Solid-State-Transformer Technology Implemented Medium Voltage Input Extreme Fast Charger for EV Charging Applications

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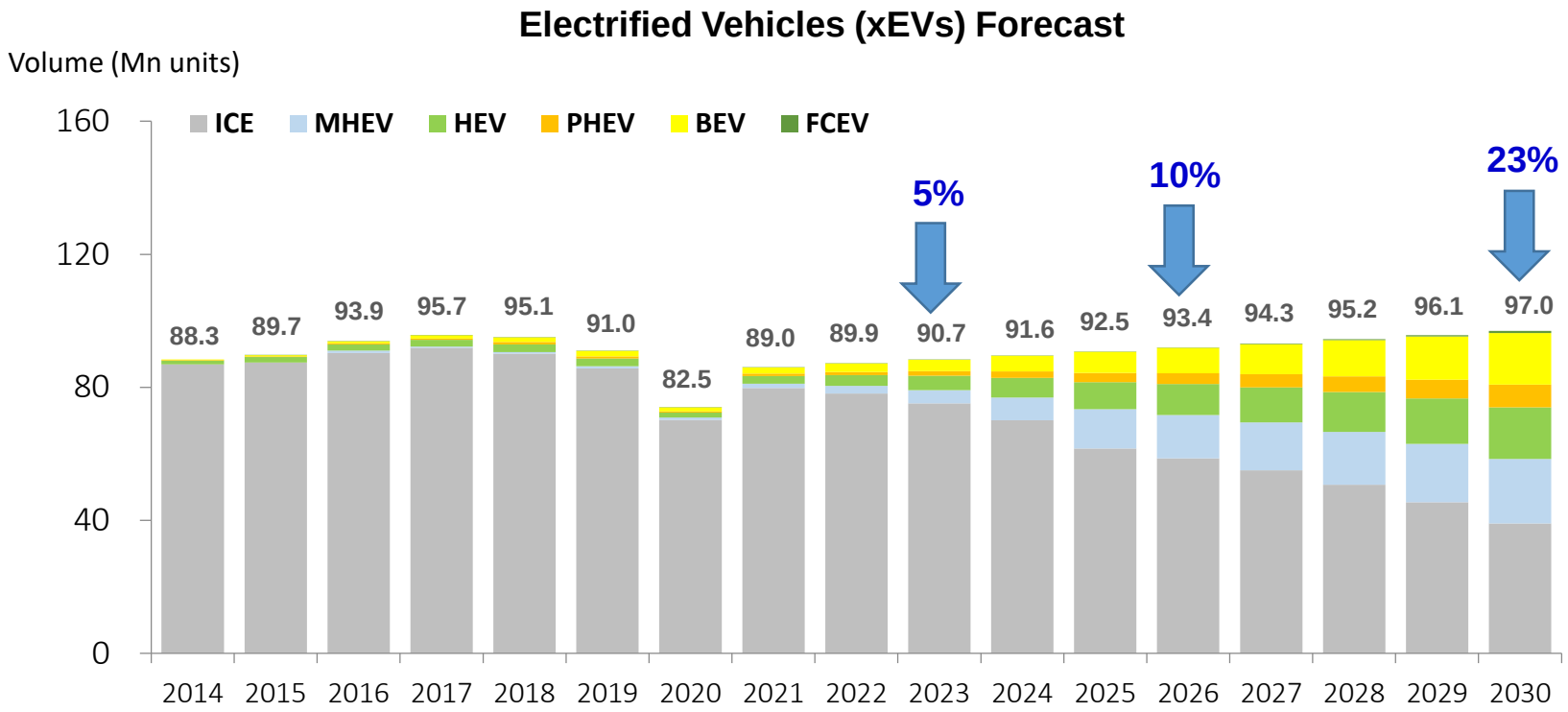
PHEV and BEV Penetration



Source: BCG(2020), BNEF (2019), Frost & Sullivan (2019), IEA (2019), SMD_MI

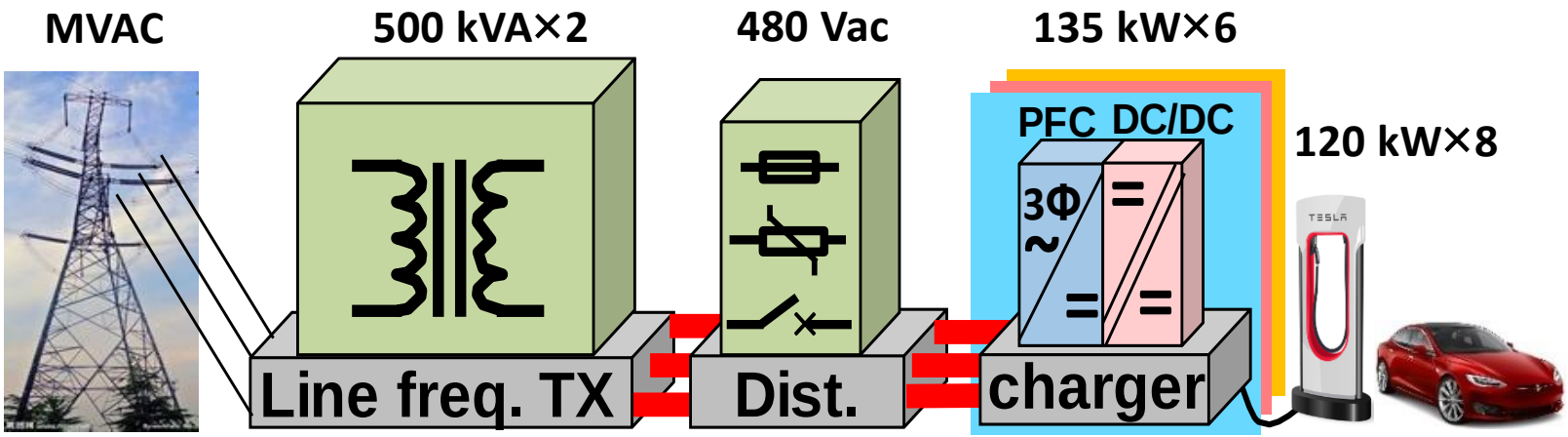
https://www.slideshare.net/TheBostonConsultingGroup/the-electric-car-tipping-point-81666290

