Cyber Security of DC Fast Charging: Potential Impacts to the Electric Grid

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Relevance of Cyber Security for High Power EV Charging

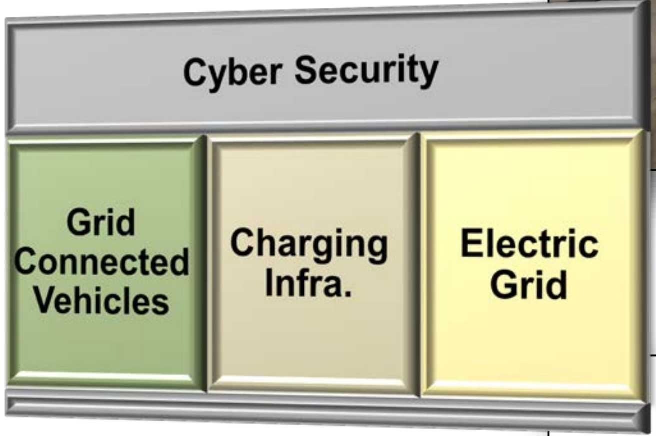
1. Public Safety
   - High voltage & high current charging infrastructure

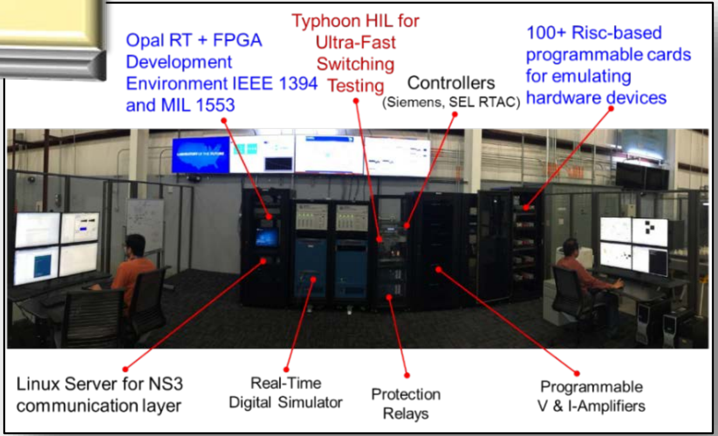
2. Potential wide spread grid impact
   - Intermittent high load: ranging from 50kW to 350+ kW
   - Increasing deployment of fast chargers to meet needs of increasing EV market adoption

3. Consumer confidence in charging infrastructure
   - Reliability and robustness required to reduce range anxiety

INL Capabilities:
EV Charging Grid Integration Research

- **Charging Infrastructure Evaluation**
  - Operational performance & dynamic response evaluation
    - Conductive (L2, DCFC, XFC)
    - Wireless power transfer (WPT)
- **Dynamic Evaluation & Analysis**
  - Power hardware-in-the-loop real time emulation
    - Communication
    - Dynamic transients
    - Power Electronics
- **Cyber Security R&D**
  - End-to-End research methodology
    - Integrated risk management
    - Consequence-driven Cyber-informed engineering (CCE)
    - Strategy development to close attack vector & gaps

