high power charging and grid interactions, charging methods
- Coupler standards; from kW to MW
- SAE J3271 Megawatt Charging System for anything that ‘Rolls, files, or floats’

HISTORICAL PERSPECTIVE ON EV BATTERIES- HORSELESS CARRIAGES (~120 YEARS AGO)

- Battery box was literally a wooden box…; motors on each wheel, rear steering

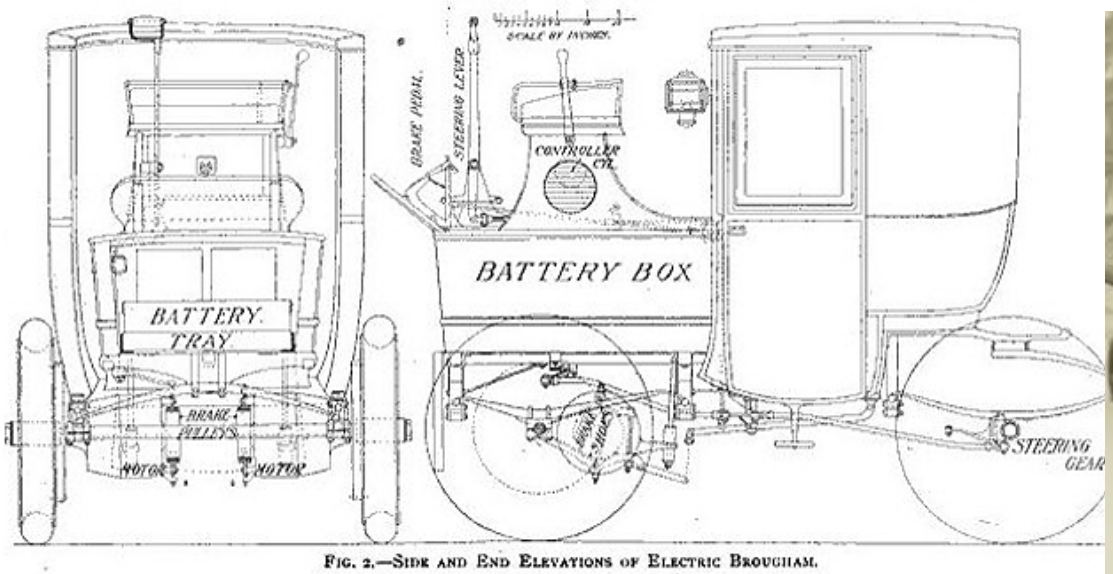
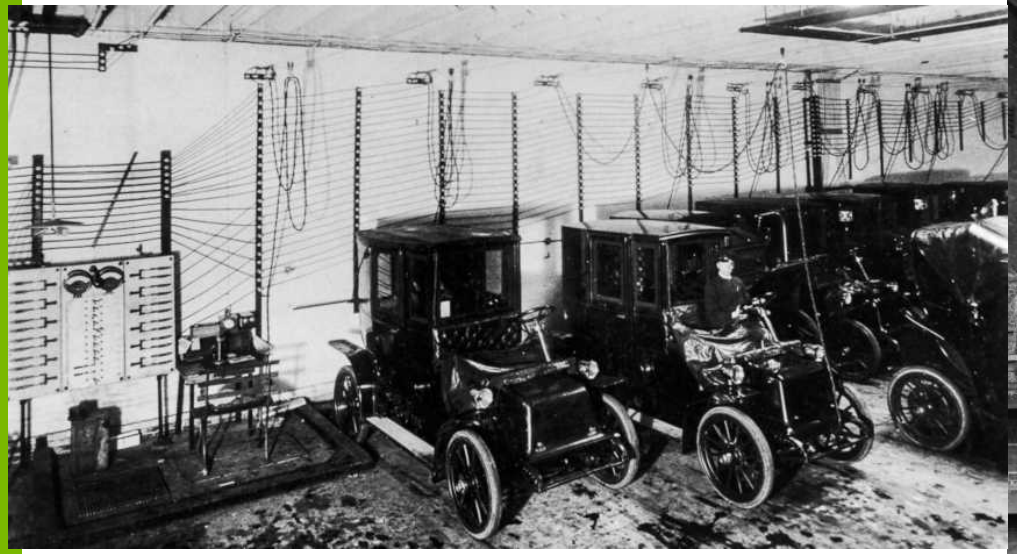


FIG. 2.—SIDE AND END ELEVATIONS OF ELECTRIC BROUGHAM.

HISTORICAL PERSPECTIVE ON EV BATTERIES- POSTAL DELIVERY, TRUCK FLEETS(~100 YEARS AGO)

- Wooden wheels for postal delivery, knob-and-tube charging wiring



DC Charging Center- knife switches, ammeters

DC Charging from ground-well

HISTORICAL PERSPECTIVE ON EV BATTERIES- GM ELECTROVAIR (~60 YEARS AGO)

- Batteries in front and rear of vehicle, rear motor/electronics

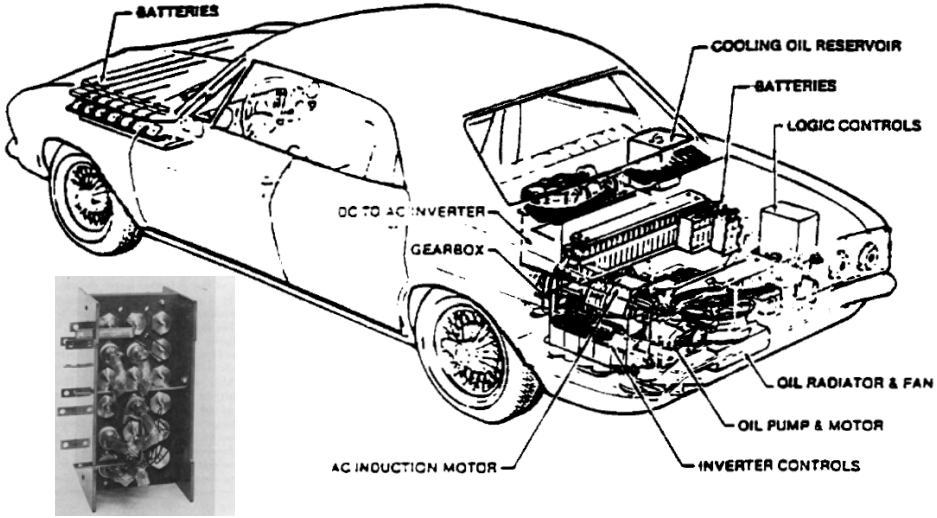
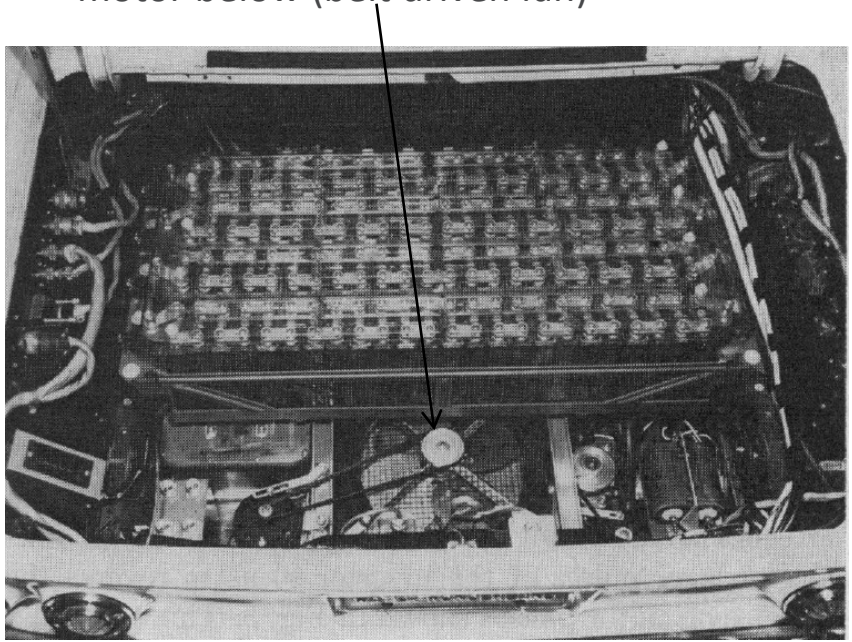


Fig. 1 CUTAWAY VIEW OF GENERAL MOTORS ELECTROVAIR

https://www.carscoops.com/2020/07/gms-electrovair-is-the-precursor-to-the-companys-electric-future/

ELECTROVAIR ELECTRONICS PACKAGING 532V SILVER ZINC BATTERIES

- Batteries in center of rear of Corvair, electronics wrapped on the sides, motor below (belt driven fan)



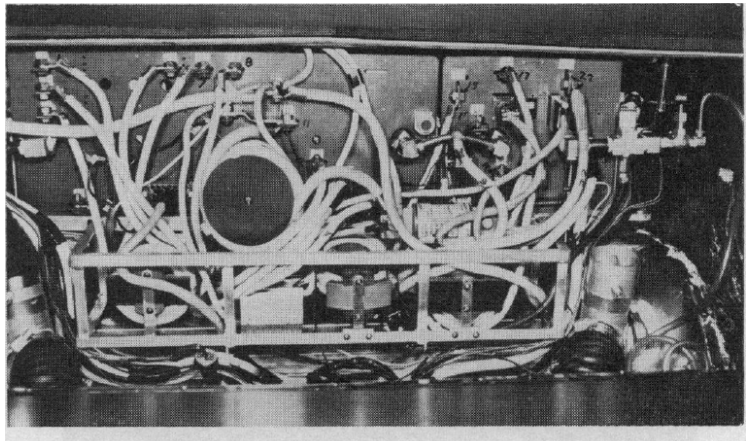
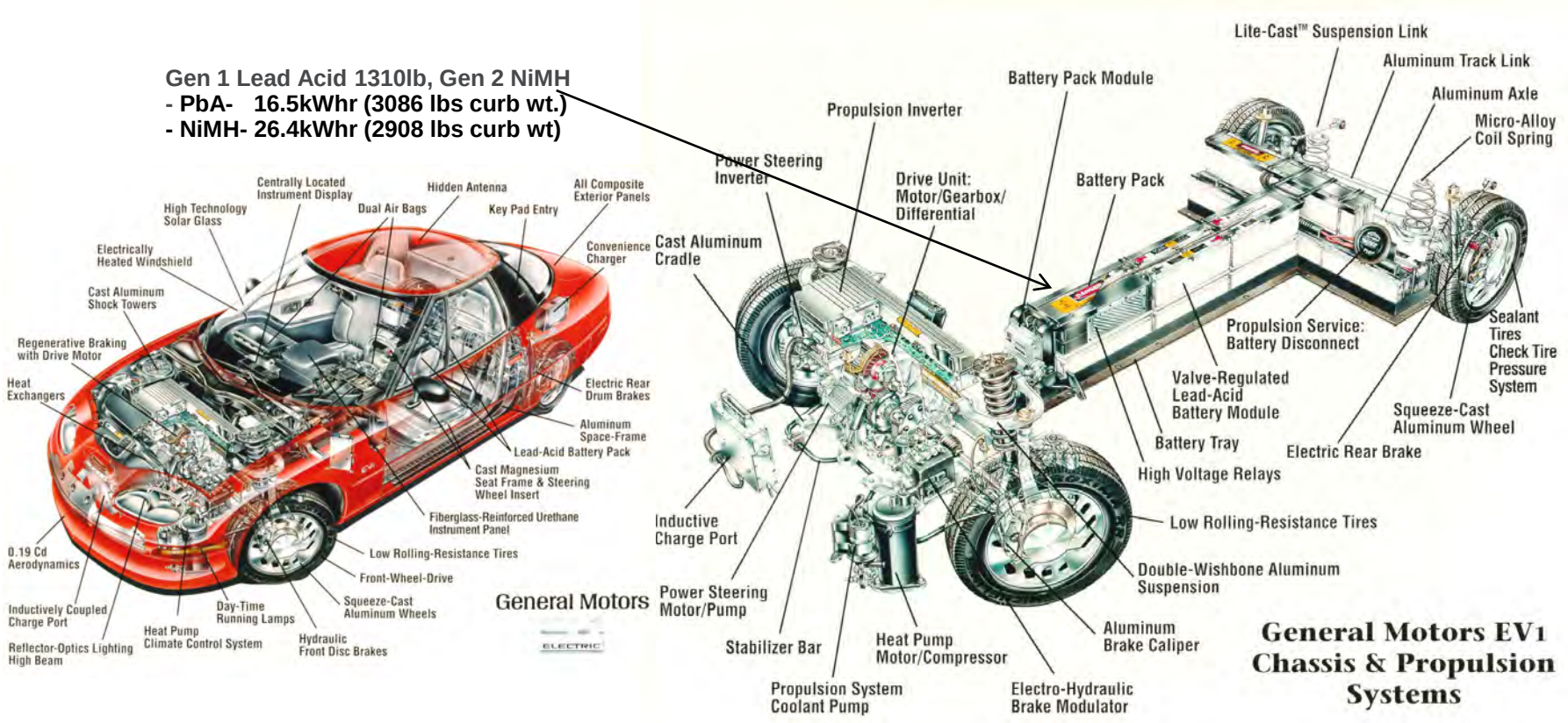


Fig. 12. Layout of modulator and inverter.

[2]. T. Salihi, P.D. Agarwal et al, " Induction Motor Control Scheme for Battery Powered Electric Car (GM - Electrovair I)", IEEE Trans. on Industry and General Applications, Sept./Oct. 1967, PP. 463-469.

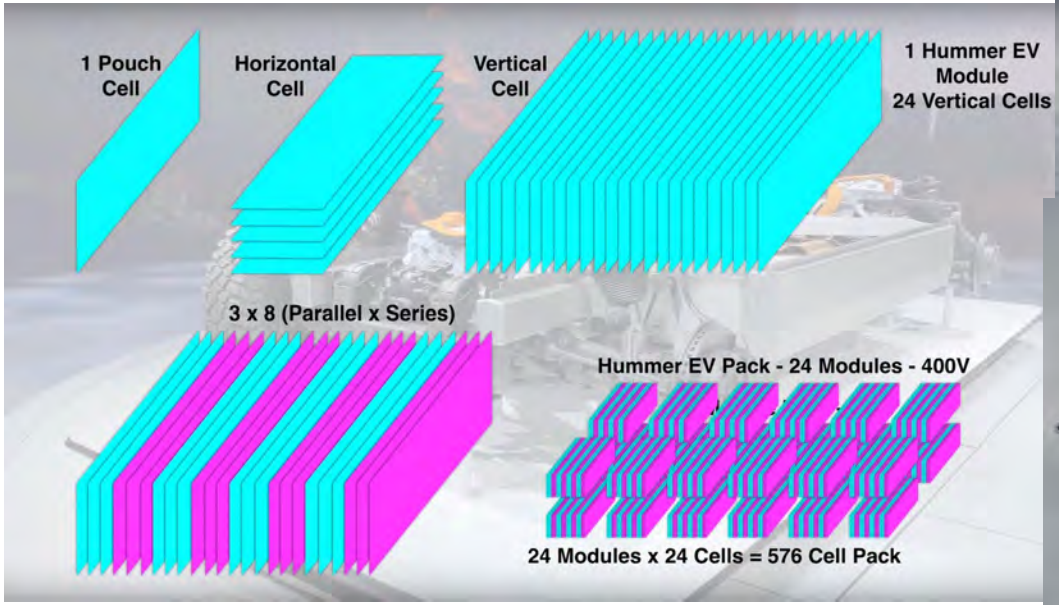
GM EV-1 Powertrain ~ 30 years ago

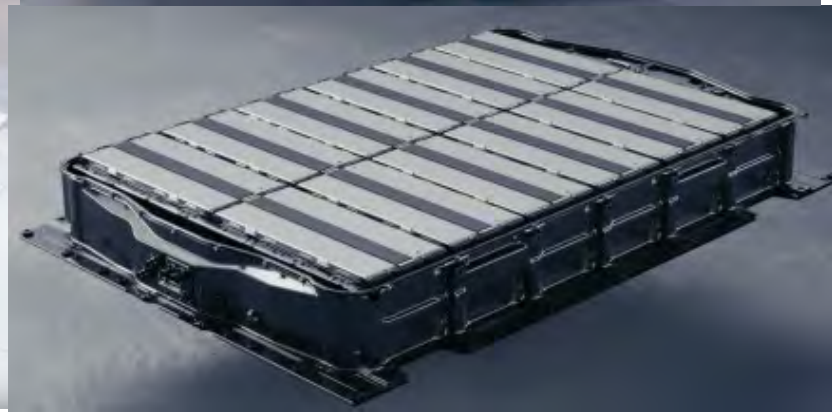
Gen 1 Lead Acid 1310lb, Gen 2 NiMH
- **PbA- 16.5kWhr (3086 lbs curb wt.)**
- **NiMH- 26.4kWhr (2908 lbs curb wt)**



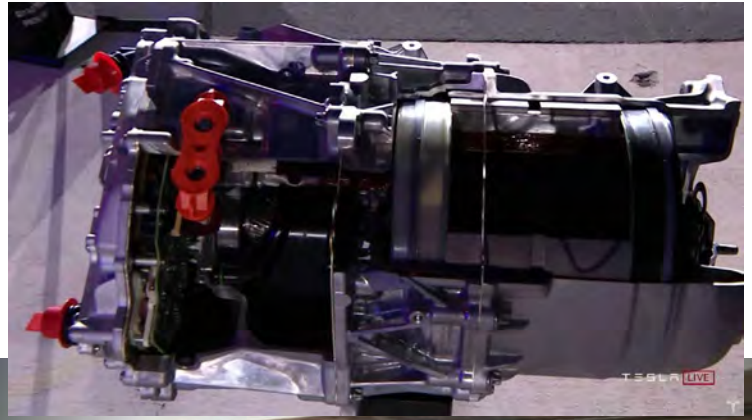
GM Ultium Battery System in Hummer EV

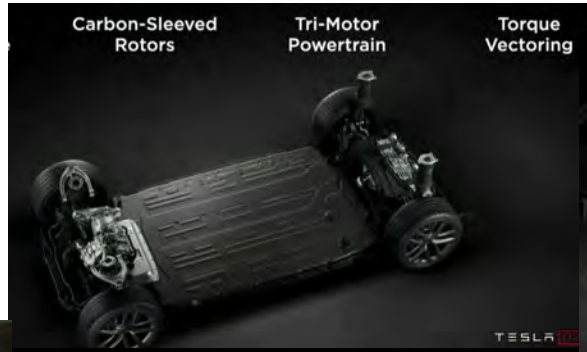
- Hummer EV versions from 50kWhr to 200kWhr
- 1000hp powertrain; 11,500 lb-ft at wheels
- 13:1 front motor axle, 10.5:1 rear motors
- 0-60 in 3 seconds (9000lbs total, 2923lb battery)