Key Objectives of the DOE 400 kW XFC Program

- ❑ Medium-voltage-input, MVAC at 4.8 kVac or 13.2 kVac
- ❑ Solid state transformer (SST)-based 400 kW/1000 Vdc/400 Adc EV extreme fast charger
- ❑ Local energy storage systems and/or renewable energy integration
- ❑ Charging speeds of 3C, or above
- ❑ To achieve a 180 mile charge within 10 minutes

DOE Program #: DE-EE0008361

Conventional DC Fast Charger System



Efficiency:	99%	×	99.3%	×	95%	=	93.4%
Footprint:	50 sqft	+	40 sqft	+	20 sqft	=	110 sqft

Conventional DC Fast Charger System

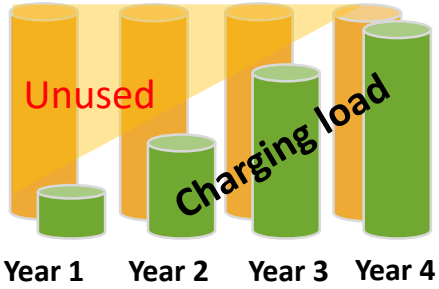
1 MVA

13 kVac

480 Vac

Installation site for Tesla Super Charger in US

TX Capacity

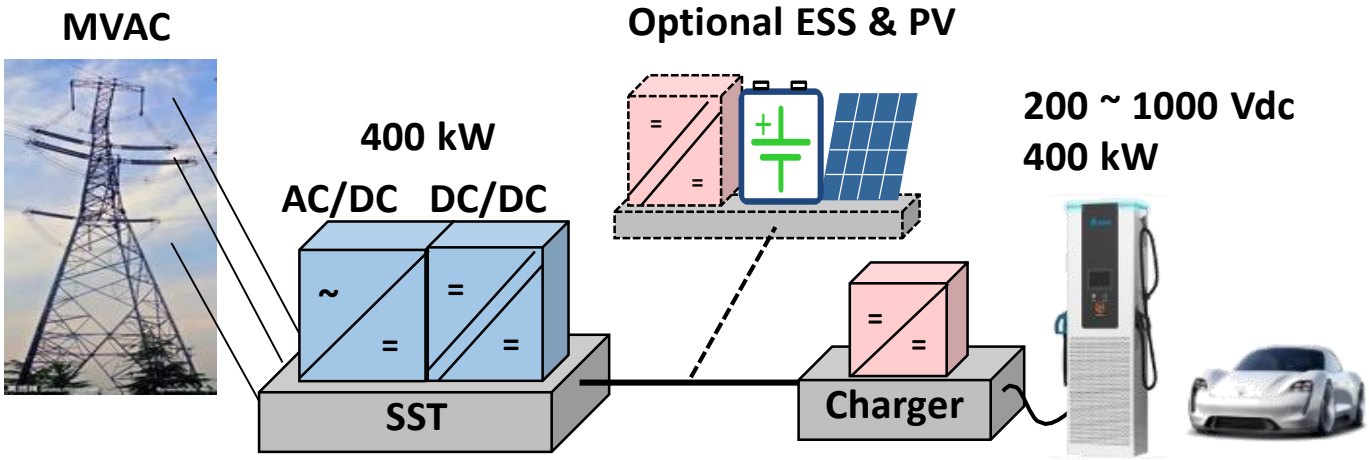


- Bulky and heavy
- Fixed voltage & power

- Space consuming
- Labor intensive

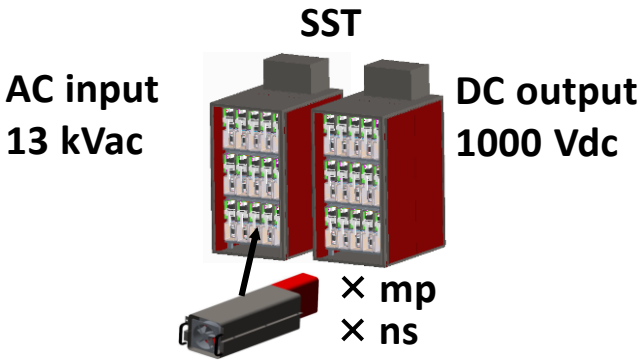
- Non expandable capacity
- High initial investment