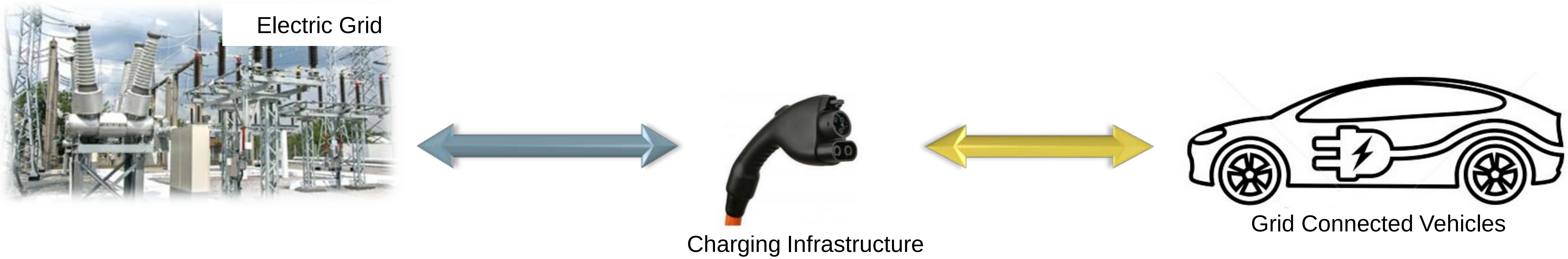




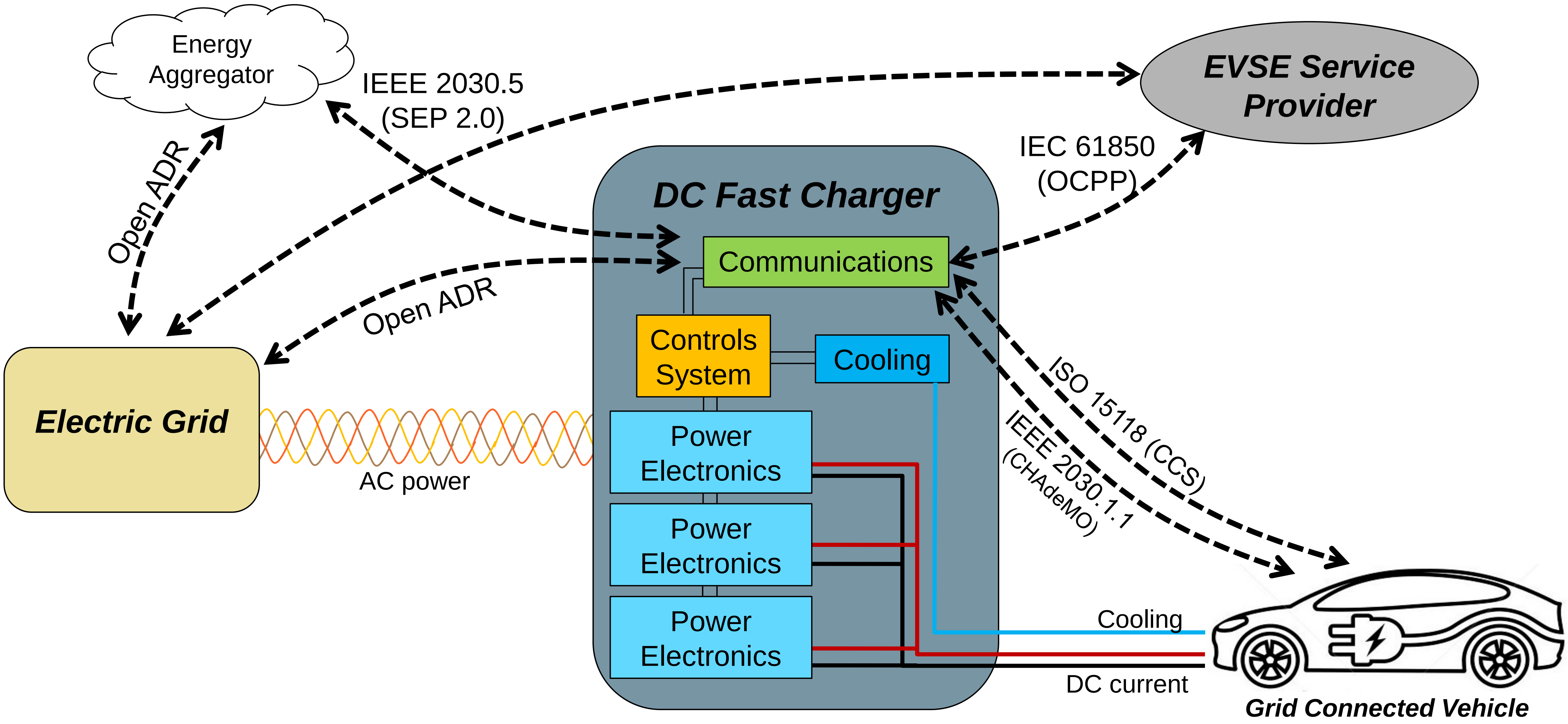
<u>INL's Capability</u>: Identify and mitigate EV charging infrastructure vulnerabilities capable of compromising electric grid resiliency and reliability