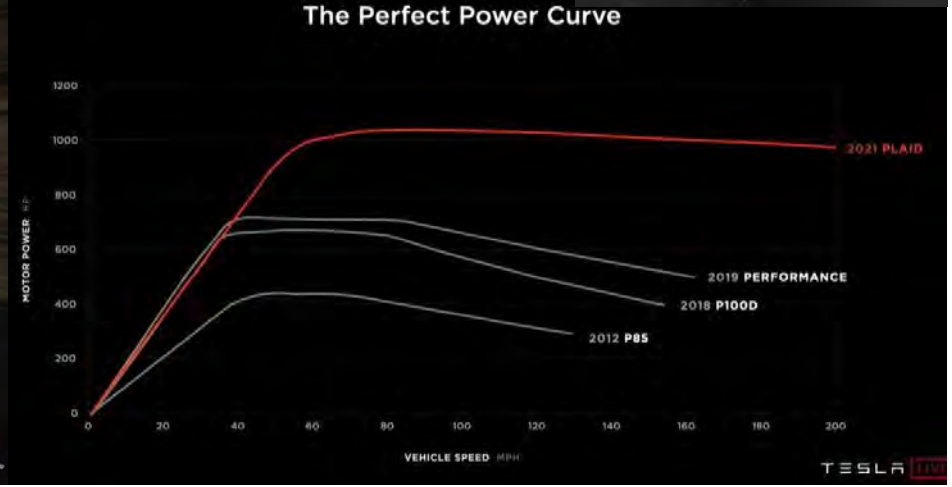




Tesla Model S- Plaid (Today)







McMurtry Spéirling EV Speed Record (1.4 sec)

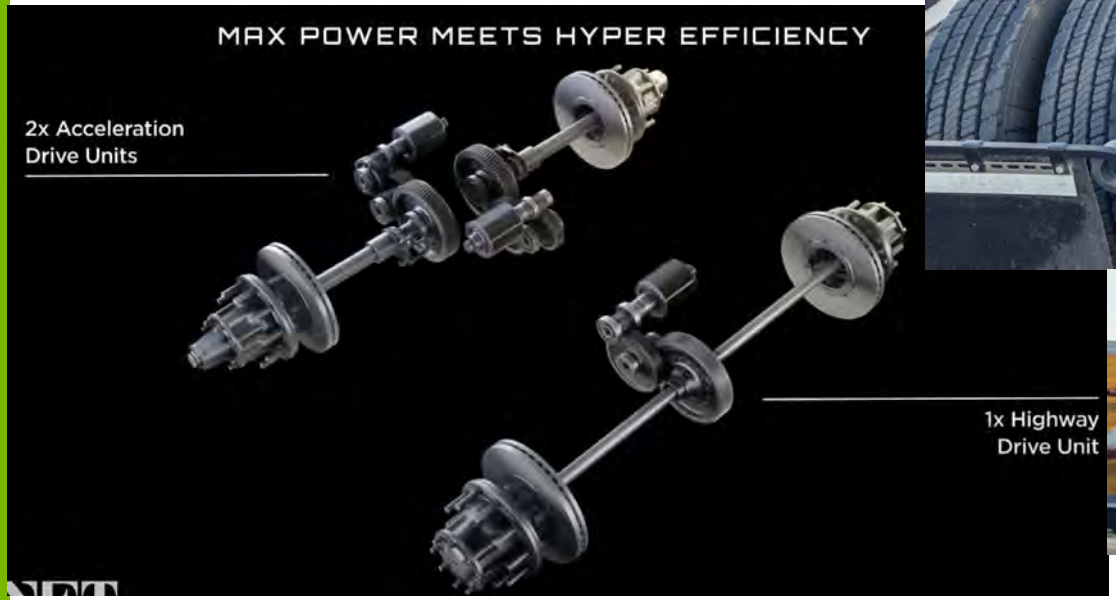
- The fan car has achieved an independently measured 0-60 MPH in 1.40 seconds and a 1/4 mile in 7.97 seconds.
- Instant grip from McMurtry's "**downforce-on-demand fan system**," sub-1,000kg (approx. 2,200 lbs.), 1,000 BHP, rear-wheel-drive.
- Track range of 25 minutes when running at GT4 race-car pace, and a road range of over 300 miles.

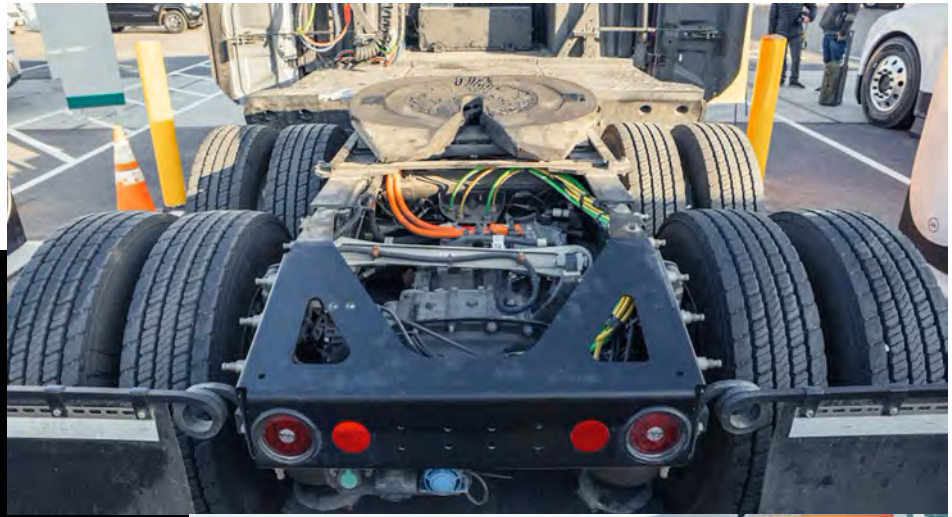
The car sat on its 150 mph limit for approximately three seconds during the run. Other metrics captured on the timing equipment were:

0-60 mph in 1.40s
0-100 mph in 2.63s
0-145 mph in 4.98s
¼ mile (400m) in 7.97s

Tesla Semi Powertrain- 3 motors, clutched axles

- Traction control/acceleration on clutched dual motors, idle during steady state for higher efficiency running on one motor





Observation: ‘Frunk is Full of Junk…” (not empty space)

- Note center mounted steering shaft, HVAC, coolant tanks, wiper motor, wash fluid bottle, small radiator inlet/flap?, license bracket camera, lots of fittings; easy access?

Tesla Semi Inlet Evolution (2017->2022)

- 2022 V2.4 MCS Inlet photos- Modesto installation compared to 2017 4x Supercharger ‘Megacharger’

SPECTRUM OF CHARGING SOLUTIONS; 'ROLLS, FLIES OR FLOATS'

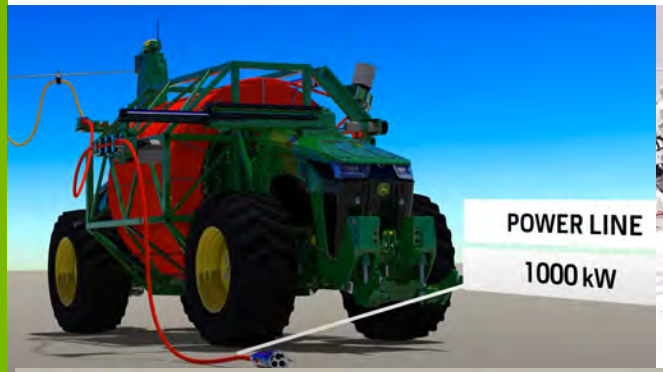
- *The gradient of conductive and wireless charging standards cover small-medium-large/heavy on road vehicles; aviation, mining, agriculture, marine, construction….*
- *Interoperability of components and systems create economies of scale, especially for wireless and conductive couplers used in multiple industry segments. Standards for each application covered by separate organizations.*

26 CCS Inlets on a Bangkok ferry

Construction/arborist platform- fits on sidewalk, 60' reach

JOHN DEERE TETHERED AUTONOMOUS SWARM TRACTOR(S) (1MW, 8KV 3KM)

- Prototype showing future of electrified agriculture- 1MW today, tethered to swarm
- Future could be more 500kW battery powered tractors….MCS automated connectors?
  https://www.youtube.com/watch?v=fzl3wkkKtoA



ROLLS, FLIES OR FLOATS; 1 MWHR TRACTOR

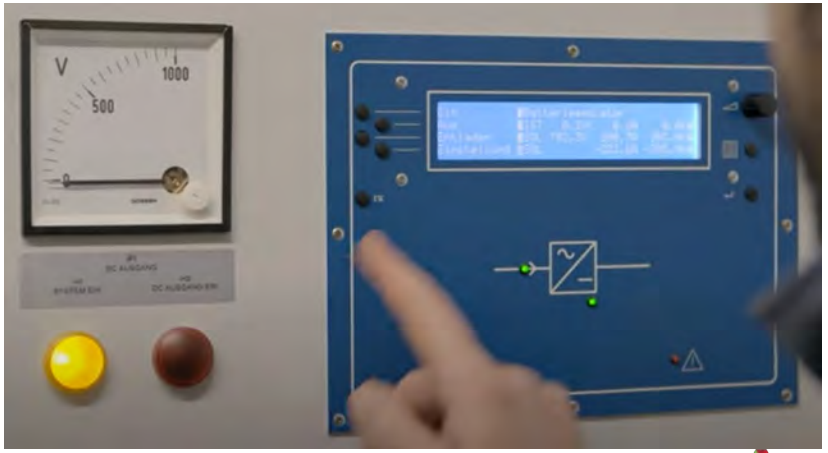
Lots of press coverage this month on latest John Deere prototype/development autonomous electric tractor; 500kW drive system, **1MWhr battery**

Example photos below of ‘office pod’ wireless control center, charging connections

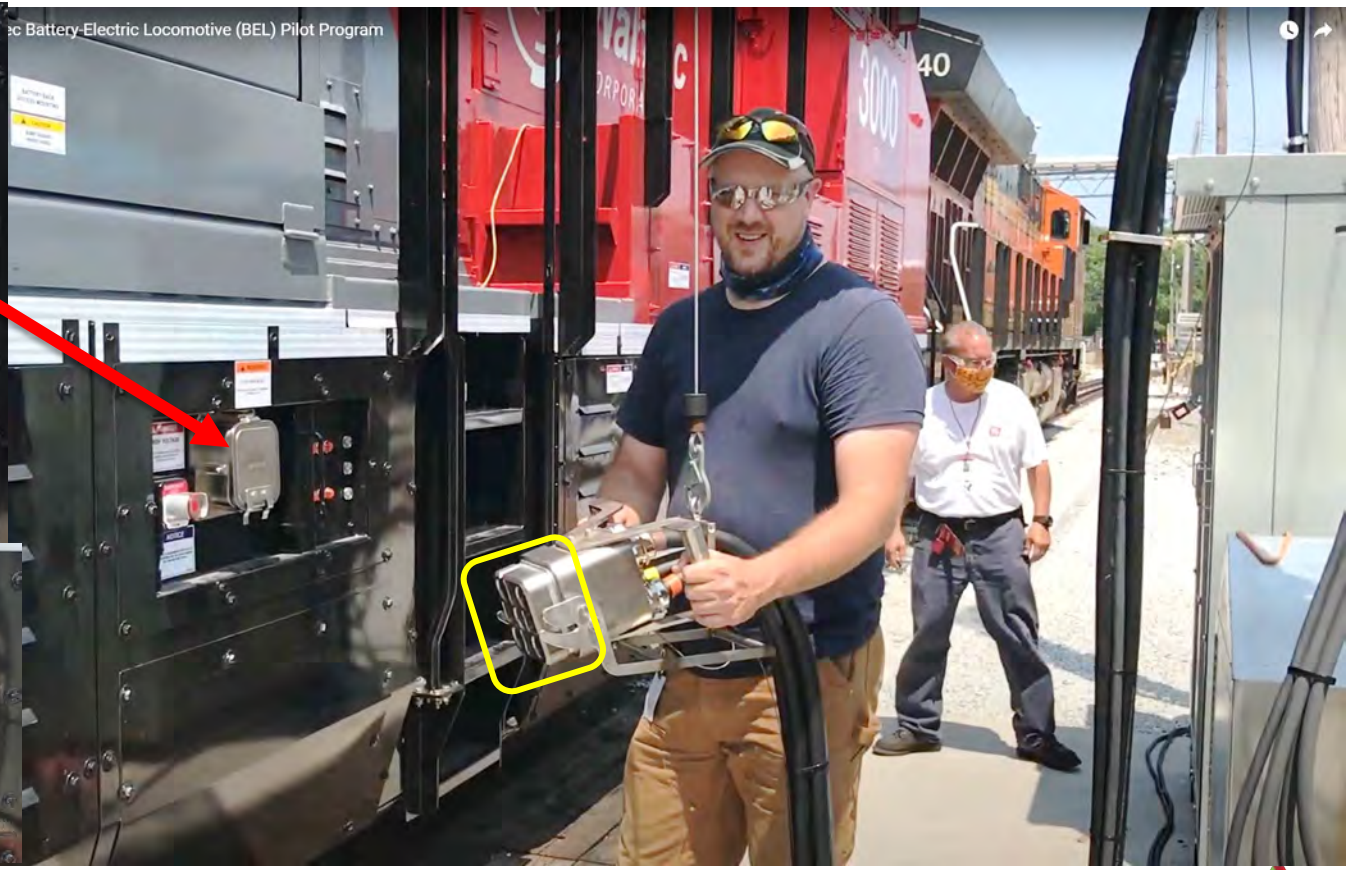
https://www.futurefarming.com/tech-in-focus/autonomous-semi-autosteering-systems/video-john-deere-shows-autonomous-electric-tractor/

ROLLS, FLIES OR FLOATS; 1MWHR TRACTOR

Looks like ‘above 700v’ DC battery systems, 230A charging from screen shot
Large Staubli 1000A single pole bayonette connectors



AMPHENOL INDUSTRIAL COUPLER/COUNTER BALANCER WABTEC 7 MWHR ELECTRIC LOCOMOTIVE (480VAC 3Φ,500A, EARTH/PILOT)



CAT 793 BEV MINING TRUCK DEMO

- https://meconstructionnews.com/55631/caterpillar-demonstrates-first-battery-electric-large-mining-truck/
- During the demonstration, Early Learner customers observed the prototype battery truck operate on a seven-kilometre course. According to Caterpillar, it monitored over 1,100 data channels, gathering 110,000 data points per second, to validate simulation and engineering modeling capabilities.
- In late September 2022, the company said it had surpassed five billion tonnes of material hauled autonomously.
- Fully loaded to its rated capacity, the truck achieved a top speed of 60km/h. The loaded truck traveled one kilometre up a 10% grade at 12km/h. The truck also performed a one kilometre run on a 10% downhill grade, capturing the energy that would normally be lost to heat and regen. Upon completing the entire run, the truck maintained enough battery energy to perform additional complete cycles.

CAT 793 BEV MINING TRUCK DEMO

- https://www.caterpillar.com/en/news/corporate-press-releases/h/caterpillar-succesfully-demonstrates-first-battery-electric-large-mining-truck.html
- https://www.youtube.com/watch?v=it0k3TYEh3k

Liebherr 264 Mining Truck; 1.4MWhr, 30 Minute Recharge

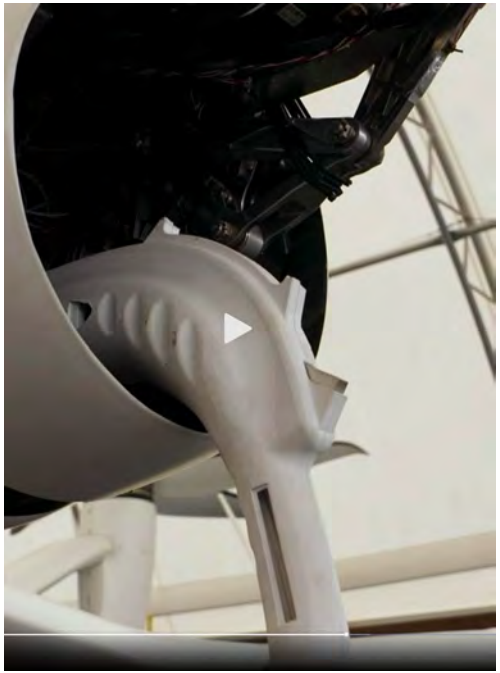
- https://electrek.co/2023/01/13/this-240t-electric-mining-haul-truck-can-charge-in-30-minutes/

  A team of 50 engineers and technicians developed the power system, which ***weighs 15 tonnes and measures 3.6m (11.8 feet) long, 1.6m (5.2 feet) wide, and 2.4m (7.9 feet)*** *high. It's made up of eight sub-packs, each with 36 modules, all individually cooled and each with its own battery management system*..

  (No details on 30 minute recharge; 2.8MW charging rate implied)

HIGH POWER CHARGING FOR ANYTHING THAT ROLLS, FLIES OR FLOATS

- Joby Aviation gains second aircraft approval; 1000 test flights to date; 200mph/150 mile range; Target of passenger service in 2024
  https://www.jobyaviation.com/news/joby-adds-second-pre-production-prototype-aircraft/



E1 ELECTRIC BOAT RACING SERIES ‘RACEBIRD’ HYDROFOIL

- Mercury Marine is serious about production electric outboard motors
  https://www.boatingmag.com/story/boats/mercury-racing-e1-series-develop-electric-competition-outboard/
- ‘Racebird’ hydrofoil has a 35kWhr battery, 50kW motor, top speed of 60mph

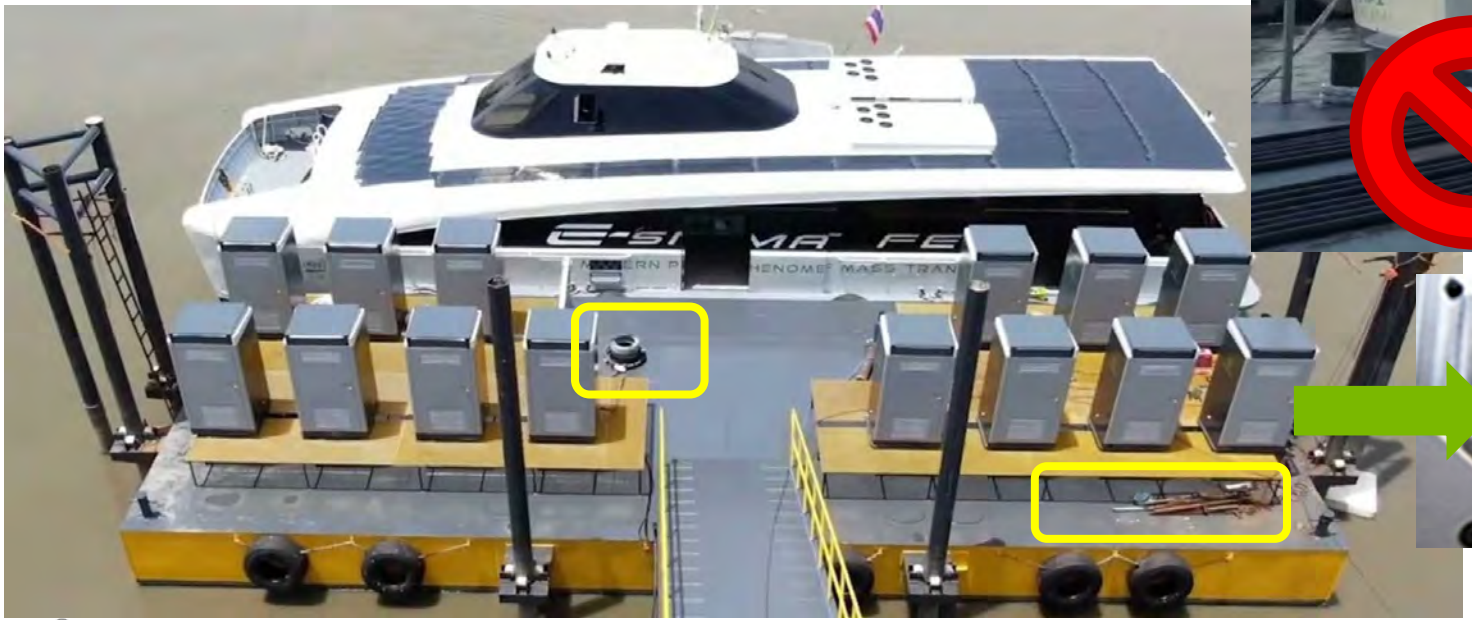
ROLLS, FLIES OR FLOATS; MW SHORE POWER

- Zinus Power (Norway) 1500v/2200A-4400A shore power; telescoping tower

https://zinuspower.com/product/charging-telescopic-autonomous/#specification

BANGKOK FERRY CHARGING EXAMPLE (26 CCS PORTS)

- *Floating Dock with 14 dual output EVSEs (cord handling/storage not evident)*
  Suspect photo is not of full installation, just placed components. 4000A power feed?