Proposed Extreme Fast Charger Solution

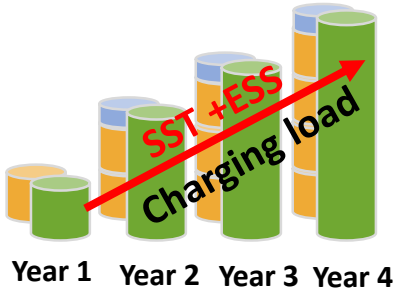


Efficiency	97.5%	×	99%	= 96.5%	Increased efficiency by 3%
Footprint:	28 sqft	+	10 sqft	= 38 sqft	Reduced footprint by 50%

Proposed Extreme Fast Charger Solution



Conceptual SST based extreme fast charging station



- Modularized structure
- Scalable voltage/power

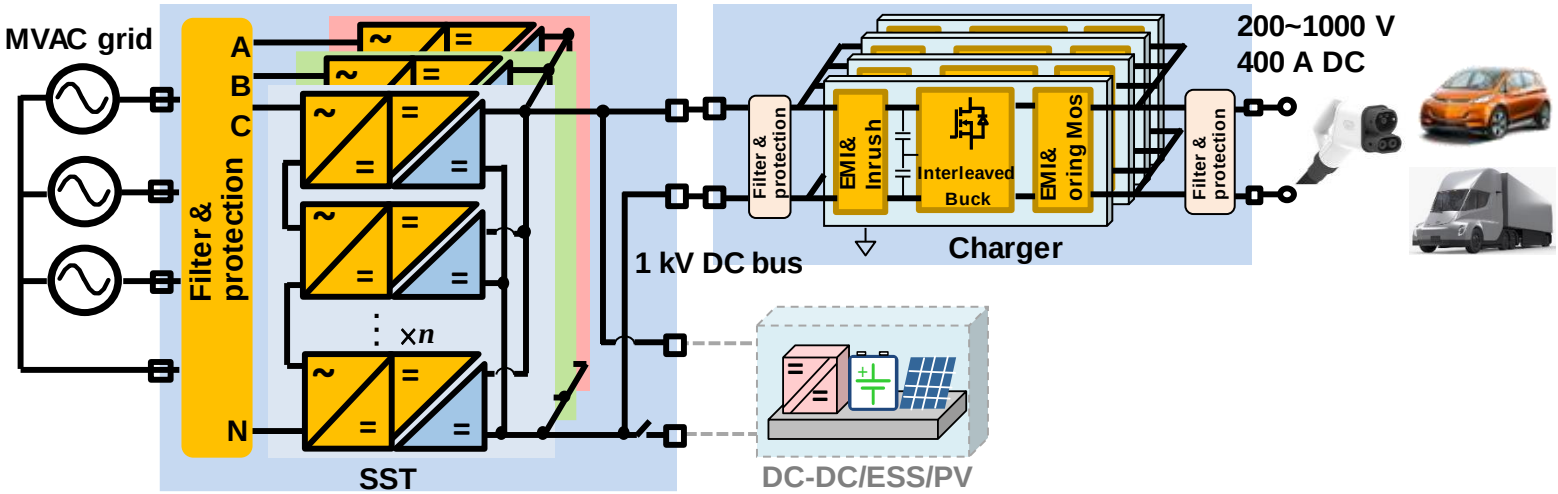
- Smaller footprint
- Easier installation & deployment
- ESS and renewable energy
- Less impact to grid

- Expandable capacity
- Lower initial cost

400 kW XFC Specification

Power Rating	400 kW
Input AC Voltage	4.8 kVac and 13.2 kVac, 3-Phase, line-to-line
AC Line Frequency	60 Hz
HV Battery Voltage Range	200-1000 Vdc
Maximum Output Current	400 Adc
Efficiency	96.5% peak
Charge Interface	J1772 CCS1
Operational Ambient Temperature Range	-25 to 50°C
Environmental Protection	NEMA 3R (outdoor)
Additional Interface	HVDC interface to Energy Storage System(ESS) / Renewable Energy Source

SST based XFC System Structure



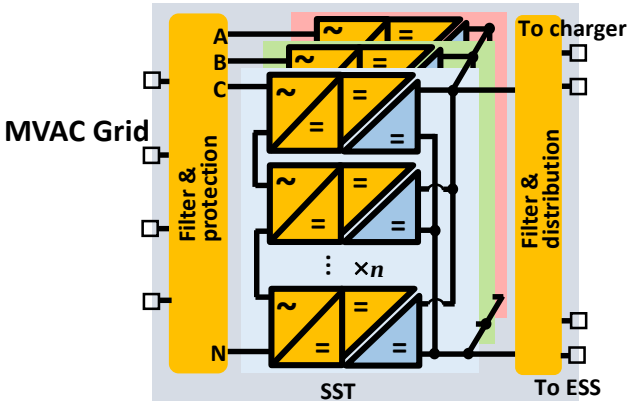
- 3-Φ MVAC input:
- 4.8 kV/13.2 kV
- iTHD < 5%, PF ≥ 0.98
- 60 Hz ± 10%