Cyber Security:
Electrified Transportation Charging Infrastructure

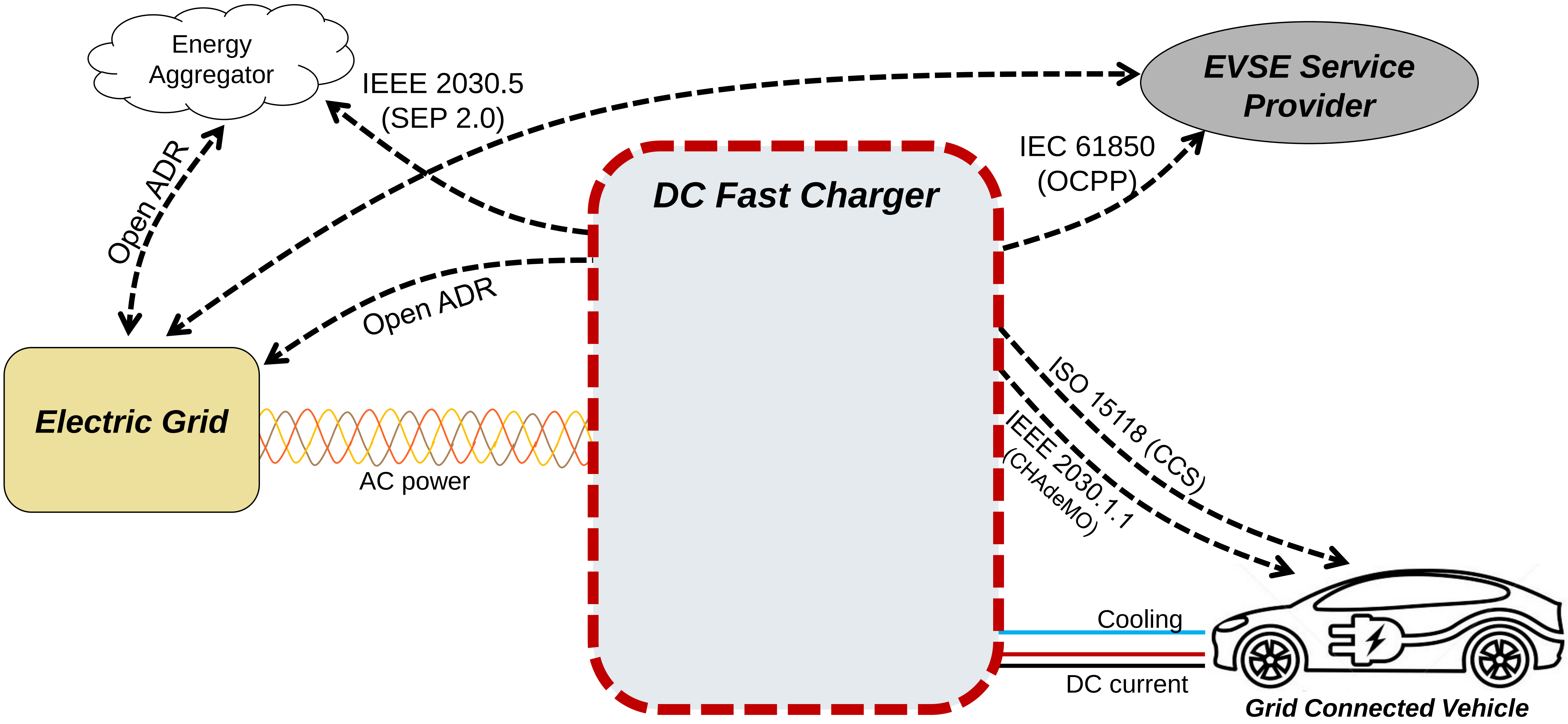
- **Vulnerabilities (Pathways and Attack Vectors)**
  - System vulnerabilities
    - Communications pathways (vehicle to EVSE, EVSE to smart grid, etc.)
    - Controls systems (power electronics, energy management, thermal controls, etc.)
    - Physical vulnerabilities (access control, electrical, thermal, etc.)
- **Risk, Threats, & Impacts**:
  - *Moderate*: denial of service (no charging)
  - *Extensive*: hardware damage / destruction
  - *Severe*: human safety; wide-spread disruption of electrical power distribution / transmission
- **Mitigation Strategies & Solutions:**
  - Prioritize mitigation of exploitable and high risky vulnerabilities