HOW FAST IS 'FAST' CHARGING IN 2022?

https://www.mdpi.com/1996-1073/15/7/2312/pdf

Term	Charging Voltage	Charging Current	Charging Power	Battery Capacity	C-rate of Charging
Slow HD-EV charging	400 VDC, 800 VDC	60 A–400 A	50 kW–150 kW	50 kWh–250 kWh	0.2 C–1 C
Normal HD-EV charging	400 VDC, 800 VDC	200 A–800 A	150 kW–400 kW	50 kWh–250 kWh	0.5 C–2 C
Fast HD-EV charging	Up to 1.5 kVDC	300 A–1 kA	200 kW–1 MW	100 kWh–500 kWh	2 C–5 C
Ultrafast HD-EV charging	Up to 1.5 kVDC	800 A–3 kA	1 MW–4.5 MW	250 kWh–1 MWh	4 C–10 C

MW+ MULTI-PORT EV CHARGING SYSTEM LABELED SEGMENTS POWER DISTRIBUTION, DC AS A SERVICE; P2030.13, ETC

From Source to Load (grid-to-battery)

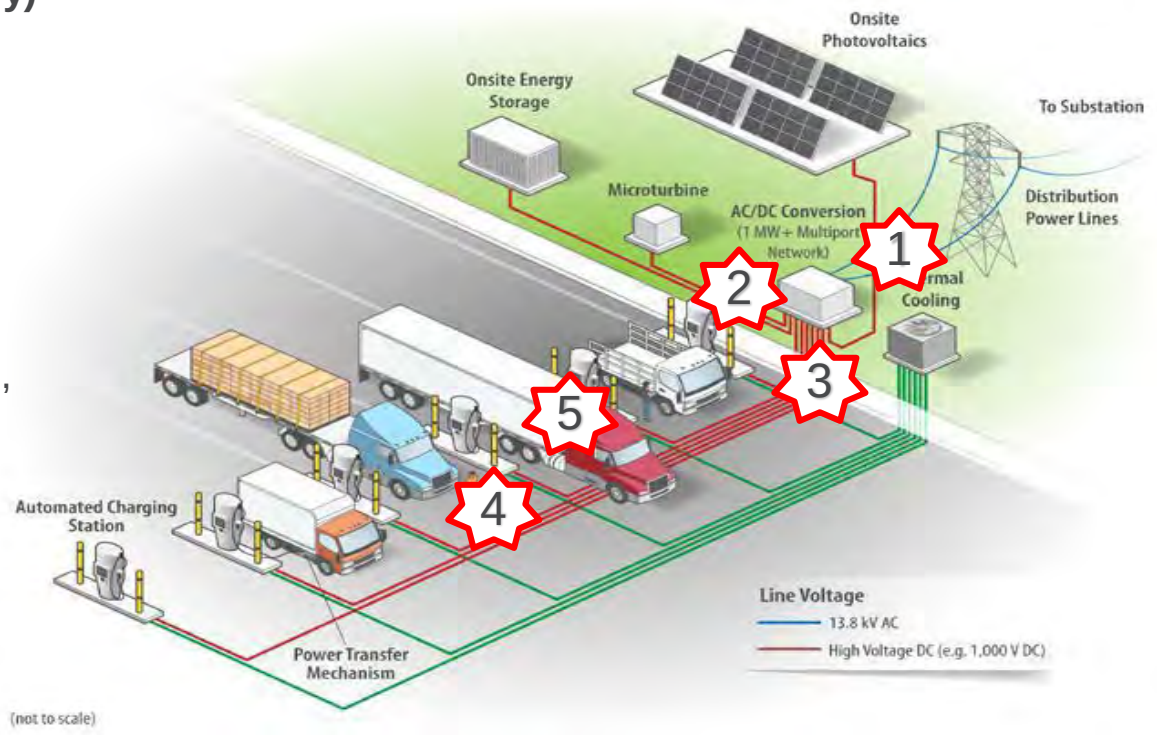
1) Utility Interconnection

2) AC/DC Power Conversion

3) DC Distribution, w/DER Elements

4) DC Dispenser Electronics, Cables, Couplers, Micro-siting

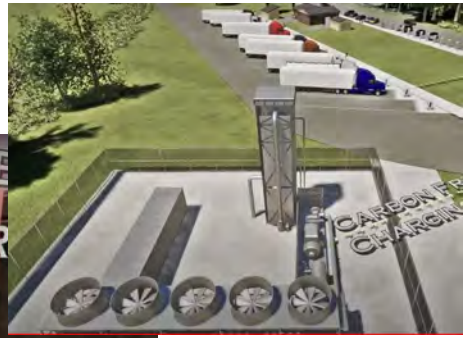
5) Vehicle Inlet, Battery-BMS, Safety



ANL MODULAR DC COUPLED NUCLEAR REACTOR PROJECT; ‘MIFI’

https://www.anl.gov/article/could-argonnes-mini-nuclear-reactor-solve-the-etruck-recharging-dilemma
https://www.youtube.com/watch?v=lvP2EvcRcgY&feature=emb_imp_woyt

- under $3,000 per kilowatt-hour for capital costs
- works at relatively low temperatures (700F) to reduce costs
- system could be standardized, mass produced on an assembly line and loaded on trucks to ship to installation sites across the country.

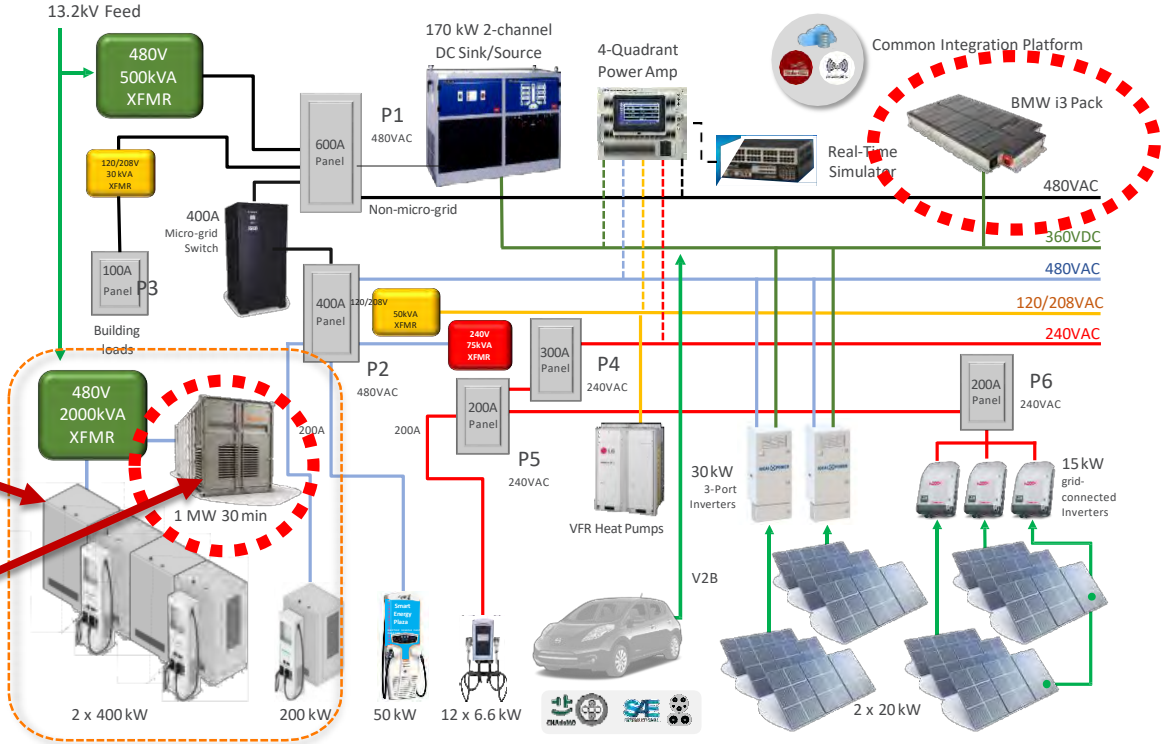


ANL SMART CHARGING PLAZA; AC AND DC COUPLER STORAGE, MW CHARGE

Mitigating the impacts of high-power charging with energy storage

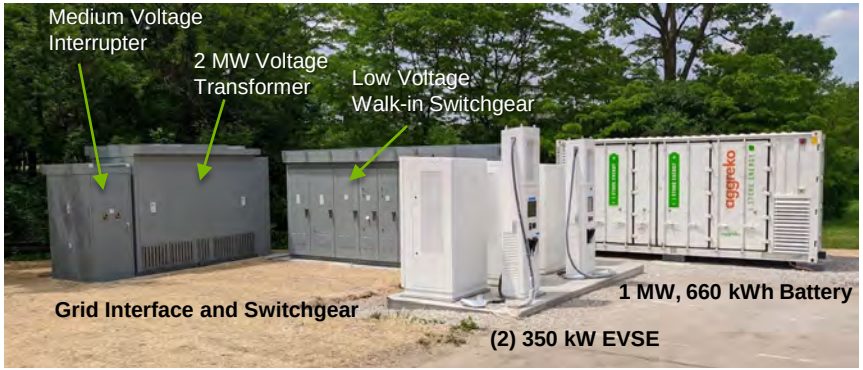
1+MW Total DC EVSEs (2x400kW+1x200kW +50kW..)

- 2667kVA transformer and switchgear
- 1 MW/500kWhr AC coupled Y-Cube storage
- 33kWhr DC coupled BMW i3 pack on DC busway



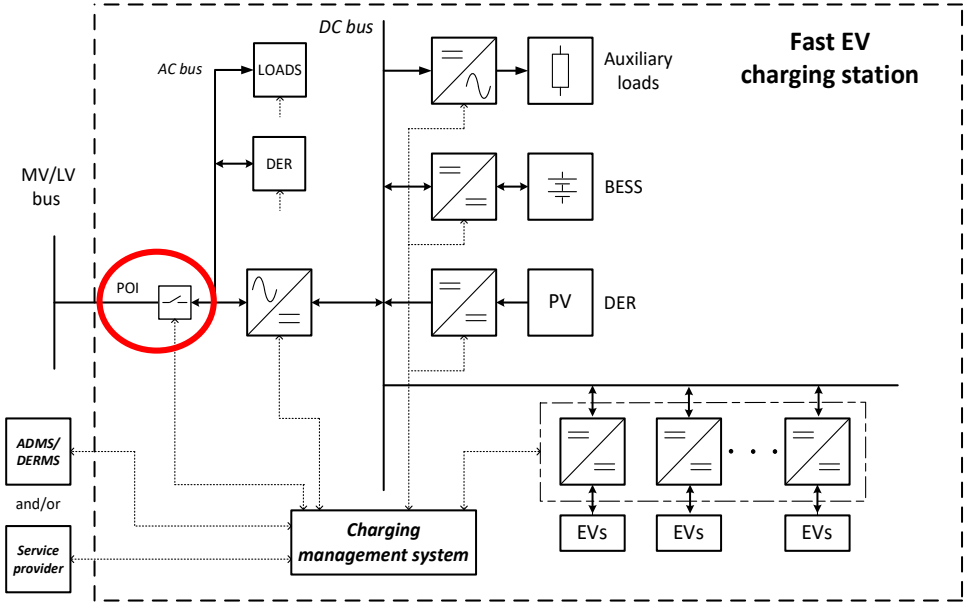
ANL AC COUPLED MW (CCS-MCS COMBINED) DC CHARGING/STORAGE

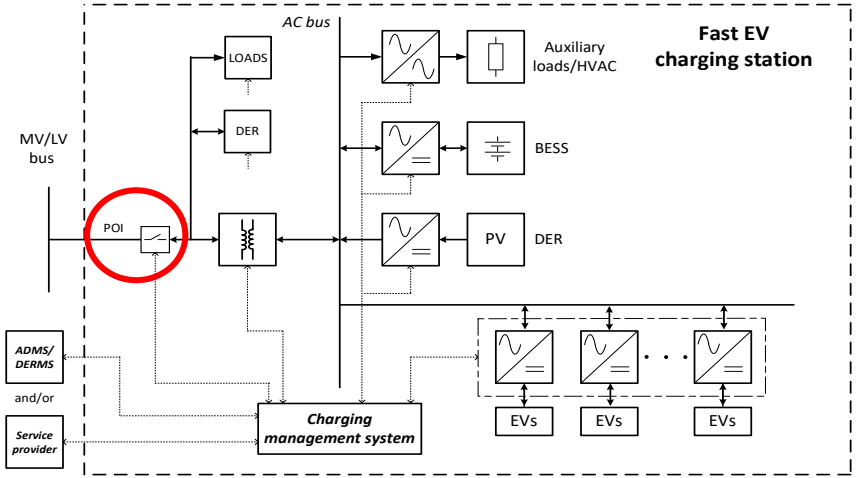
- 5x 200kW power conversion cabinets, 3x 500A dispensers (1500A/1MW total)
- Aggreko 1 MW 480vac coupled storage system, 80kW on PV canopy
- Dedicated metering (Schneider SCADA) on each branch/device



IEEE P2030.13- GUIDE FOR ELECTRIC TRANSPORTATION FAST CHARGING STATION MANAGEMENT SYSTEM FUNCTIONAL SPECIFICATION

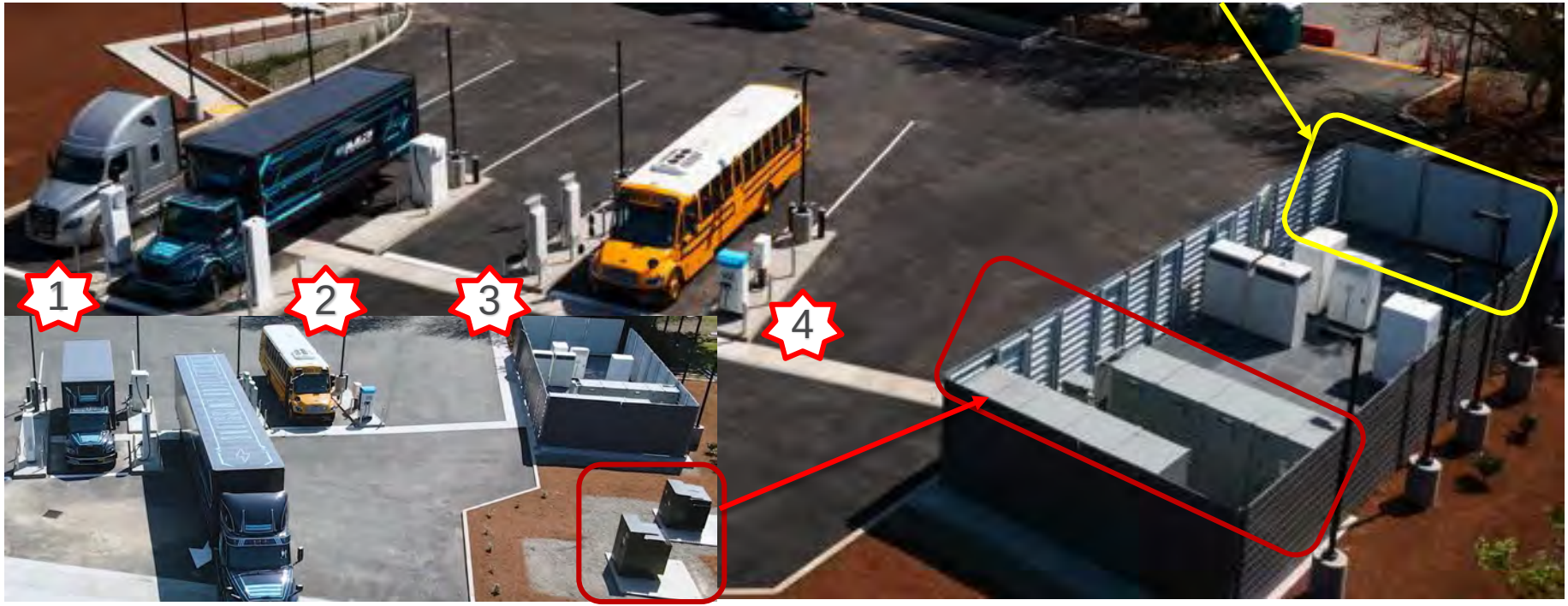
- DC and AC bus system diagrams in P2030.13 (POI-point of interconnection is significant)
- V2G and DC as a Service implications/interpretations, islanded/microgrid operation modes
- Applicable to kW level systems/chargers to MW sized installations, w/wo storage/PV





ELECTRIC ISLAND CHARGING PLAZA; PORTLAND (DTNA, PGE)

5MW (2x2.5MW transformers), reconfigurable gutters/covers, 4 charging islands {left to right} (ABB, BTCP, Chargepoint, Power Electronics SA/Proterra), Phase 2: MCS/MW EVSE, V2G capabilities and peak shaving energy storage



MONTGOMERY COUNTY EAAS MICROGRID

- Schneider Alpha Struxure “Energy as a Service” (EaaS) financing (capital investment by Schneider, monthly fee for all charging/energy delivered to 70 bus fleet (4.14MW charging)
- 6.5MW microgrid; 4.3MWhr
- PV, BESS, generator, etc

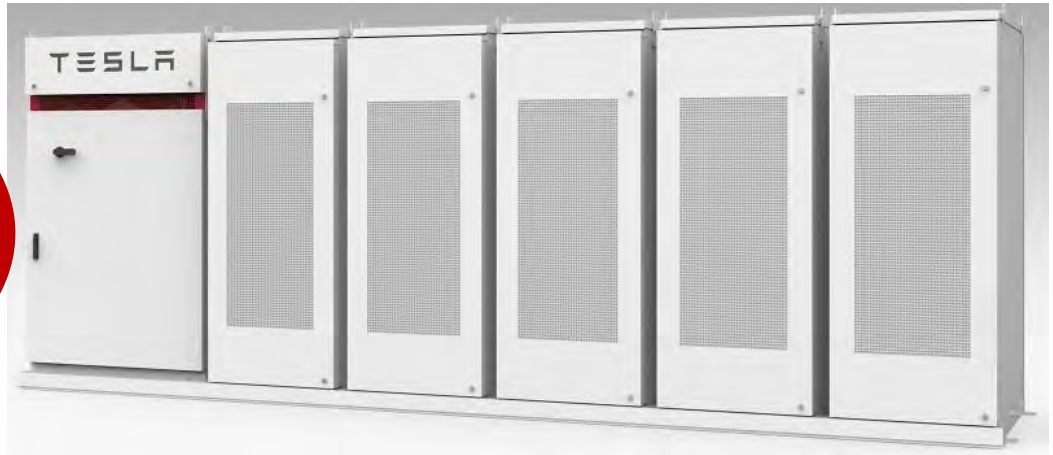
TERAWATT PV, STORAGE AND CHARGING

- TeraWatt infrastructure comprehensive platform for grid connection, logistics, equipment, on-site generation, storage

ELECTRIFY AMERICA- TESLA POWER PACK STORAGE; 210KW, 350KWHR

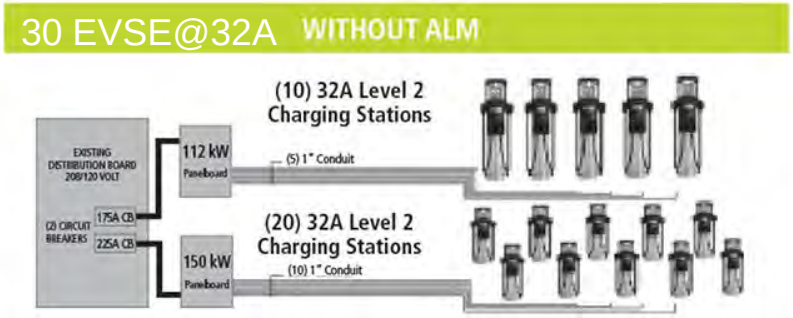
https://electrek.co/2020/09/17/tesla-batteries-60-electrify-america-charging-stations/

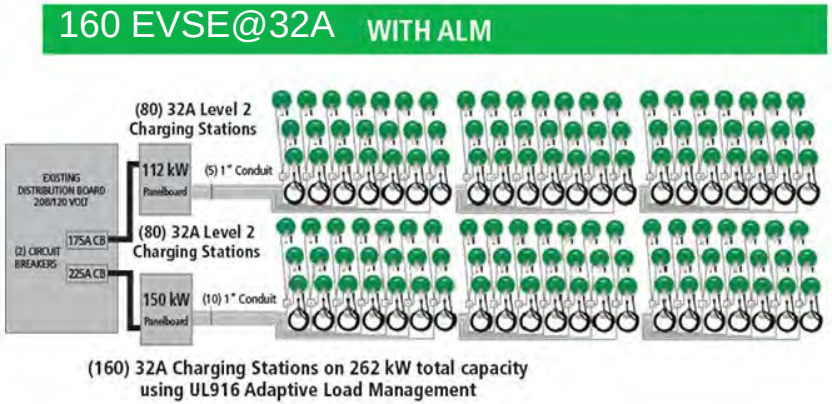
Electrify America confirmed that they already deployed the system at roughly 60 sites and they plan to have "100 to 120" charging stations with Tesla Powerpacks by the end of the year.