- SST DC output:
- 400 kW power
- Interface for ESS/PV

Charger output:
- 200 ~ 1000 Vdc
- 400 Adc max current
- SAE J1772 charging interface CCS1

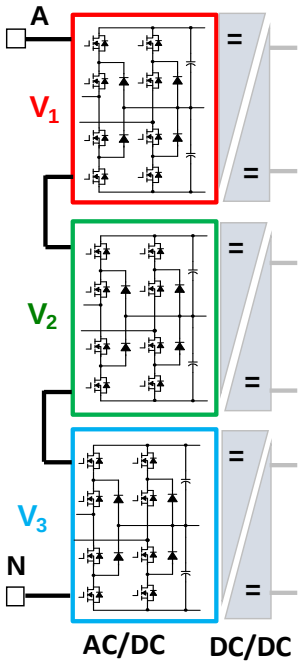
System Level Topology and Control

Series input paralleled output (SIPO) structure



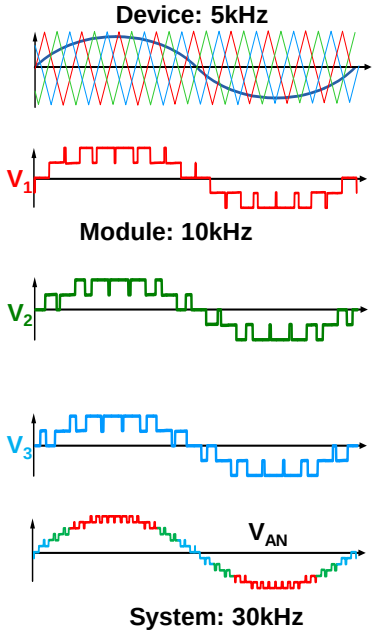
4.8 kVac, 3×3 cells per phase
13.2 kVac, 1×9 cells per phase

- Scalable structure
- Redundant operation



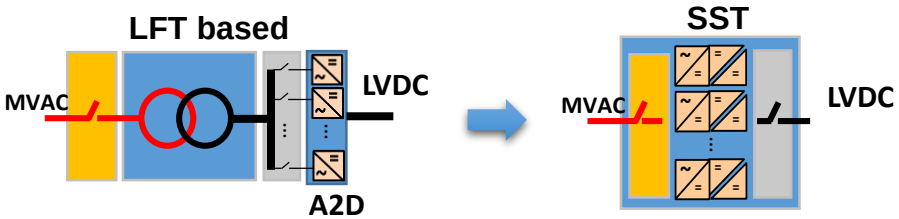
- 3-level Diode Neutral Point Clamped (DNPC) AC/DC
- Fewer isolation components
- Simpler system structure

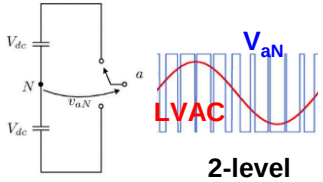
Phase-shifted modulation

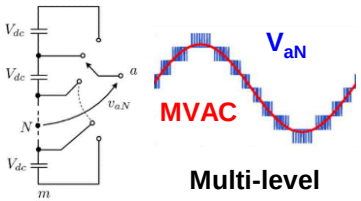


- fsw multiplied by 2N. N stands for number of modules
- Better THD, smaller filter
- Lower fsw for higher η

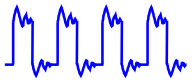
Technical Challenges for SST



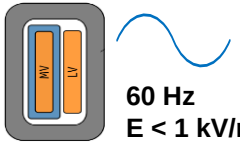




Si IGBT
f_{sw}< 40 kHz
dv/dt < 10 kV/µs
480 Vac input



SiC MOSFET
fsw>100 kHz
dv/dt>50 kV/µs
13.2 kVac input



60 Hz
E < 1 kV/mm

60 Hz + 200 kHz
E > 4 kV/mm

System

- Scalable design
- MV grid fault tolerance
- Balance for multiple cells

Power module

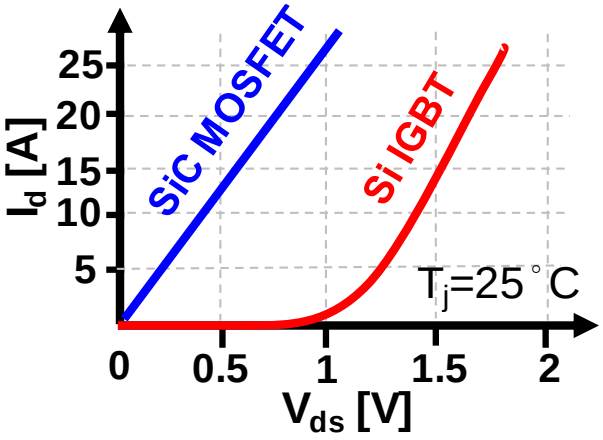
- High efficiency, high frequency
- Noise & dv/dt with SiC