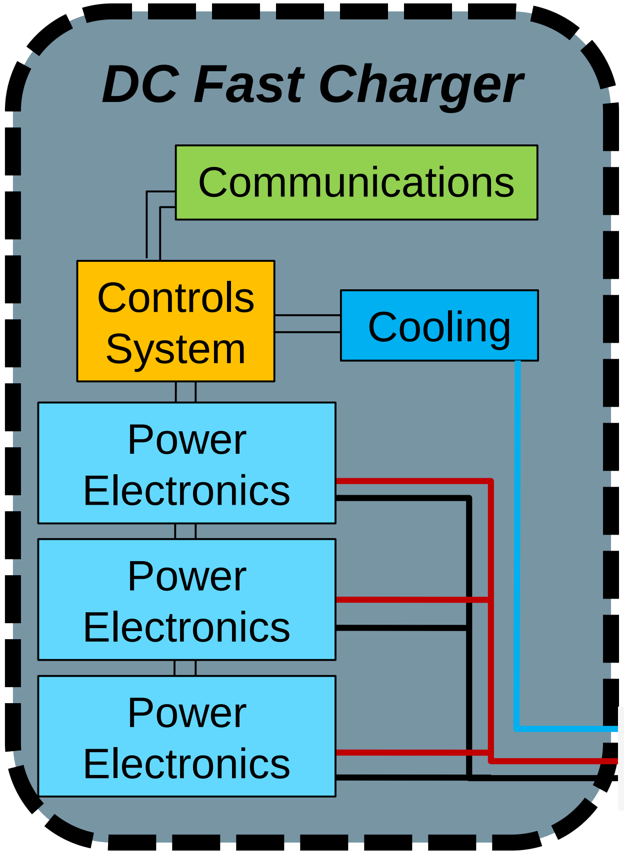
EV Charging Communications and Controls



External Attack Surfaces and Attack Vectors



Internal Attack Surfaces and Attack Vectors



Project Scope

- Identify and evaluate high risk vulnerabilities of 50 kW DC Fast Charging system (DCFC)
  - Scope to date: internal attack vectors
    - power electronics, internal controls systems, and internal communications
- Determine extent of possible impacts
  - Hardware damage
  - Impacts to electric grid
- Develop cyber-informed engineering methodologies

- Evaluation of production DCFC (50 kW) with J1772 CCS and CHAdeMO
- Vehicles utilized during evaluation
  - 2014 EV with CHAdeMO
  - 2015 EV with J1772 CCS

Photo source: Nissan

Photo source: CHAdeMO

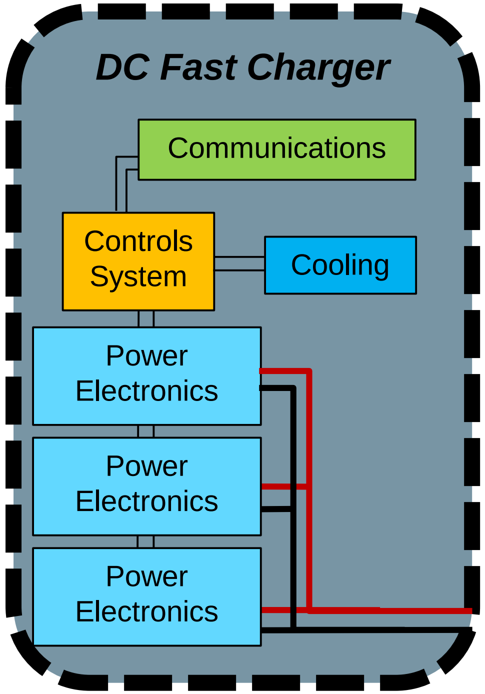
Photo source: BMW

SAE Combo (CCS)