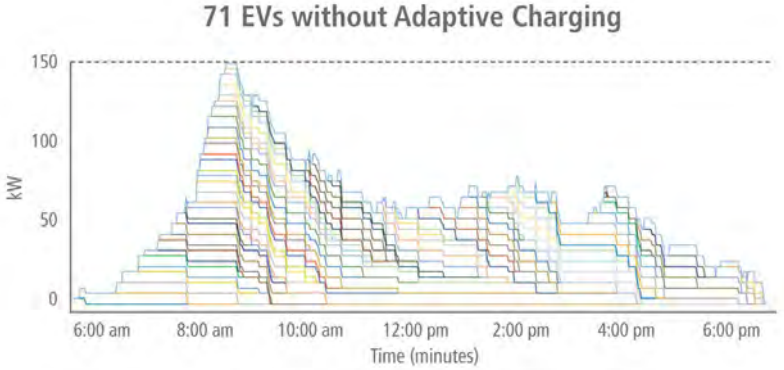


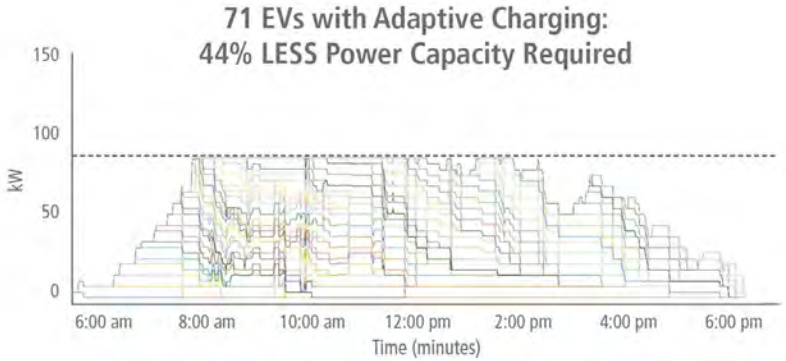
ACTIVE LOAD MANAGEMENT EXPANDS RESOURCE FROM 30 TO 160 EVSE

Powerflex Systems; UL916 safety certified (AC charging) https://www.powerflex.com/turnkey-solutions/





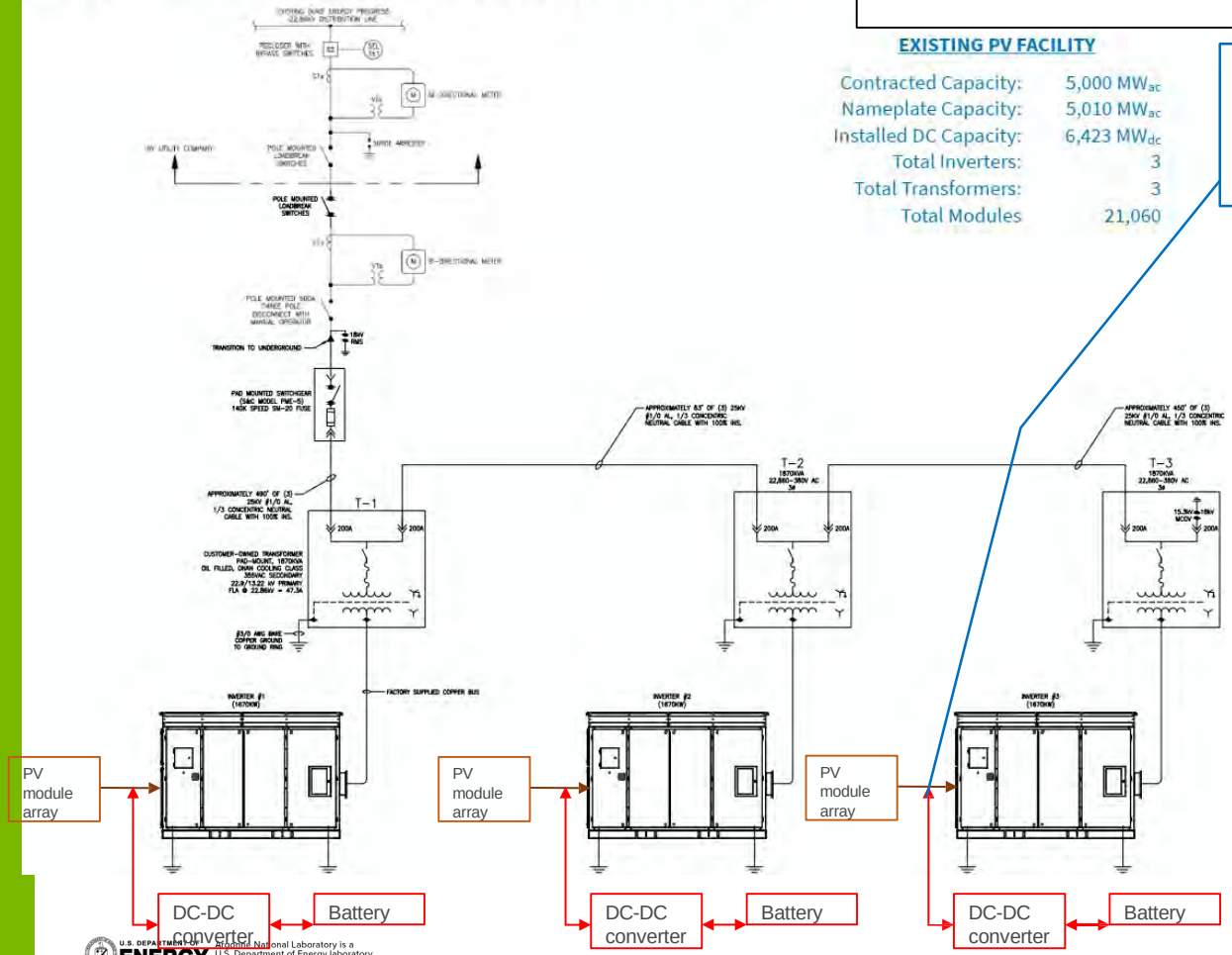




Not a single car had to stay later to receive the same amount of energy as the chart above.

North Carolina - Existing QF Energy Storage Retrofit SLD Example

DUKE MOUNT HOLLEY NC MICROGRID DC-COUPLED STORAGE



EXISTING PV FACILITY

Contracted Capacity:	5,000 MW_{ac}
Nameplate Capacity:	5,010 MW_{ac}
Installed DC Capacity:	6,423 MW_{dc}
Total Inverters:	3
Total Transformers:	3
Total Modules	21,060

DC connection point: ease/difficulty of connection will highly vary by site.

One or two DC metering points (transducers + meters) required, per ESS installation. In this drawing, three ESS installations are shown.

Positives

- (+) Mid-day clipped energy capture
- (+) Minimal losses for conversion of PV generation to ESS charging
- (+) No additional equipment needed on AC side in order to manage interconnection
  - Charging from grid not possible
  - No additional export: Export controls unchanged from existing (either at each inverter, or via plant controller)

Negatives

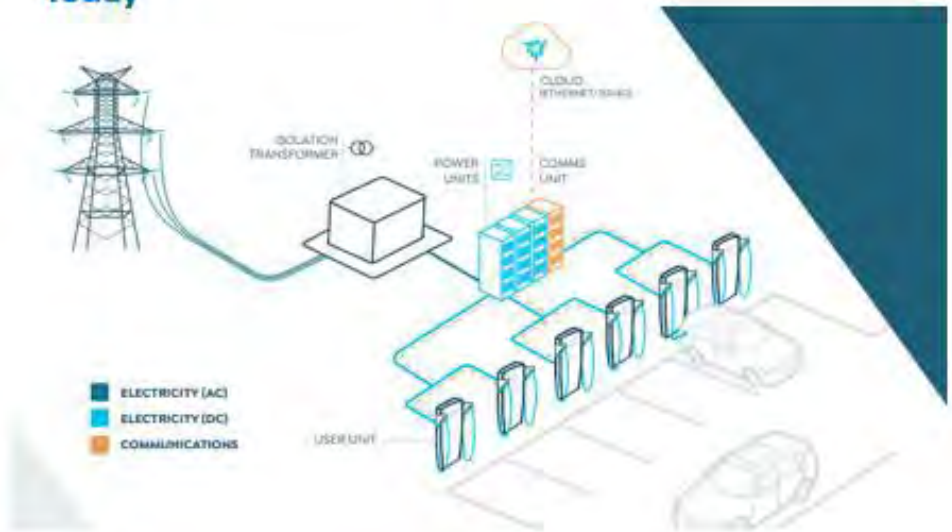
- (-) ESS systems tied to each inverter: real limitations on physical placement, number, sizing
- (-) DC connection point complexity
- (-) DC metering integration for billing/accounting

MOUNT HOLLY – MICROGRID TEST LAB

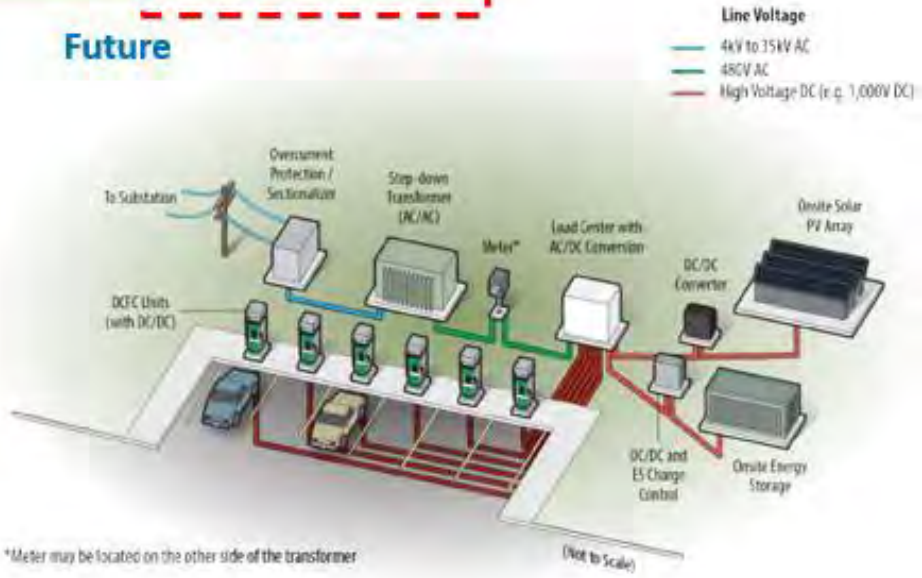

AJEYKBRVEQ
PFRTHEKVXN
TFUTUREKDB
DCISNEDCTG
EJYABRVEQD
BAY 5 DC MICROGRID
THE FUTURE IS DC

GRID BRIDGE

Today



Future

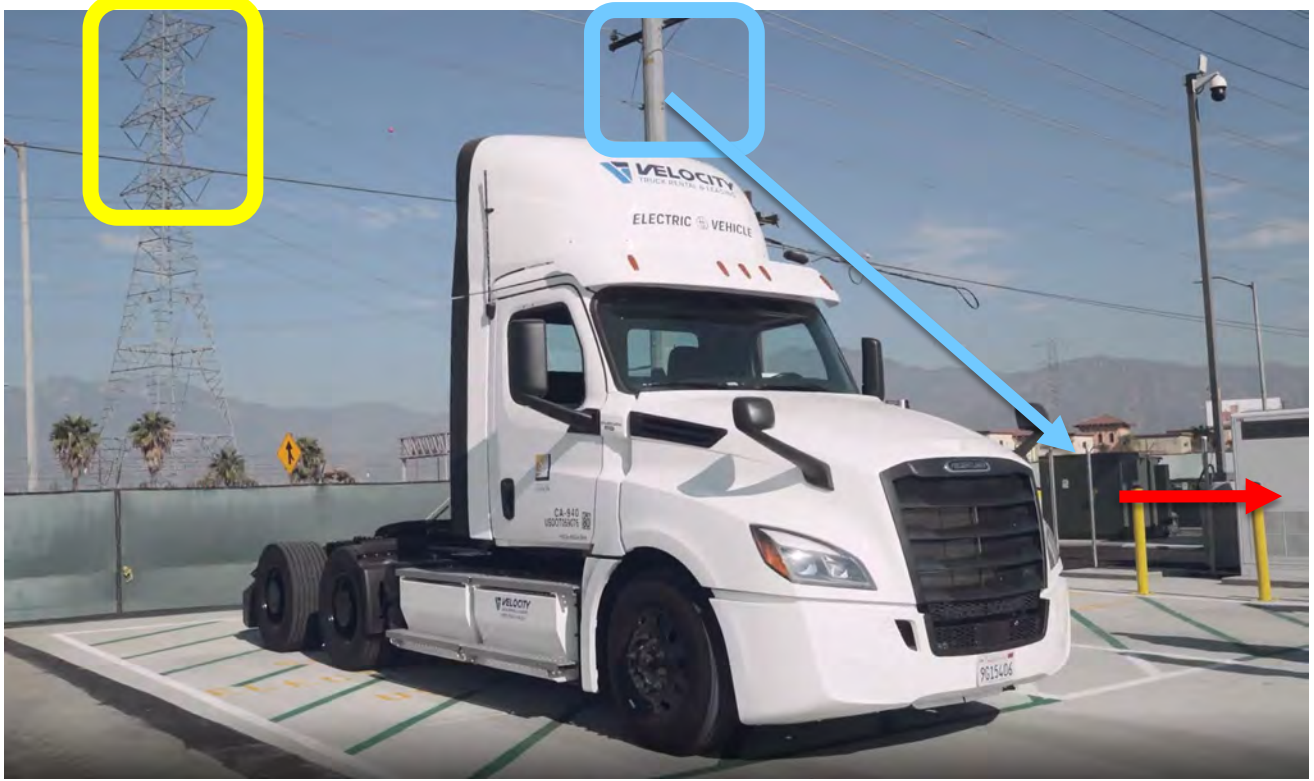


PRACTICAL EXAMPLES OF SITE PLANNING: ONTARIO CALIFORNIA

TA Petro Ontario California truck stop ~600 parking spots (on left); again as many on right. Electrifying up to 1200 parking/charging spots is both an opportunity and a challenge

REPRESENTATIVE TRANSMISSION-DISTRIBUTION-LV PATH

- Photos of the ABB/SCE-Irwindale CA, showing **transmission(HV)**, **distribution(MV)**, **charger(LV)**, DC
  https://energized.edison.com/stories/sce-celebrates-arrival-of-new-electric-big-rig



CLASS 8 TRUCK EV CHARGING LOW VOLTAGE-DC PATHWAYS

DCAAS CABLE DUCT BANK- PV, DATA CENTER INSTALLATIONS

https://unitedwc.com/maxiamp-cable-bus/ ; alternative to busway/busbars

VS

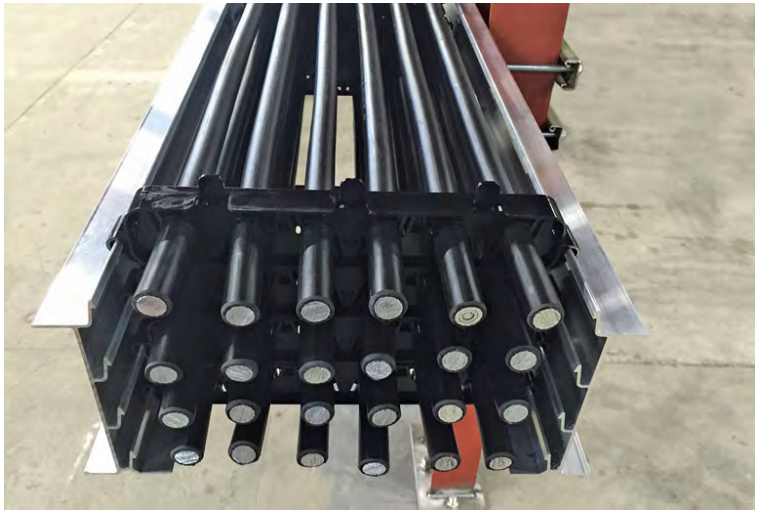


Photo Essay: Finished FritoLay Charging Installation

- Google Maps view of whole facility; 2MW of PV, employee, box truck EVSEs, Telsas