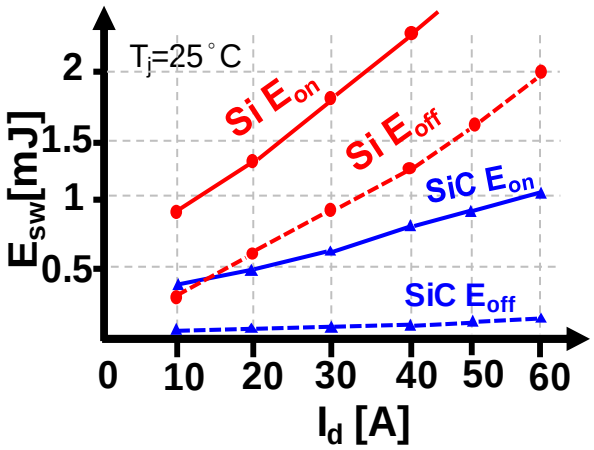
Insulation

- Concentrated E-field
- Partial discharge

High Voltage/High Frequency Switching

Property of SiC vs. Si Device

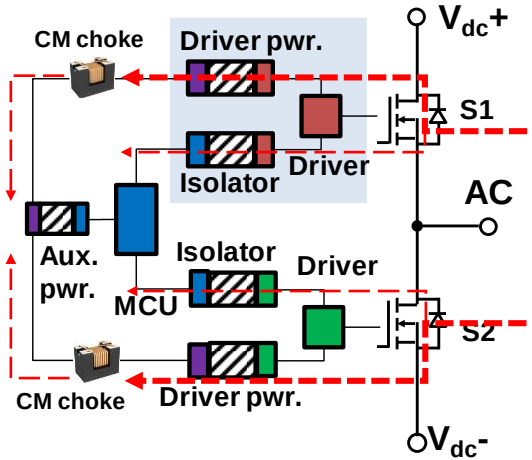




- Low conduction loss
- Low switching energy

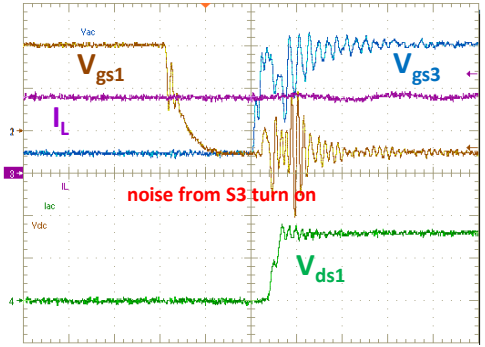
High Voltage/High Frequency Switching

SiC gate driver design



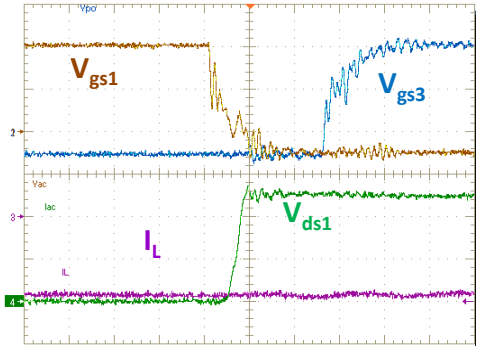
- Controlled EMI propagation path
- Higher CM noise immunity

Problem w/ SiC Device



- High dv/dt and EMI noise

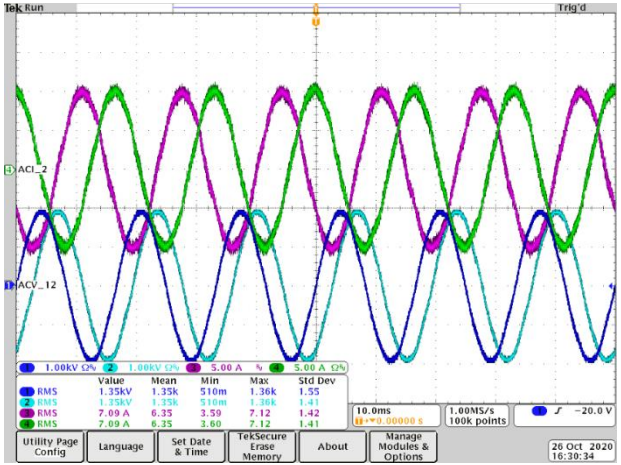
SiC driver w/ SiC device



- Improved switching transient
- Reduced false triggering risk

Experimental Waveforms

AC/DC stage waveforms (Line Cycle)



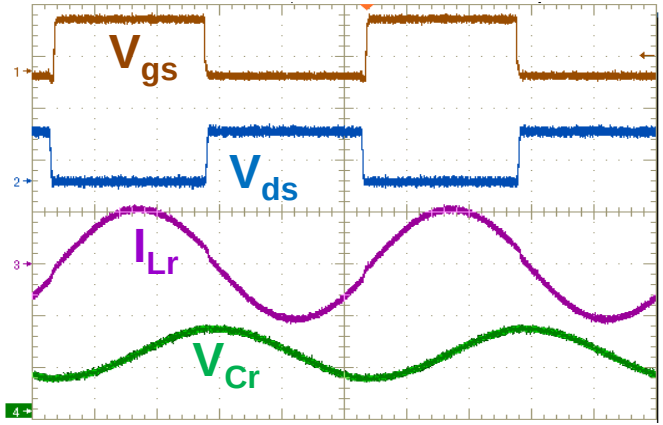
Input Phase Currents

Input Line Voltages

Isolation Probe attenuation is 10,000:1 (DP30-10k-LVC)