Photo source: SAE International

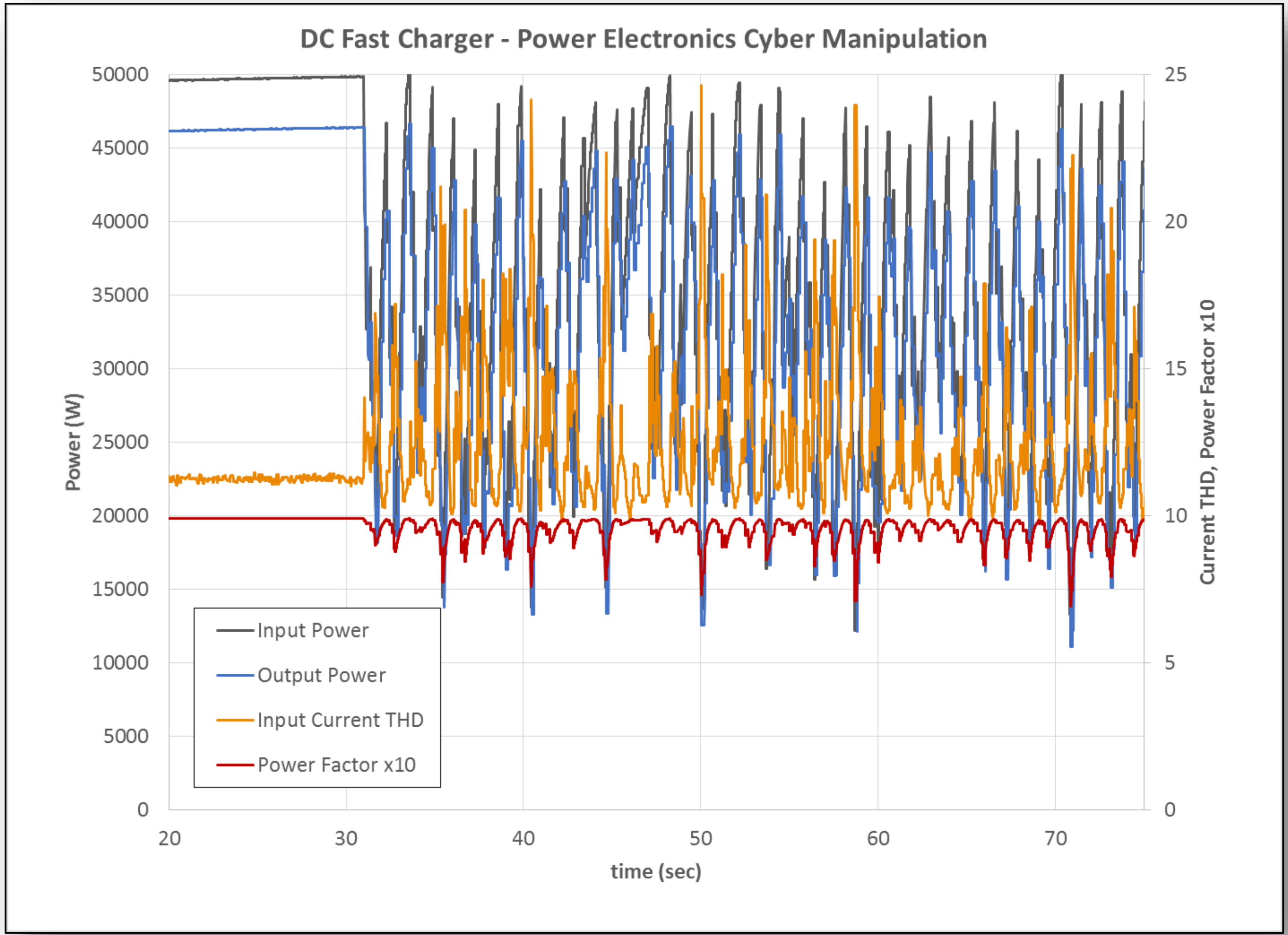
Attack Vectors - DCFC

- Minimal details presented: do not publically disclose detailed malicious information
  - DCFC internal power electronics communications are disrupted
    - Using off the shelf communication tools (send & receive messages)
    - “Man in the middle” module was not used
  - After physical access was obtained (open DCFC enclosure), connection was easily made to the single internal communications network
  - With remote access achieved, same control manipulation is enabled since the HMI is connected to the single internal communications network
- Able to manipulate modular power electronics controls system inside DCFC
  1. Disrupt controls coordination between power electronics modules
  2. Simultaneously turn off all power electronics modules
- Unable to directly control high speed switching inside the power electronics modules
- Unable to over charge the EV (excessive current over EV requested current)
  - EV stopped charge event: shut down command or opening battery contactors