Photo Essay: Finished FritoLay Charging Installation

- Google Maps view MCS chargers, transformers for CCS and MCS DC stations

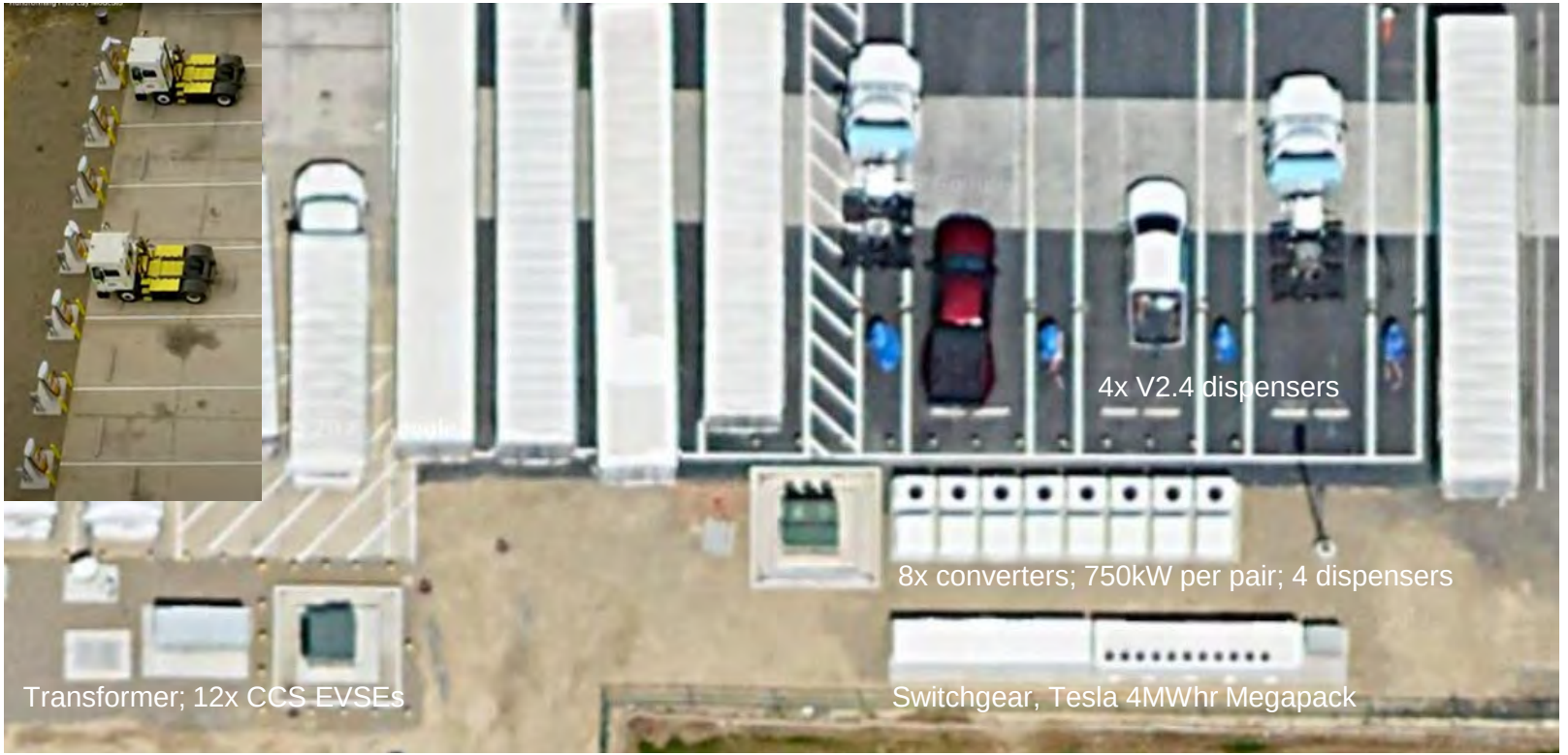


Photo Essay: Finished FritoLay Charging Installation

- FritoLay video; MCS chargers, dispensers, bollards, transformer, etc

Photo Essay: Finished FritoLay Charging Installation

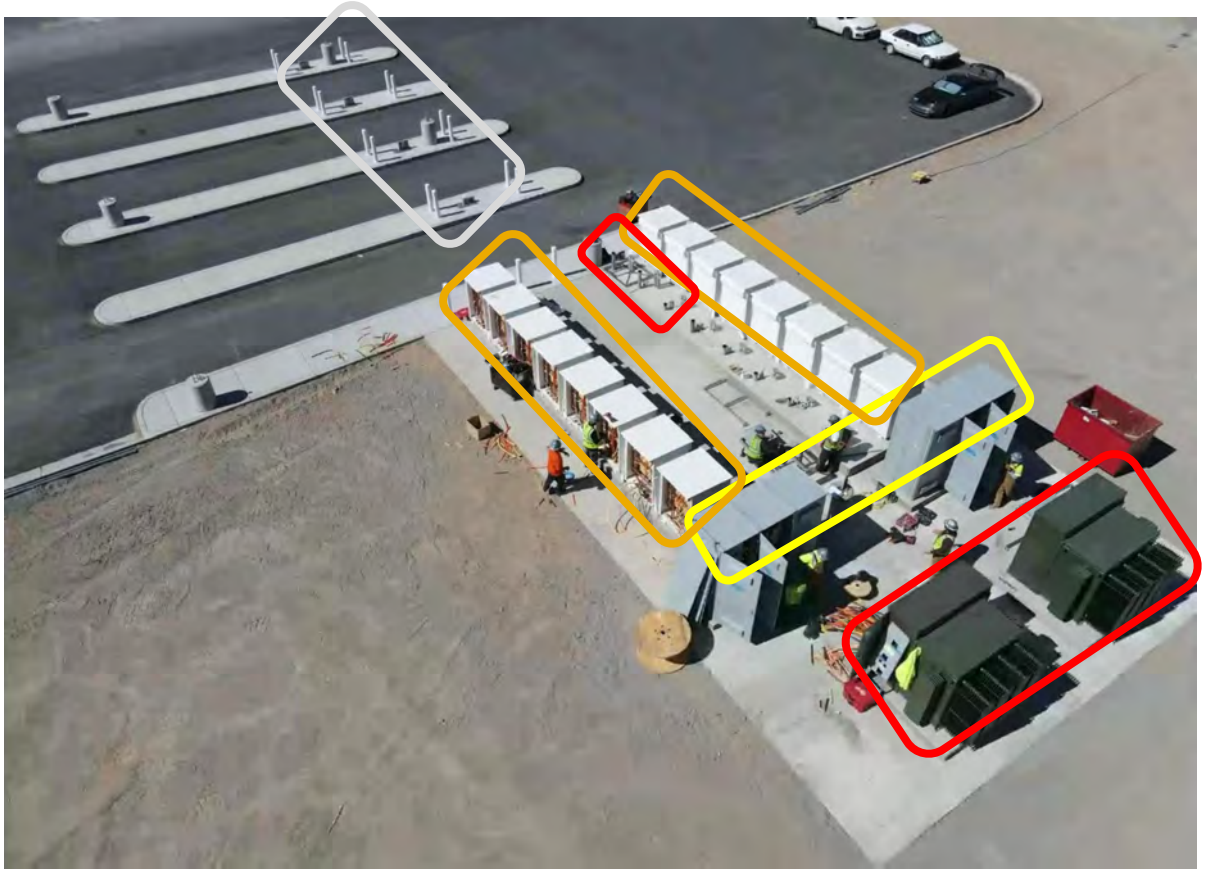
- FritoLay June 2022 clear photo; bollards, equipment, striping,
- No pull-through, must unhook trailer before charging….each day

TESLA MCS CHARGING INSTALLATION-NEVADA

- Ground work image
- Note size of trench and conduits (in/out) from transformer to converters to dispensers
- Transformers(2) conduit connections- bottom
- Load centers- middle
- Power converters (16/32) connections- center
- Dispenser/charge cable (4) stations- top

TESLA MCS CHARGING INSTALLATION-NEVADA

- Final wiring image
- Assuming 2x 2.5MVA transformers (5MVA input)
- Ignoring losses, max simultaneous output per port is 5MW/4=1.2MW
- Simple math on 16 sets of converters, 5MW= 312 kW Isolation transformers suggest parallel output converters
- Where is the liquid cooling chiller for charging cables (inside dispenser kiosks)?



BALANCING ACT; SCALING, FINANCING, EXPANDABILITY, INTEROPERABILITY

- This work group is focused on multi-port MD/HD electric bus and MD/HD truck charging source-to-destination (utility interconnection to battery terminal), up to 1MW or above
- More realistically multiple vehicles at a single location, addressing utility interconnection **pad mounted transformer 2.5MVA limitations.**
- At the 1MW-2.5MW level, ignoring losses this equates to simultaneous charging of

  - **1 to 2.5** charging ports at **1MW** each
  - **2 to 5** charging ports at **500kW** each
  - **10 to 25** charging ports at **100kW** each
  - **50 to 125** charging ports at **20kW** each

- One can do the math on oversubscription of 4-10x for sharing DC sources (10's at MW level to hundreds at the 100kW/20kW per port from one 480vac/2.5MW AC-DC conversion feed (**1500vdc*1666A=2.5MW** DCaaS DC bus distribution feed)

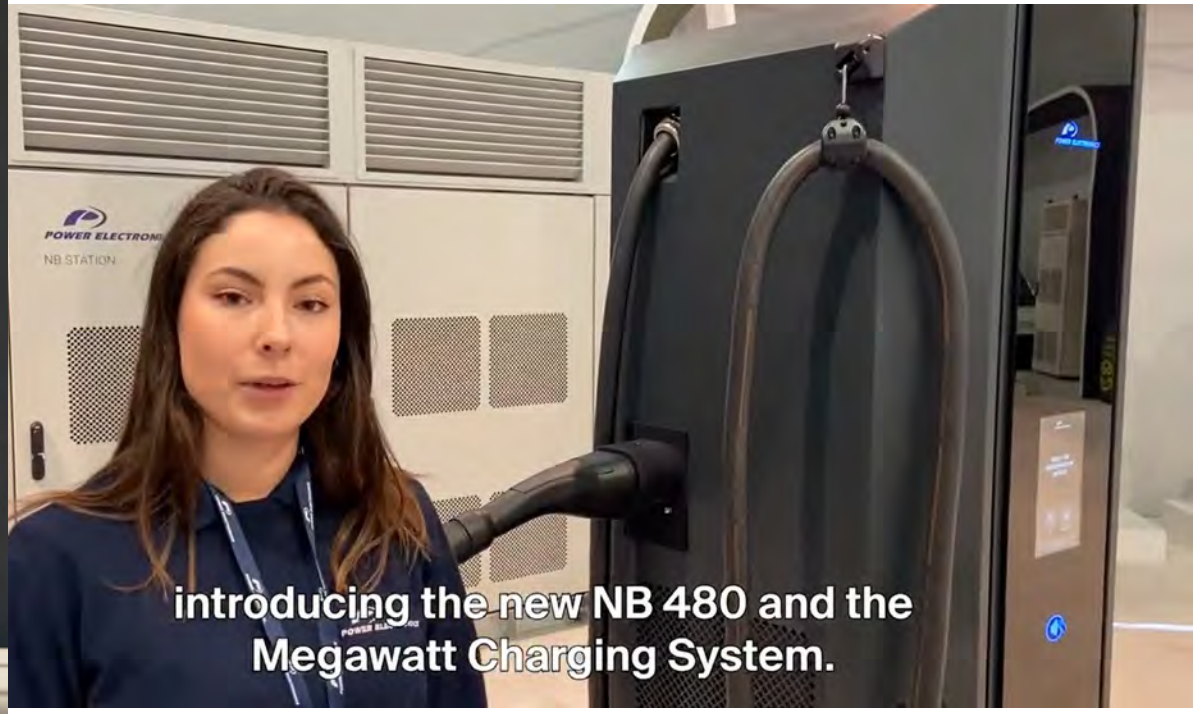
HELIOX MULTI-TIER CHARGING STRATEGY

- https://www.heliox-energy.com/megawatt-charging-system/

- **Rapid charge 1 vehicle at 1MW** Optimally charge a truck in minutes by devoting the whole system to one vehicle at 1MW and 1000A. (MCS level 2)
- **Charge 3 vehicles simultaneously at 360 kW** With one MW system, you can charge 3 vehicles at once each at 360 kW and 350 A. (MCS level 2)
- **Charge 6 vehicles simultaneously at 180 kW** Charge 6 vehicles at once with a one Megawatt system distributing power equally at 180 kW. Plus easily add more systems as you grow.

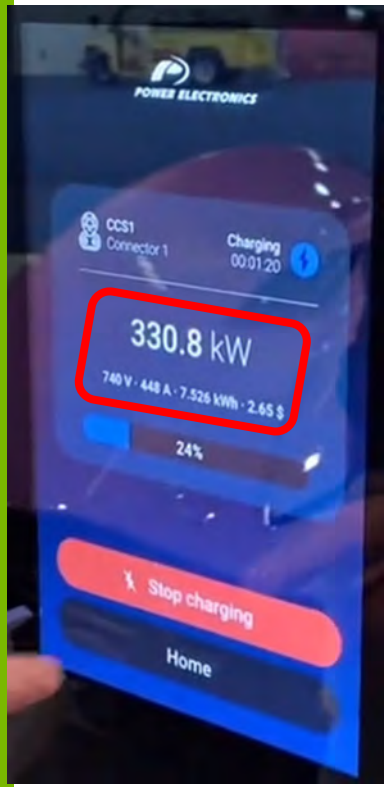
Power Electronics SA (Spain), CES Booth; NB480-MCS

- 6 meters^3 , 1400kW; Rema J3271 coupler



Power Electronics SA (Spain), CES Booth; NB480-MCS

Power Electronics SA (Spain), CCS Output



DesignWerk- Swiss; Megawatt Container Solution

https://cleantechnica.com/2022/12/19/designwerk-unveils-megawatt-charging-system-for-electric-trucks/
https://www.designwerk.com/en/megacharger/

- Pilot deployment in spring 2023
- 1800kWhr storage; secondary use
- 2.1MW(3000A, 500v-900v) output
- 90% mains-to-vehicle efficiency

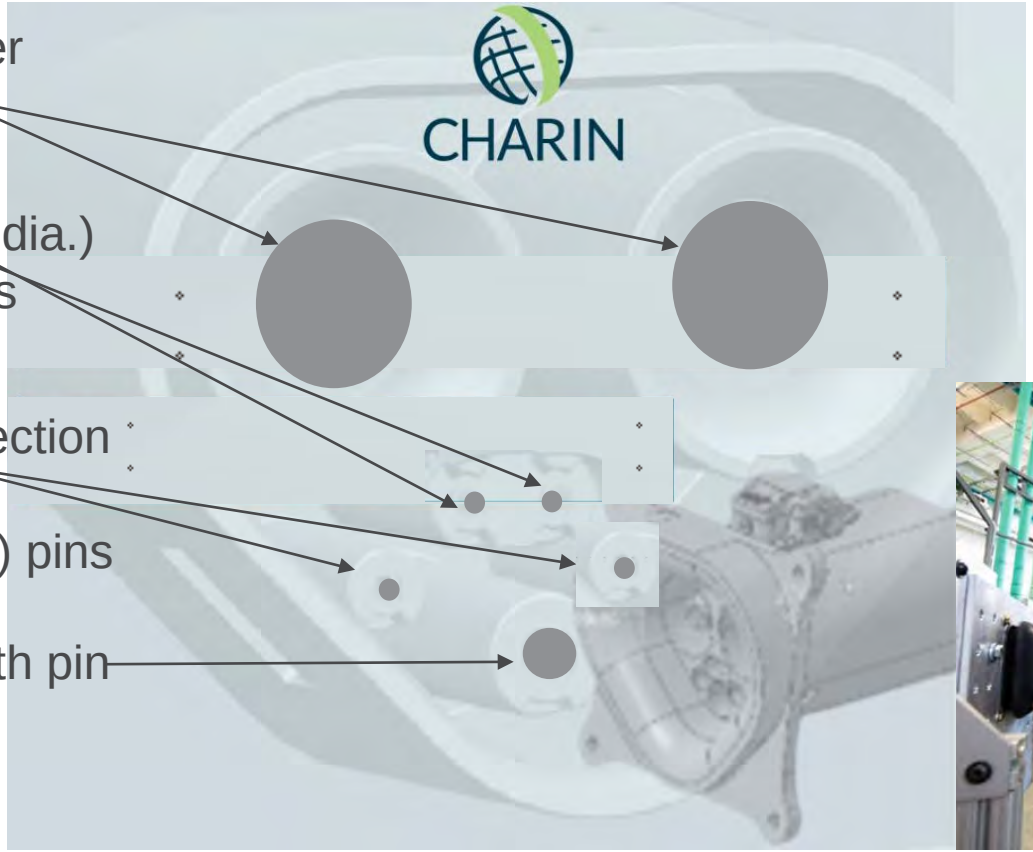
Demonstration project	Megawatt battery charging system for heavy commercial vehicles
Dimensions LxWxH	8500×2550×3000mm
Weight	25 t
AC input data	88-400 kW, TN 3×125-580 A, 400 VAC +-10%, 50 Hz
AC plug type	CEE 125 and fixed connection, 3P+N+PE
Battery buffer	1'800 kWh
Technology battery storage	NMC, Second Life use or new
DC output data	max. 3'000 A, 500-900 V, max. 2'100 kW
DC connector type	Liquid cooled, CCS type 2, MCS
Efficiency	Mains > Battery > Vehicle > approx. 0.9

MEGAWATT CHARGING SYSTEM-SUBSECTIONS

- SAE J3271 TIR covers the system level charging description/requirements. The subsystem requirement specifications will be referenced in the main document, pointing to subsections listed below.

- **Subtopic documents:** (base document TIR first, then subsections)
  - SAE J3271/1; Electromechanical coupler/inlet requirements (like J1772)
  - SAE J3271/2; Physical/software layer communication (~J2931, J2847, J1939)
  - SAE J3271/3; Charging cables (cooling, cord handling/automated connection)
  - SAE J3271/4; Use cases including DER/microgrid interconnections (V2G)
  - SAE J3271/5; Interoperability/testing requirements

(PUBLIC DOMAIN) DIAGRAM OF CHARIN MCS V3.2 DESIGN/FUNCTIONS



+/-DC Power
(<3000A)
20mm dia.