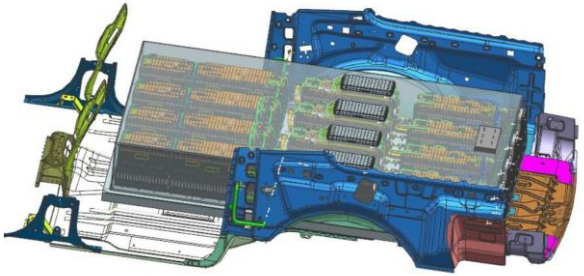
- Good THD and power factor at AC grid side

DC/DC stage waveforms (Switching Cycle)



- Soft Switching for high efficiency at high switching frequency

Retrofit Vehicle RESS/HVDS System



Battery Cells / Modules

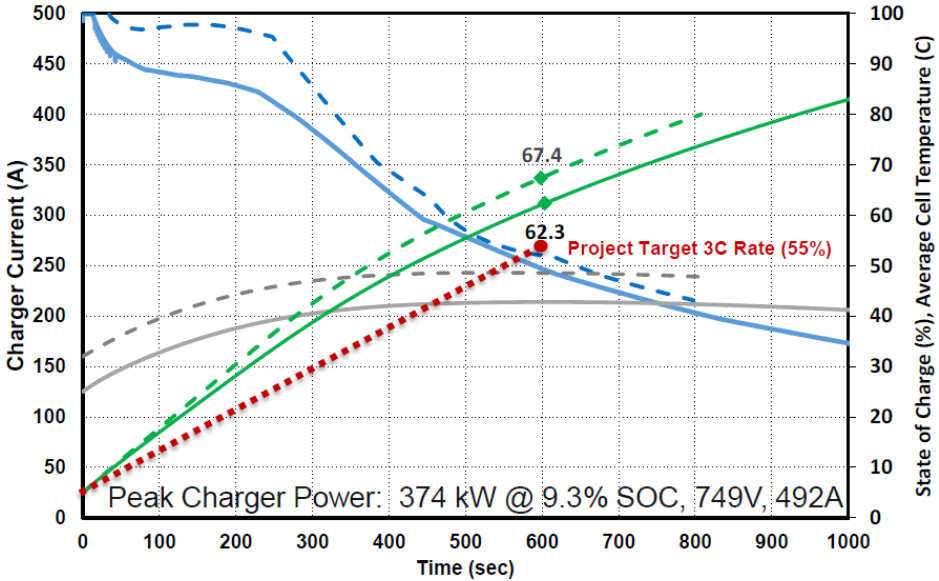
Retrofit BEV Vehicle in Progress

Battery Module Configuration

- 768 Volt cells to achieve >3C charge rate
- 192 series, 4 parallel string configuration for 800 V charging

- ***Courtesy of DOE Program partner General Motors***

Vehicle Charging Profile Analysis Result



Charger Current, 25C Initial Temp — Charger Current, 32C Initial Temp
Cell Temperature, 25C Initial Temp — Cell Temperature, 32C Initial Temp
State of Charge, 25C Initial Temp — State Of Charge, 32C Initial Temp

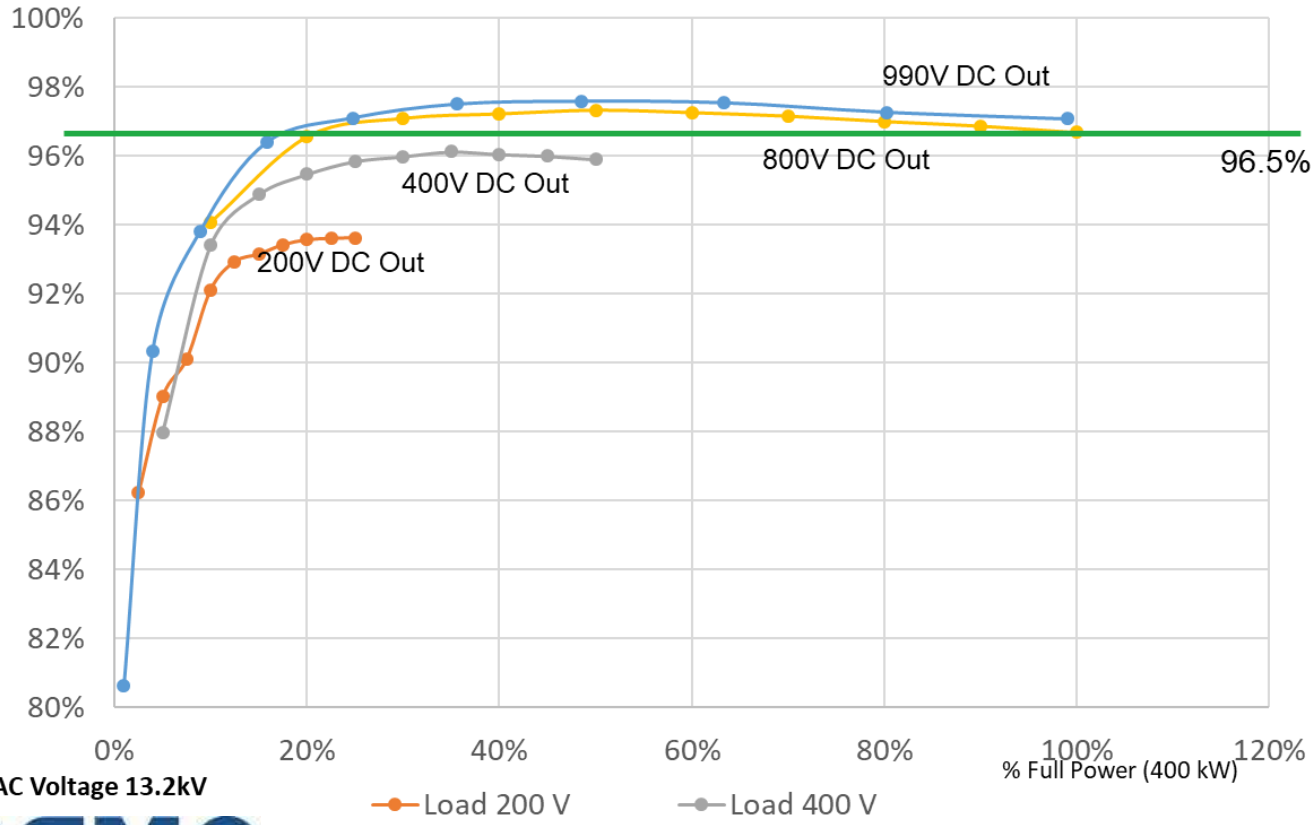
SOC increased by 57.3% and 62.4% respectively in 10minutes. The target is 50%.

400 kW SST XFC System Testing

- **Completed full power test**
  - **Input 13.2 kVac,**
  - **Output 200 - 1000 Vdc, 400 kW,**
  - **Peak efficiency 97.5%**

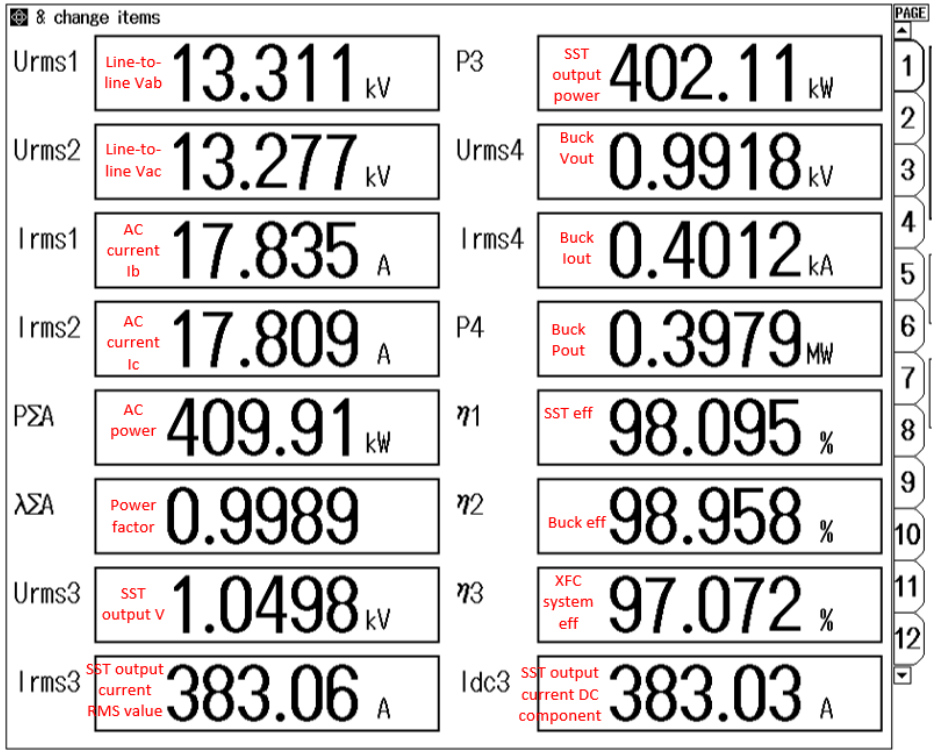
- ***Courtesy of DOE Program partner NextEnergy Test Site***

System Efficiency (SST + Buck Converter)



AC Voltage 13.2kV

System Efficiency (SST + Buck Converter)