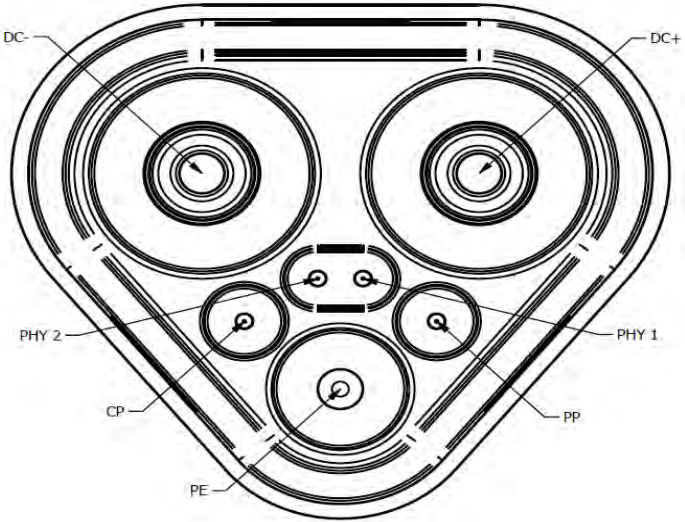
(8mm pitch, 3mm dia.)
comms/detect pins

(34mm pitch) connection
detection; comms
(aux/future function) pins

Protective earth pin

MCS 2.4 Coupler at
CharIN testing event

(J32771 MCS V3.2 DESIGN/FUNCTIONS

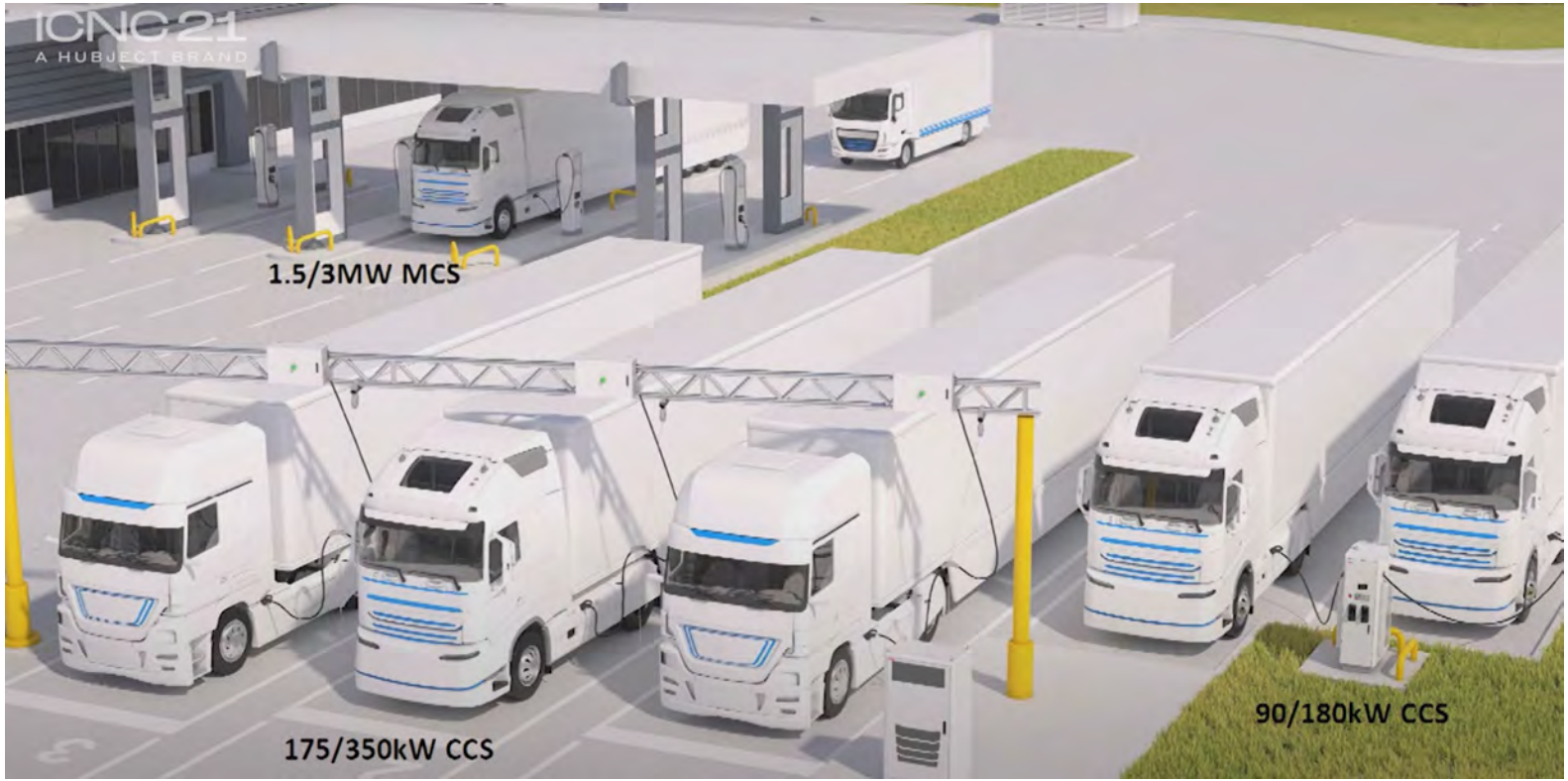


STAUBLI CES 2023 BOOTH- MCS COUPLER

https://youtu.be/sFAJcGPBsxQ?t=1587

DC CHARGING SOLUTIONS(ABB)- 90KW TO 3MW, CANOPY-GANTRY

Properly sized charging solutions based on mission of the vehicle



MICROGRID DC CHARGER EXAMPLE: TRITIUM PKM150 (6X25KW OUTPUT)

- **Dispenser unit:** 950vdc input, 150-920vdc output, 150kW, 97%, 661lbs, (79" x 34" x 12")
- **'DC Microgrid unit':** 360kW/450A output ~1200lbs, (93" x 26" x 44"); multiple dispensers from 950vdc DC link from 'microgrid chassis'
- https://www.tritiumcharging.com/wp-content/uploads/2021/12/PKM150-Data-Sheet.pdf

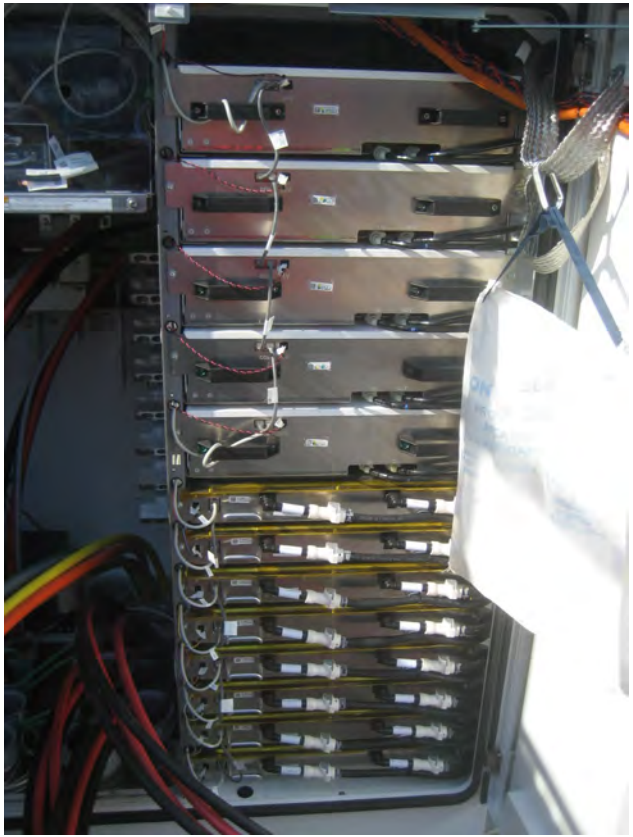
TESLA SUPERCHARGER V3- NAMEPLATE RATINGS 350KW+575KW=925KW

https://youtu.be/5FWlFdLwV94?t=245

Nameplate ratings: ***Input*** *480vac/430A (350kW, 5*70kVA modules)*
DC In/Out(shared)*: 575kW (880v-1000v, 640Adc);* ***Port DC:*** *250kW, 500v*631A*

TESLA SUPERCHARGER COMPONENTS- CONVERTERS TO FEED DISPENSERS

- AC/DC converters, DC/DC modules
- MODBUS serial data(?)
- Liquid cooling connections on each module, exchanger on top
- Internal AC/DC connections at rear
- DC Output conductor connections (2x2/0 compression lugs, 670A)
- Wye caps on DC outputs



PENSKE ONTARIO CA; SIEMENS 6X150KW=900KW STATIONS

https://taas.news/article/111832/Penske_Truck_Leasing_continues_to_expand_heavy-duty_EV_charging_network

21 heavy-duty commercial vehicle DC fast-charging positions at Penske Truck Leasing's facilities in San Diego, Chino, Anaheim, Temecula and La Mirada

Includes Fluency site located energy storage system to manage/shave demand

44X 150KW (6.6MW PEAK) MEZZANINE CHARGING INSTALLATION

Project Reference Hamburger Hochbahn

Virtual Tour through Depot „Alsterdorf“ - 2

4x RESIBLOC Transformer each 2000 kVA cast resin technology for maximum mechanical and thermal stability

1x SAFEPLUS switchgear in metal housing for distribution applications including current/voltage sensors, relays and substation automation

4x MNS low voltage switchgear for power distribution and motor control

44x HVC Depot Box attached to ceiling with hanging CCS cable (7-10m)

44x HVC 150 Power Cabinets offering 150kW continuous DC power at highest efficiencies

GRID-EMOTION™ CHARGING POINTS AND SYSTEMS, CONTAINERIZED CHARGERS AND DIGITAL SOLUTIONS

Containerized charger and substation

Your solution for fast energization

- Up to 500kW power
- Grid-forming power converter
- Battery racks and battery management system
- Designed for grid integration of EV charging infrastructure depots and terminals
- For power requirement up to 500kW and energy storage of 670kWh
- Remote monitoring and control system
- Standardised enclosure for fast delivery at site

- Prefabricated walk-in, modular outdoor enclosure
- Thermally insulated for increased equipment lifetime
- Robust and light weight design
- Wide range of ratings & capacities as well as layouts in steel, concrete and GRP
- Protection degree: IP 43/23D (MV switchgear/transformer)

HITACHI ABB

GRID-EMOTION™ CHARGING POINTS AND SYSTEMS, CONTAINERIZED CHARGERS AND DIGITAL SOLUTIONS

Battery Energy Storage System (BESS)

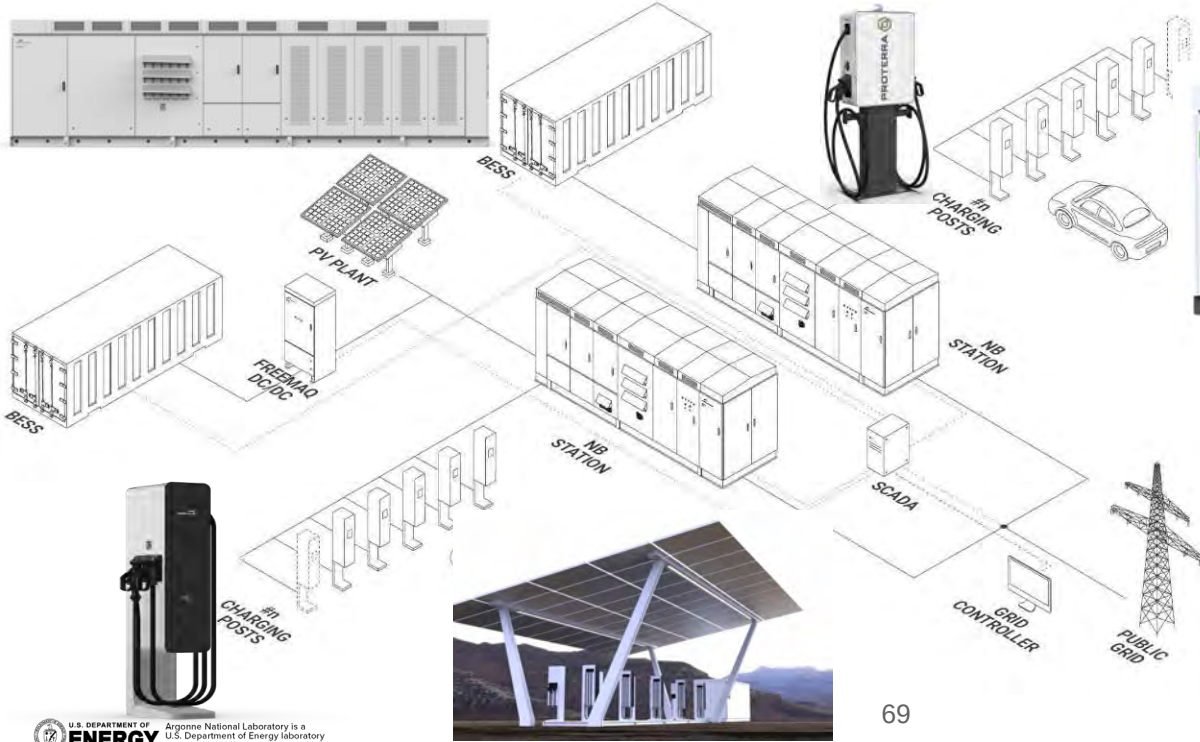
Stationary BESS for small depots or city terminals

- Up to 500kW power
- Grid-forming power converter
- Battery racks and battery management system
- Designed for grid integration of EV charging infrastructure depots and terminals
- For power requirement up to 500kW and energy storage of 670kWh
- Remote monitoring and control system
- Standardised enclosure for fast delivery at site

DC AS A SERVICE/INTEGRATED PV-STORAGE W/SCADA POWER ELECTRONICS SA NB1400: {1.5MW, 500KW PORTS}

NBSHV1400S at 1.5MW (1000vdc/1400A), 4x600kW pantographs; 6x 350kW CCS1, up to 20 total ports 40 sequential; Solar + storage coupled to the 1.4MW charging station skid, including the MV switchgear.

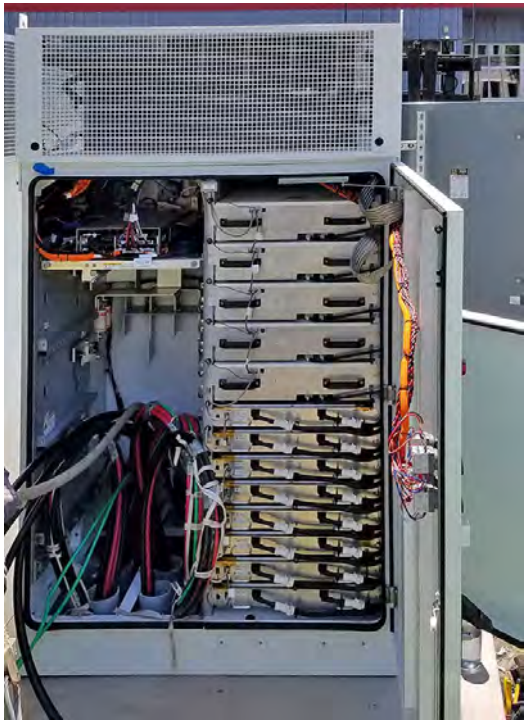
https://www.proterra.com/press-release/proterra-chargers-enable-fleet-electrification/



https://power-electronics.com/wp-content/uploads/Descargas/Ingles/Leaflets/Mobility/Leaflet_Nube_station.pdf

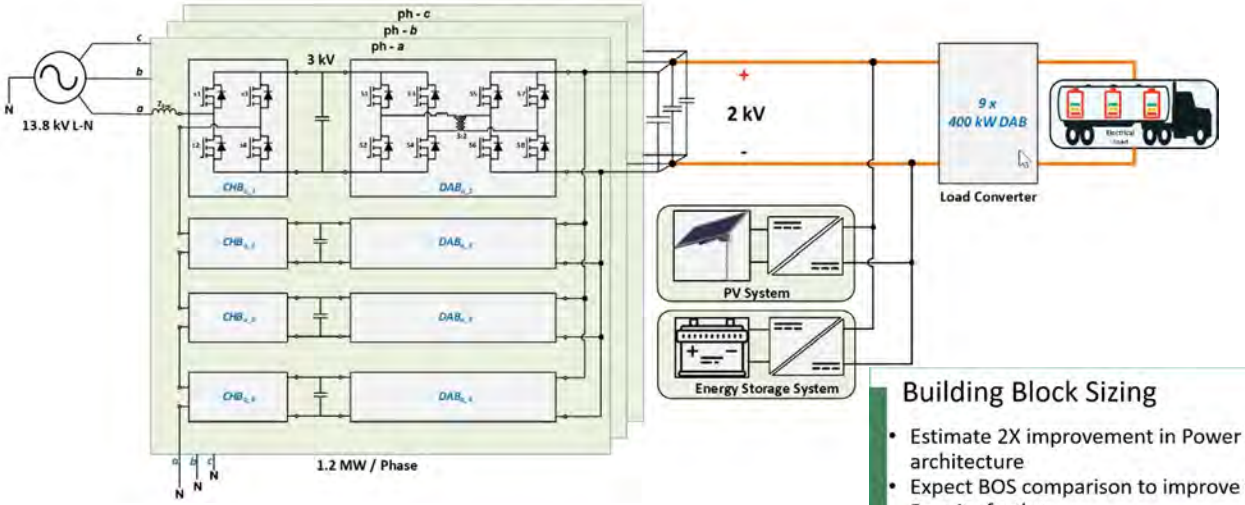
TESLA SUPERCHARGER V3 LAS VEGAS SITE; 24 X 250KW =6MW ELECTRONICS-DISPENSERS, (6 CABINETS) PV LOCAL GENERATION

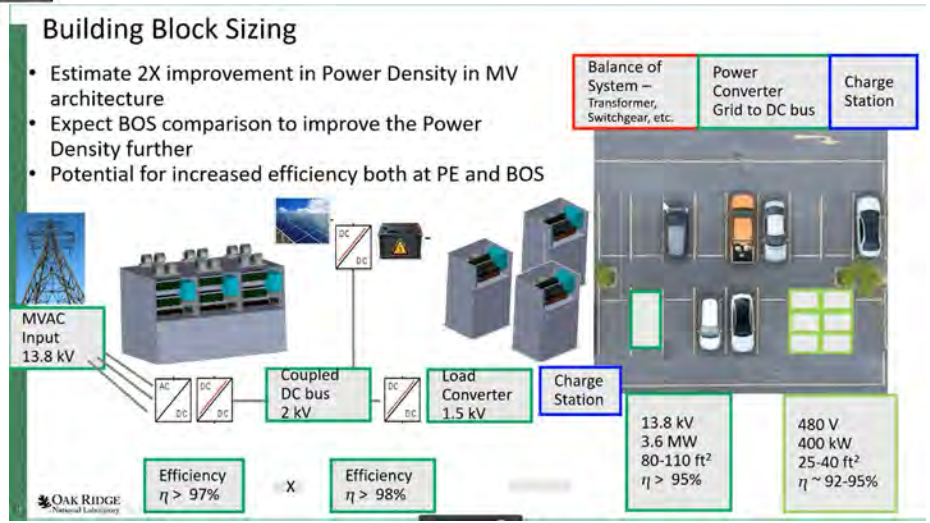
- Shared DC link between converter cabinets, liquid cooled 70kVA AC/DC modules, DC/DC converter output modules
- 2.5MVA feed transformer



ORNL POWER ELECTRONICS: SST/DC DISPENSER APPROACH

HTTPS://WWW.ENERGY.GOV/SITES/PROD/FILES/2020/06/F75/ELT204_MEINTZ_2020_O_5.7.20_754PM_LR.PDF



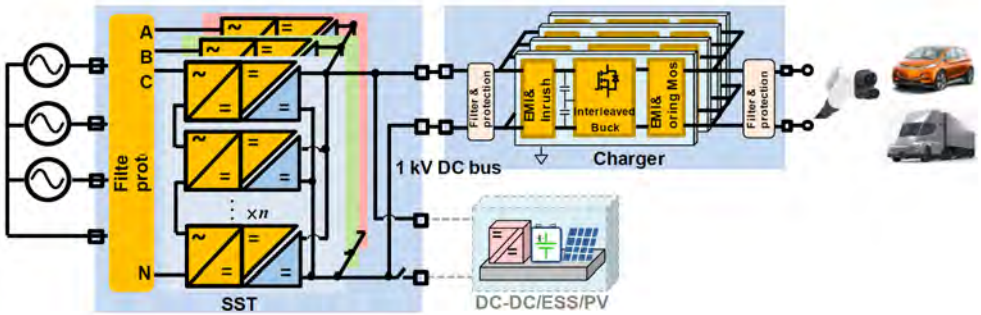


DELTA ELECTRONICS DCAAS XFC-SST ARCHITECTURE

- Medium voltage converters on each phase leg; interleaved output converter(s)
  https://www.energy.gov/sites/prod/files/2020/06/f75/elt241_zhu_2020_o_4.27.20_642PM_LT.pdf

Motor Control Center (MCC) panel

Someday?

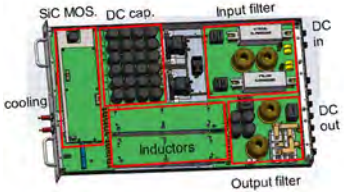


3-Φ MVAC input:
- 4.8kV/13.2kV
- iTHD<5%, PF≥0.98
- 60Hz±10%

SST DC output:
- 1050V±3%
- 400kW power
- Interface for ESS/PV

Charger output:
- 200V~1000VDC
- 400A max current
- SAE J1772 charging interface CCS1

- Size:33.4”x7.8”x7.8”
- Weight: 51 lb



- Size:16.5”x3.1”x30”
- Weight: 79 lb
- Power density: 77W/in³

DELTA ELECTRONICS SST FED CHARGING

- Excerpts from summary on Autoline- https://youtu.be/h7elaoiS7Kc?t=361
- 13.6kV fed system; DOE FOA funded, deployed at Willow Run(MI), 500A output
- Charged Lightning, Lyric and Hummer EVs; 25% net weight, ~97% wall-to-battery

BI-DIRECTION DC CHARGING NODE; WOLFSPEED 22KW DC/DC CONVERTER

22kW Bi-directional; 900vdc bus, ~99% eff. https://www.wolfspeed.com/power/products/reference-designs/crd-22dd12n

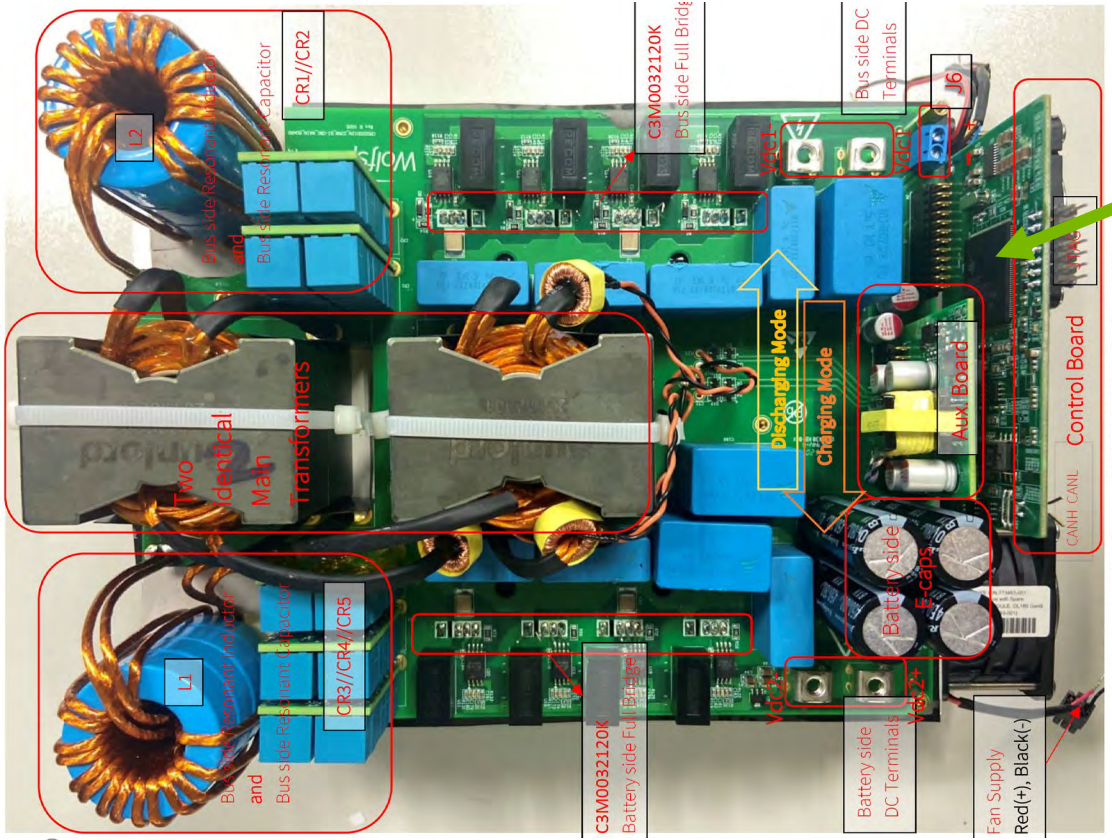
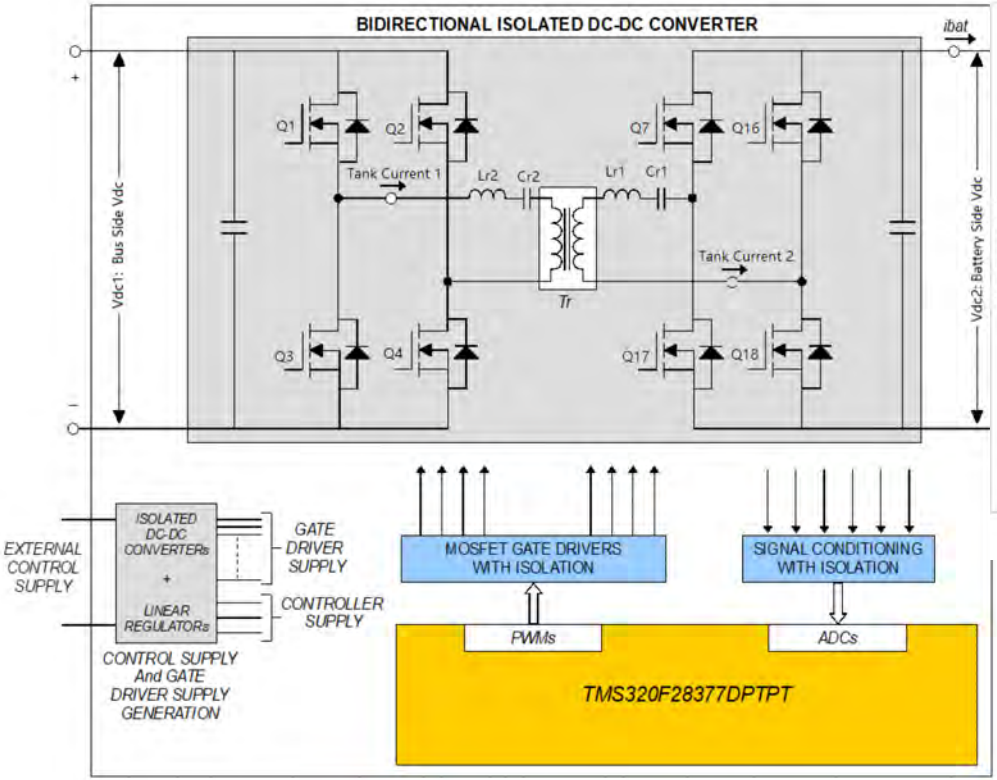


Figure 11. Top View of PCBA (250mm*190mm*55mm

- 250 x 190 x 55mm footprint
- Microcontroller board built in with CAN communication (TMS320F28377DPTPT)
- SiC MOSFETs - C3M0032120K (1200V, 32mΩ, TO-247-4)
- EV charger requires fuses, precharge, output contactors, status display
- Goal is to achieve IP67 with sealed unit, conductive cooling to mounting location
- (2% loss*22kW=440W)

BUILDING TEST ARTICLES, CONTROLS; WOLFSPEED 22KW DC/DC CONVERTER

22kW Bi-directional; 380v-900v input, 200v-800v, 36A output, 8kW/l, CLLC resonant converter; 135-250kHz



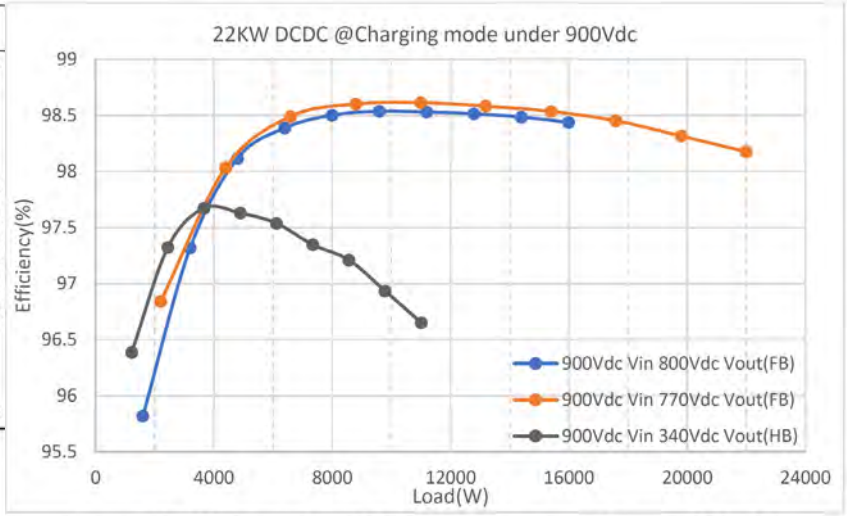


Figure 13: Efficiency Data (DC/DC Charging mode), VIN = 900 VDC

EVGO SECONDARY USE BATTERY BUFFER, UNION CITY CA (44KWHR, 30KW)

https://infocastinc.com/market-insights/power/energy-storage-battery/
https://electrek.co/2018/05/21/bmw-i3-battery-pack-uk-national-grid-energy-storage-project/

770 packs-BMW Leipzig facility
500 i3 packs- UK National Grid

VARIOUS SECONDARY USE BATTERY BUFFER EXAMPLES

https://electrek.co/2017/08/29/renault-electric-car-charging-stations-used-ev-battery-packs/
http://www.spiersnewtechnologies.com/energy-storage

Spiers New Technology, Nuvation BMS
WattTower- 2800lb, 56kWhr,
400vdc, 108s4p stack; 85”x36”x39”

JOLT ENERGY (IRELAND/GERMANY) MOBILE STORAGE CHARGING SYSTEM

https://jolt.energy/

Merlin-One Mobile station; 160kW, 200kWhr storage, 230 x 120x 110 cm Island Mode: fresh charging station dropped in urban location via truck when empty (5x 40kWhr charges?)

*The third option is to connect the MerlinOne to the **medium voltage grid,** allowing the charger to operate continuously at high-power, while at the same time providing charger-to-grid (C2G) services*

JOLT ENERGY (IRELAND/GERMANY) MOBILE STORAGE CHARGING SYSTEM

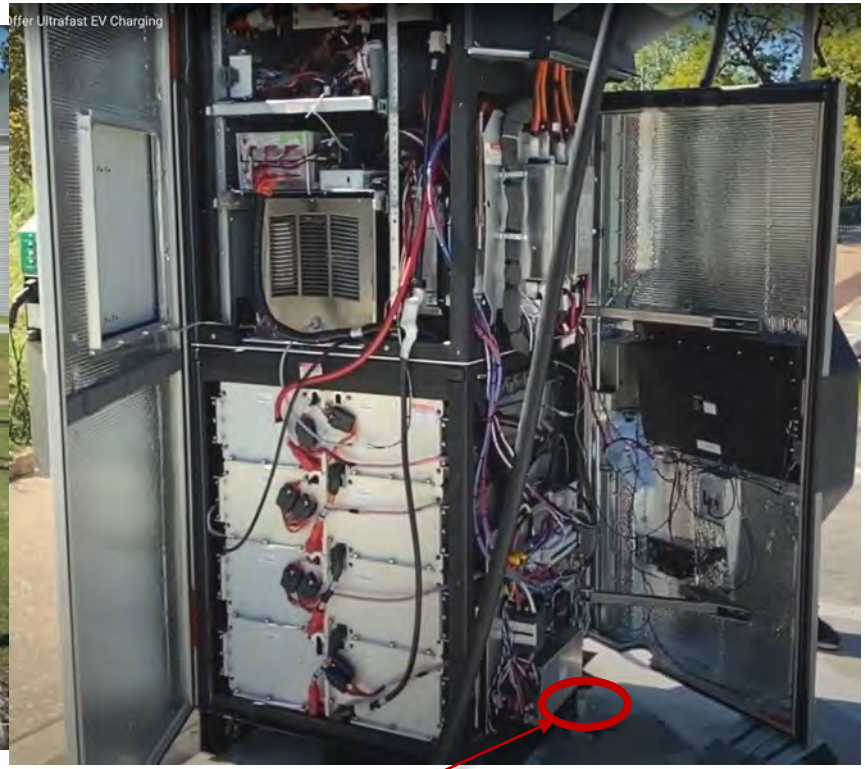
https://jolt.energy/mobile-charging/

Merlin-One Mobile station; moved to event location, transport energy on truck platform (side opening EVSEs)

- **10 Cars full-power simultaneously (3.2MW?)**
- **320 kW per charging point**
- **2 MWh energy on-board**

FREEWIRE BOOST CHARGER- 160KWHR STORAGE, 120KW DUAL OUTPUT

https://assets.ctfassets.net/ucu418cgcnau/56reLufWaEuOY7oYajeK2Y/08a88be7902c36bcac2a688cd622736b/D1-4_Ethan_Sprague_Freewire.pdf
https://freewiretech.com/products/dc-boost-charger/, https://www.youtube.com/watch?v=P30MW6OXCA8



3800lbs, 40”x 43” x 96”H

27kW (208v-240vac, 80A 3Φ, 120A 1Φ input)

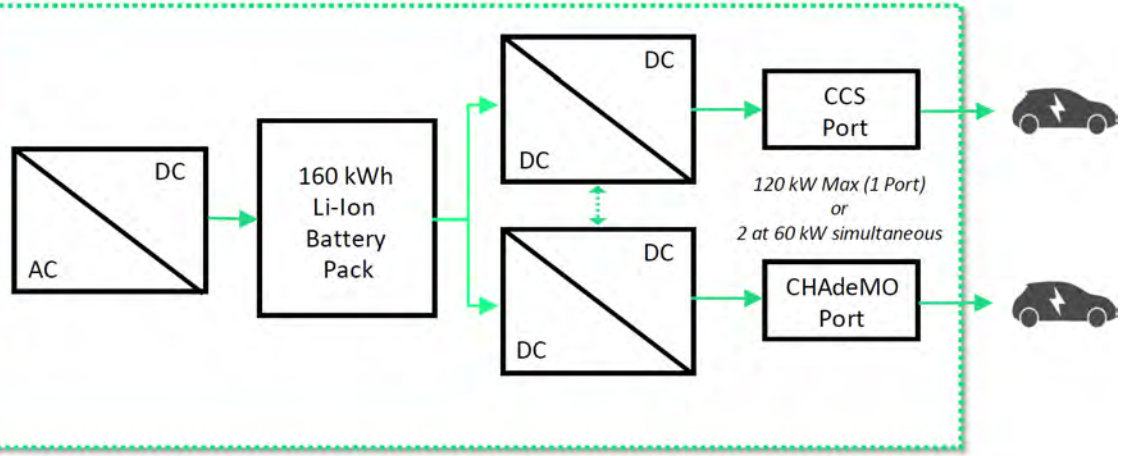
FREEWIRE BOOST CHARGER- SINGLE UNIT VERSION OF DC DISTRIBUTION

How it Works

Low voltage AC power input → AC power converted to DC → Integrated battery discharges → 2 high-efficiency DC converters → Dual connectors for simultaneous fast charging

AC Grid Service

240 or 208 Vac, Up to 27kW

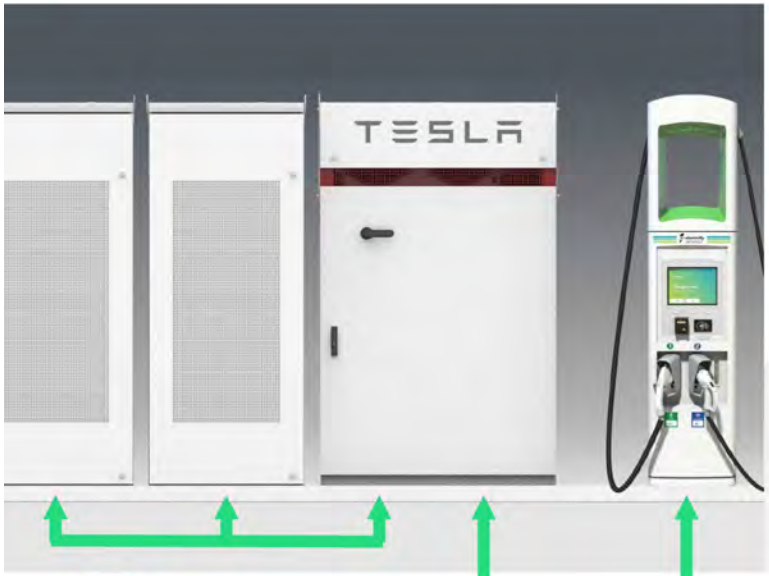


FREEWIRE BOOST CHARGER- FOOTPRINT COMPARISON (FREEWIRE PHOTOSHOP)

18x
More space efficient

- Integrated energy storage and electrical infrastructure means no unsightly and expensive upgrades

FREEWIRE BOOST CHARGER- CO-LOCATED VS INTEGRATED TOPOLOGY



Lower Cost

Fast Deployment

Low Complexity

Small Footprint

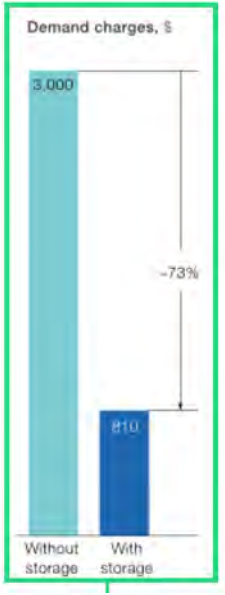
VS

Higher Cost

Slow Deployment

High Complexity

Large Footprint



480V 3⌀
240kW

The alternative approach has significant downsides:
Requires significantly more infrastructure (~10X)
Only addresses demand charges, not infrastructure costs
Requires much larger footprint (~20X)

240V 1⌀ or 208V 3⌀
27kW

VW/DU-POWER NEW ENERGY MOBILE CHARGER W/STORAGE (193KWHR)

http://www.du-power.com/en/products/list.aspx?lcid=1 /

204kW max out, 150kW each
2550 kg/5610lbs; 1.3x1.1x2.2m
7kW, 40kW 220-380vac input

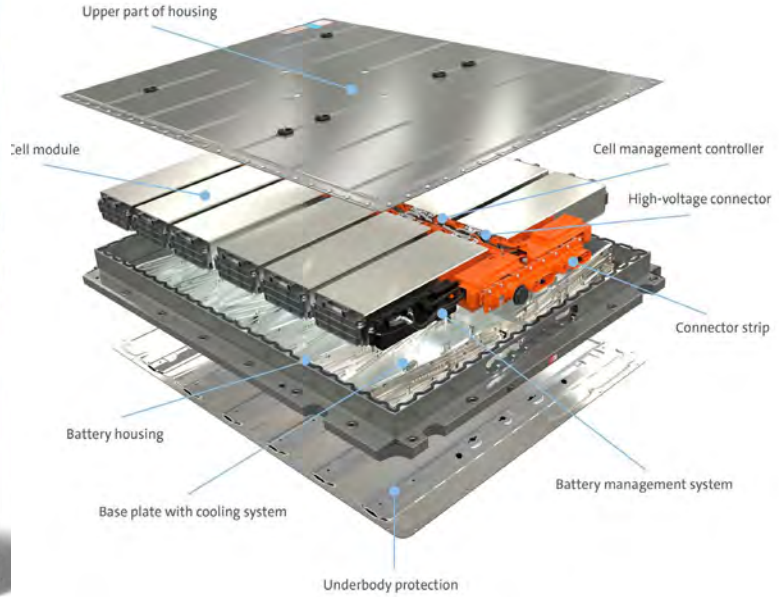
Key Product Features

		AFC-200-LH	AFC-100-AH
KEY	Dimension (M)	1.3×1.1×2.2	1.0×1.0×2.0
	Weight (g)	2550	1500
	IP Grade	Machine: IP55 / Battery Pack : IP67	Machine: IP54 / Battery Pack : IP67
	Assembly of whole machine	Integrated	
Energy supplement system	Single charging power	max 7KW@220V 32A	
	Three phase charging power	max 40KW@380V 63A	
	Voltage platform (V)	DC 200~920	DC 200~750
	Energy storage capacity (KWH)	193	96
Charging system	System Maximum (KW)	204	120
	Single Gun Maximum (KW)	150	80
	Charging distribution	Dynamic switching	
	Number of gun heads	2	
Cooling system	Battery cooling	Liquid cooling	
	Power module	Liquid cooling	Wind cooling
HCI	Screen size	43'	27'
	Touching Screen size	10'	
Other features	EMC Level	CLASS B	CLASS A
	Noise control	<55dB	<75dB
	Networking form	4G/WIFI	
	Form of payment	Credit card , Vin auto identification , APP	
	BMS auxiliary power supply	12V DC	
	safety system	Anti theft door lock, access control switch, water immersion test, collision power failure	
	Interworking protocol	MQTT (CHINA)	

VW/DU-POWER NEW ENERGY; 100-150KW OUTPUT, 360KWHR STORAGE

https://insideevs.com/news/408565/volkswagen-flexible-fast-chargers-china/

1.4 x 1 x 2.4m Using VW MEB battery modules (92kW per vehicle 300kg cell mass)

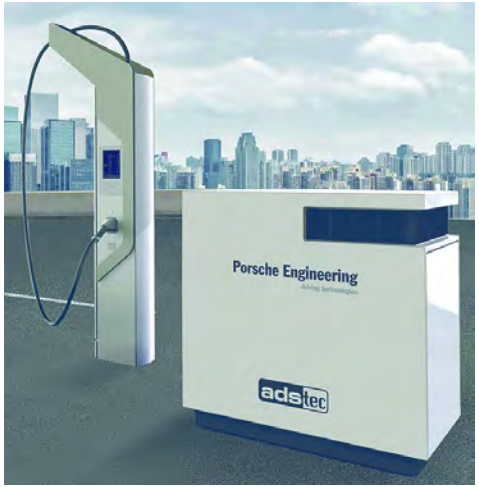


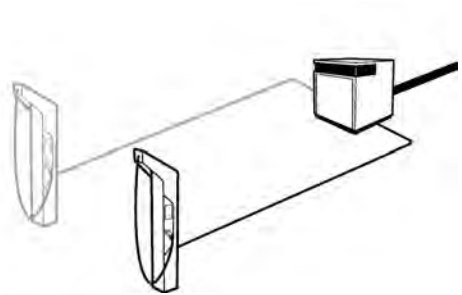
PORSCHE-ADSTEC DC COUPLED STORAGE (NO DEPLOYED PHOTOS FOUND)

https://www.porscheengineering.com/peg/en/services/chargingsolutions/

Reduced to the basics. Optimized for efficiency.