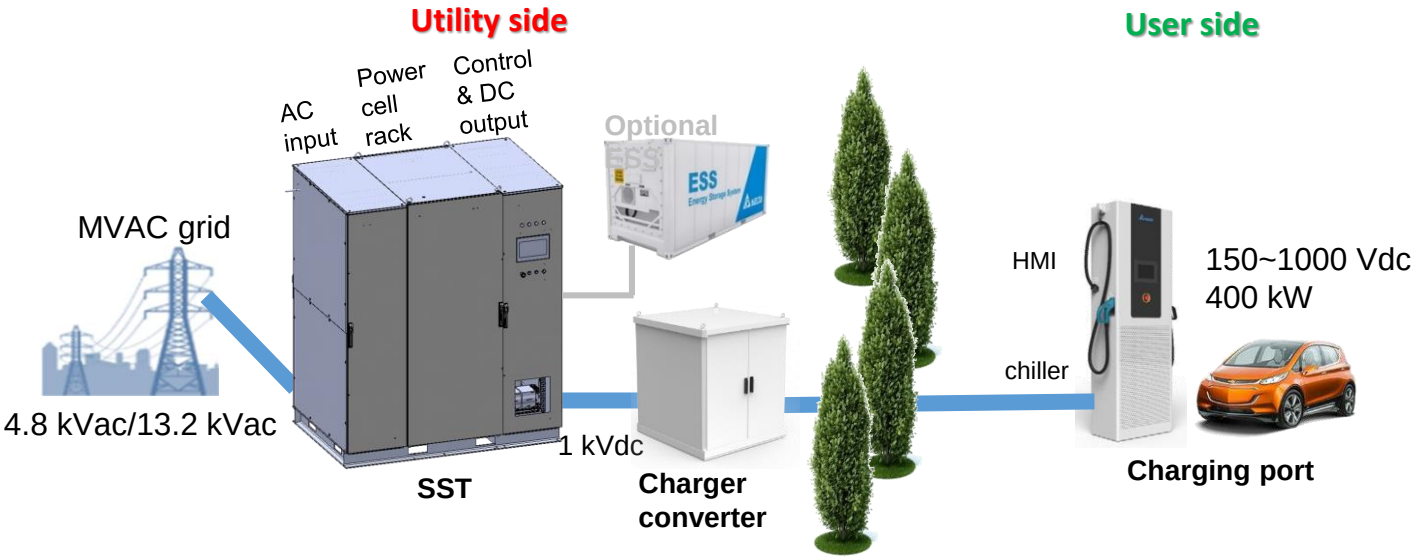
- **Power Analyzer Measurement**
- **Yokogawa WT-1800**

DCFC Vehicle Charging Test with Chevy Bolt

- **Completed vehicle charging communication test**

- Courtesy of DOE Program partner General Motors Bolt Vehicle

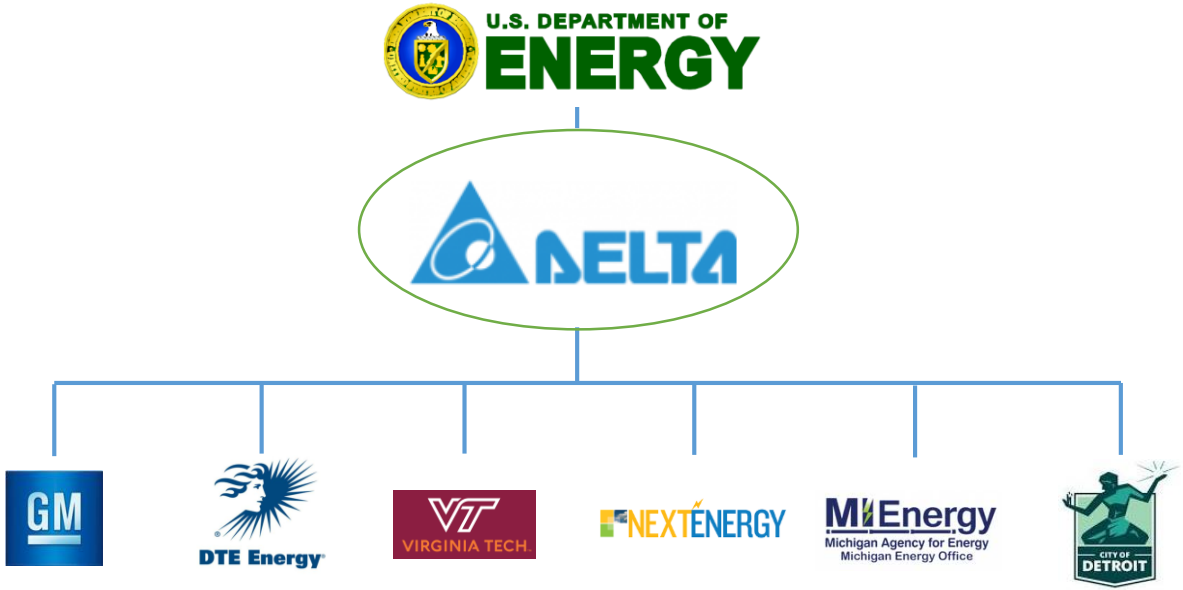
Future XFC System Application



Summary

- A solid state transformer (SST) technology has been introduced for XFC
  - Input 13.2 kVac,
  - Output 200 – 1000 Vdc, 400 kW/400 Adc
- SST enabled 50% footprint reduction and reached 97.5% peak efficiency
- EMI issues has been resolved with novel gate drive design
- SiC device has been utilized in the design with soft switching technology
- Vehicle charging test has been completed

Acknowledgement to the DOE Program Partners



DOE Program #: DE-EE0008361

Thank you!