So that the Charge Box can provide sufficient power output for fast-charging, it works with a battery as a buffer. This is ***supplied with 20 to 110 kW from the mains…*** *total power* ***output of 320 kW*** *which can be shared two charging stations. There's also a fully equipped version with* ***140 kWh*** *and two 160-kW charging stations that can be combined for 320 kW.*





TESLA POWER PACK STORAGE INTERNAL CONNECTIONS/SPECS

https://www.intermepro.com/wp-content/uploads/2020/07/Datasheet_Powerpack2-5_All.pdf

Each power pack has 16 pods, isolated DC/DC converter on each; 2199kg, 4847lb
10 x 70kVA inverter for 70kVA grid tied AC power; 1120kg, 2470lb

TESLA POWER PACK STORAGE INTERNAL CONNECTIONS/SPECS

https://www.intermepro.com/wp-content/uploads/2020/07/Datasheet_Powerpack2-5_All.pdf

INVERTER RATINGS

AC Voltage	380–480 VAC 3-phase
Nominal Frequency	50 or 60 Hz
Inverter Size (at 480 V)	Scalable up to 700 kVA

POWERPACK RATINGS

Configuration	Power/Energy[1]	Roundtrip[1] System Efficiency
1.2 hr:	130 kW / 160 kWh	84.5% [2]
1.6 hr	109 kW / 174 kWh	86%
2 hr	108 kW / 215 kWh	86.5%
4 hr	57 kW / 228 kWh	90%

[1] Net energy delivered at 25°C (77°F) including thermal control
[2] Frequency regulation and peak power options, available under certain conditions

MECHANICAL AND MOUNTING

Enclosure	IP67 (Pod) NEMA 3R / IP35 (Powerpack) NEMA 4 / IP66 (Inverter)
Powerpack Unit Dimensions	L: 1308 mm (51.5 in) W: 822 mm (32.4 in) H: 2235 mm (88 in)
Powerpack Unit Max Shipped Weight	2199 kg (4847 lbs)
Inverter Dimensions	L: 1014 mm (39.9 in) W: 1254 mm (49.4 in) H: 2242 mm (88.3 in)
Inverter Max Shipped Weight	1120 kg (2470 lbs)
Operating Ambient Temperature	–30°C to 50°C (–22°F to 122°F)

TESLA MEGAPACK STORAGE INTERNAL CONNECTIONS/SPECS

https://www.tesla.com/blog/introducing-megapack-utility-scale-energy-storage
https://www.intermepro.com/wp-content/uploads/2020/07/Datasheet_Megapack.pdf

- W: 7125 mm (23 ft 5 in) D: 1600 mm (5 ft 3 in)
- 400–480 VAC 3-phase; 2 hr: 1257 kW / 2514 kWh. **4 hr: 739.5 kW / 2958 kWh**
- Max VoC: 1500 Vdc, 2390Adc, 56,000lbs

TESLA MEGAPACK STORAGE INTERNAL CONNECTIONS/SPECS

Flexible offering designed for utility-scale projects

- Modular inverter Powerstages allow greater configuration flexibility
- Supports Capacity Maintenance Agreements (CMA)
- Integrate solar PV with DC coupling (future feature)

Proven inverter and battery technology drives design efficiency

- One Megapack includes up to 17 independent battery modules
- Configurable for 2 to 6+ hour charge/discharge cycles
- Best-in-class site-level energy density

Turnkey solution enables rapid and cost-effective deployment

- Up to 40% expected reduction in EPC costs compared to Powerpack
- Pre-assembled and pre-tested at Tesla's Gigafactory
- No DC connections required onsite

TESLA MEGAPACK SPECIFICATIONS; 3MWHR, 1540KVA, 2390ADC, 1500V

ELECTRICAL

AC Voltage	400–480 VAC 3-phase
Nominal Frequency	50 or 60 Hz
Continuous Charge/Discharge Duration	2 to 6+ hours
AC Power/Energy Available per Megapack[1]	2 hr: 1257 kW / 2514 kWh 4 hr: 739.5 kW / 2958 kWh
Inverter Size (at 480 VAC)	2 hr: Scalable up to 1540 kVA 4 hr: Scalable up to 910 kVA
PV	Interface: Direct DC Coupled Max VoC: 1500 Vdc Max Imp: 2390 Adc

Megapack is a customizable energy system capable of being sized according to customer needs. Below are specifictions for standard system sizes available without customization.

MECHANICAL AND MOUNTING

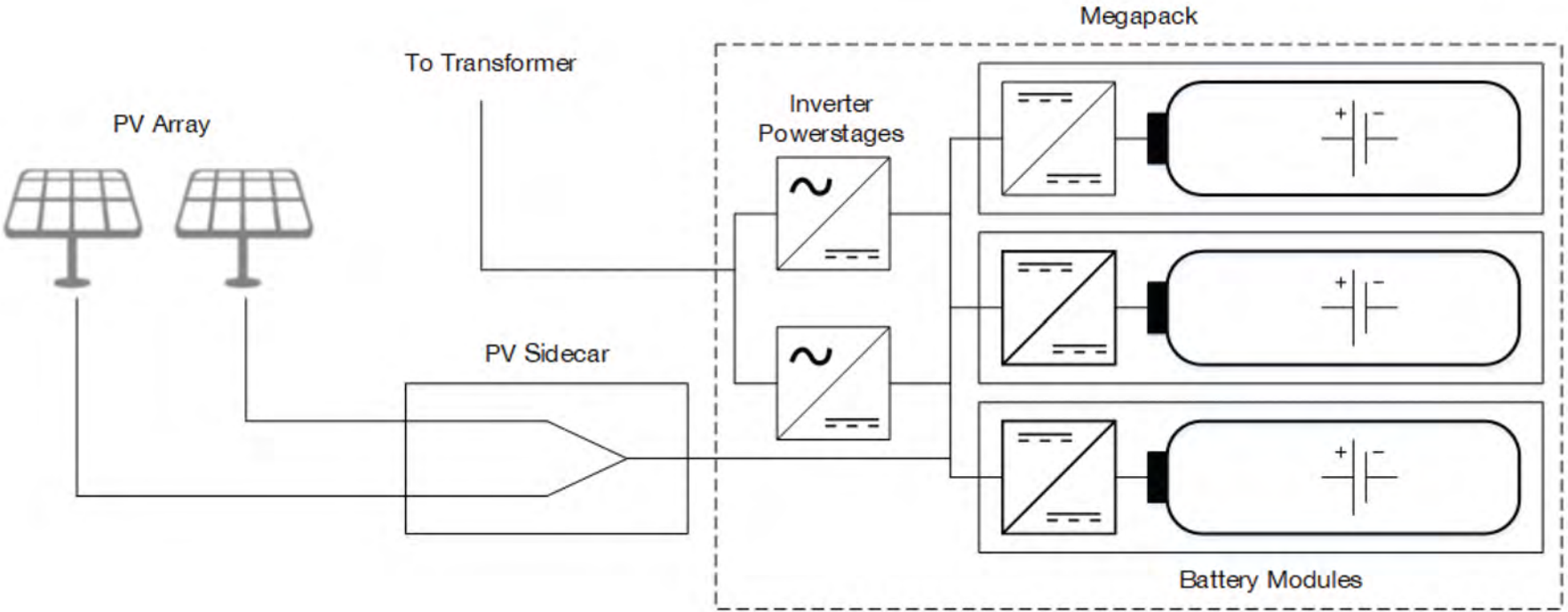
Ingress Ratings	IP66/NEMA 3R (Main enclosure) IP20 (Thermal system)
Unit Dimensions	W: 7125 mm (23 ft 5 in) D: 1600 mm (5 ft 3 in) H: 2516 mm (8 ft 3 in)
Unit Maximum Weight[2]	Standard: 25,400 kg (56,000 lbs) Light: 19,700 kg (43.430 lbs)
Operating Ambient Temperature	–30°C to 50°C (–22°F to 122°F)

[2] Optimized for global payload limits

REGULATORY (Expected Listings)

Lithium-Ion Cells	NRTL listed to UL 1642
System	NRTL listed to UL 1973, 9540, 9540A 1741 SA

TESLA MEGAPACK SPECIFICATIONS; PV-STORAGE TOPOLOGY (DCAAS-LIKE)



TESLA MEGAPACK SPECIFICATIONS; DIRECT PV CONNECTED INPUT

ELECTRICAL - AC INTERFACE

Battery Power/Energy Available (Net AC) per Megapack[1]	Scalable battery module quantity. 2 hr: Up to 1257 kW / 2514 kWh 4 hr: Up to 739.5 kW / 2958 kWh
Shared Solar/Battery Inverter Size (at 480 VAC)	Scalable up to 1540 kVA at 70kVA increments

[1] Nominal energy at 25°C (77°F) including thermal management loads

MECHANICAL AND MOUNTING

Ingress Ratings	IP66/NEMA 3R (Main enclosure) IP20 (Thermal system)
Unit Dimensions	W: 830 mm (2 ft 9 in) D: 1600 mm (5 ft 3 in) H: 2516 mm (8 ft 3 in)
Unit Maximum Weight	500 kg (1100 lbs) for PV Sidecar

ELECTRICAL - PV DC INTERFACE

PV Interface Type	Direct DC Coupled, via Tesla provided PV Integration Unit No PV DC/DC Converter
PV Interface Ratings	Max VoC: 1500 Vdc Max Imp: 2390 Adc
Maximum Power Point Tracking	MPPT Min V: 734 Vdc MPPT Max V: 961 Vdc Curtailment via MPPT or zonal disconnects
PV Inputs	Input Zone Count: 16 Input Size: 250-400 Adc Contactors and IGBT disconnects per zone Zonal current and voltage monitoring

COMMUNICATIONS

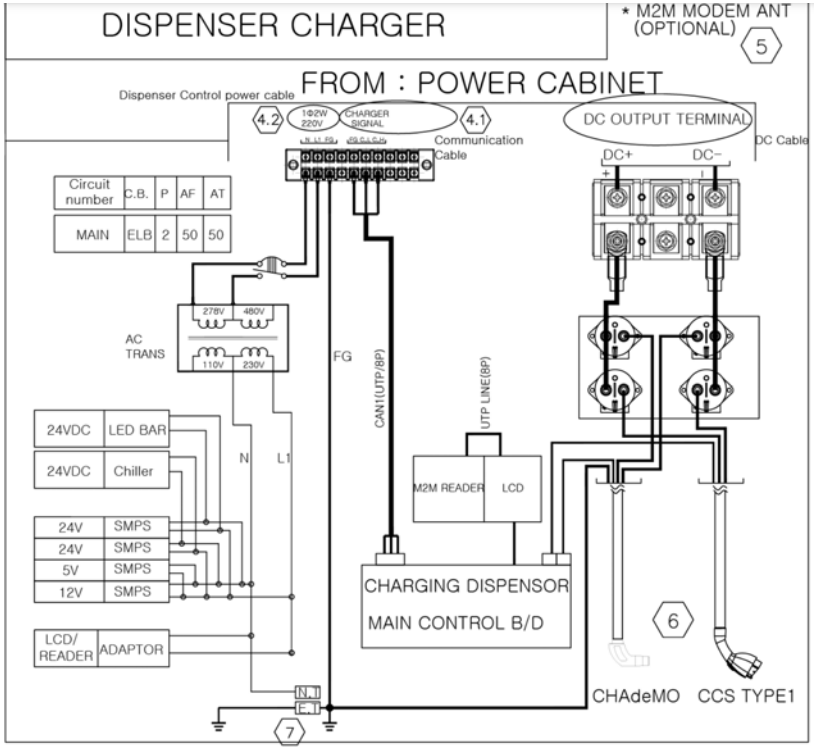
Protocol	Modbus TCP DNP3

BACK UP MATERIALS

WHAT'S INSIDE A DC EVSE? (CONVERTER/ DISPENSER)

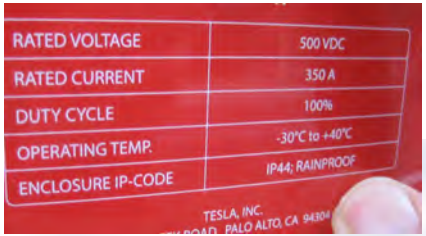
Parallel Modules
AC/DC converters, comm.

User kiosk with payment-
display, cables, cooling, meter



TESLA SUPERCHARGER INSTALLATION- COMPLETED MG&E, MADISON WI

- Row of 8 (250kW) dispensers; liquid cooled cables, enclosure around switchgear/2x350kW linked converters

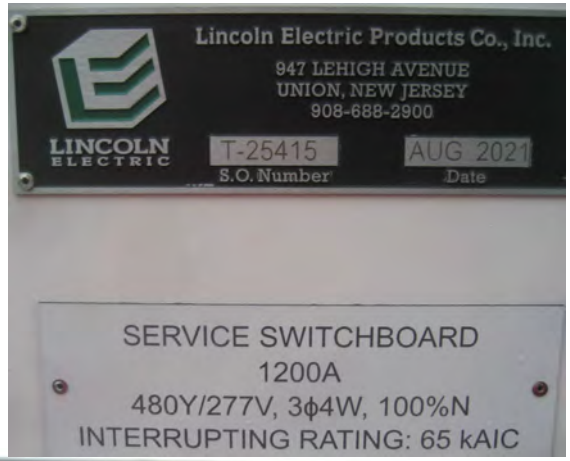


TESLA SUPERCHARGER, SITE PERSPECTIVE IMAGES

- Precast transformer pad; 1MVA transformers, (13kV primary wires shown)
- 8cu. yards concrete used to form on-site pad for converters/switchgear
- Precast bases for 8x dispensers, steel layout template for placing conduits

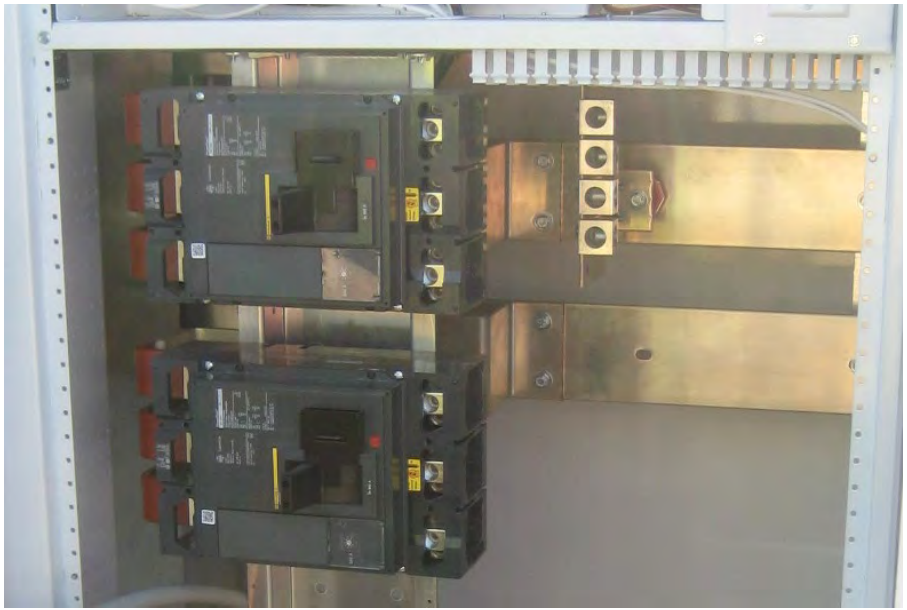
TESLA SUPERCHARGER COMPONENTS- SWITCHGEAR

- 1200 A feed from transformer; CTs inside, meter on outside
- Schneider 1200A main circuit breaker



TESLA SUPERCHARGER COMPONENTS- SWITCHGEAR

- Panel board side; dual 600A circuit breaker for each power converter; 2x 500mcm cables, 3 conductors, PE
- Telemetry on circuit monitoring, condensation heater



TESLA SUPERCHARGER COMPONENTS- CONVERTERS TO FEED DISPENSERS

- 2x 350kVA input, DC link to share ~1000vdc link (700kW)
- Red/black output cables to dispensers (2x2/0 aluminum)
- Yellow/orange 480vac input conductors (2x 500mcm)
- 480vac input-to-~1000vdc converters (5x70kVA) in upper right section
- ~1000vdc to ~400vdc DC/DC converters (lower right) 8x125kW modules

TESLA MCS CHARGING INSTALLATION-NEVADA

Lots of white-on-white trucks, chargers, bollards; 4x vehicles-lans-dispensers

TESLA MCS CHARGING INSTALLATION-NEVADA

https://twitter.com/hwfeinstein/status/1460365764754436097?s=20

- Twitter images- first two kiosks, limited detail
- Note height, cable length (2 meters?)
- Fuzzy photo of MCS plug

TESLA MCS CHARGING INSTALLATION-MODESTO

- ~7ft high dispensers, cable diameter/coupler shape observations (MCS V2.4); 2” diameter cable (8”w kiosk?)

TESLA MCS CHARGING INSTALLATION-MODESTO

- Frito Lay/Pespico fleet, transformer, switchgear, converter array, Megapack battery
- 8x sets; (500kW ea?=4MW total?), 4 dispensers=1MW each?; 2.5MVA+megapack

TESLA MCS CHARGING INSTALLATION-MODESTO

- Frito Lay/Pespico fleet; switchgear, aux transformer power, converters, dispenser