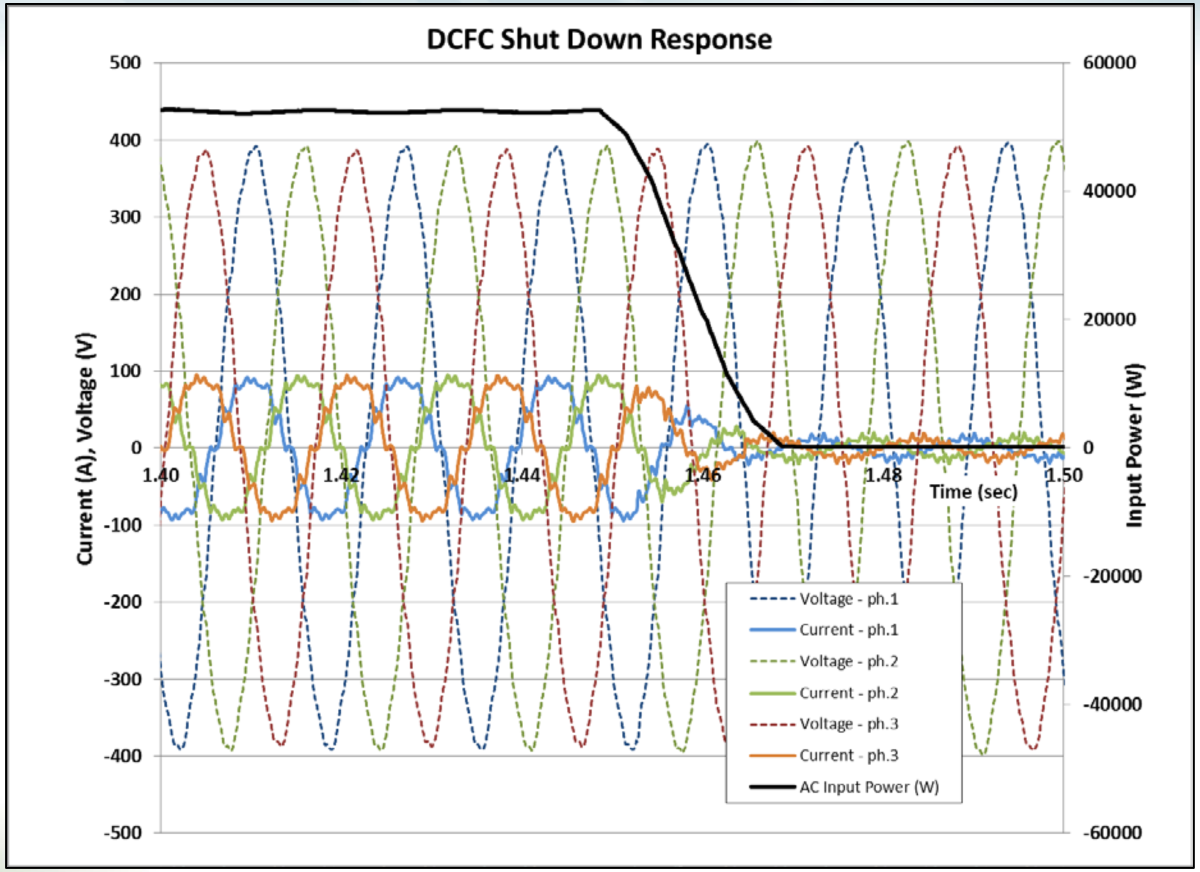
Recent Results and Findings

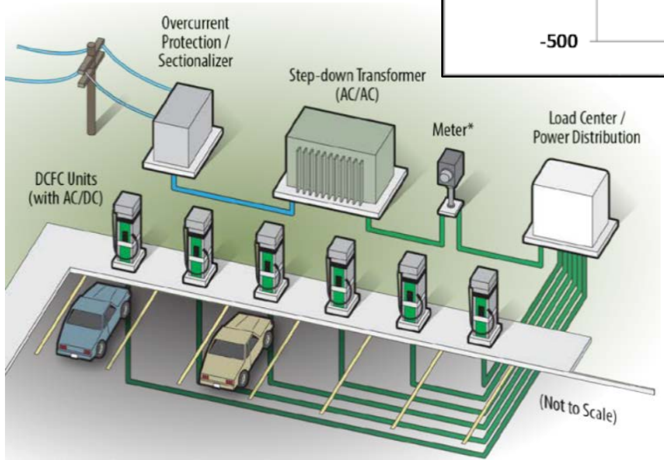
- Disrupt controls coordination between power electronics modules
- Response of the DCFC:
  - Fluctuation of:
    - Input power from grid
    - Input power quality
      - Power Factor
      - Current THD
    - Output power to EV
  - Results in power quality outside of industry limits
    - Power Factor: <0.8
    - Current THD: > 20%



Recent Results and Findings

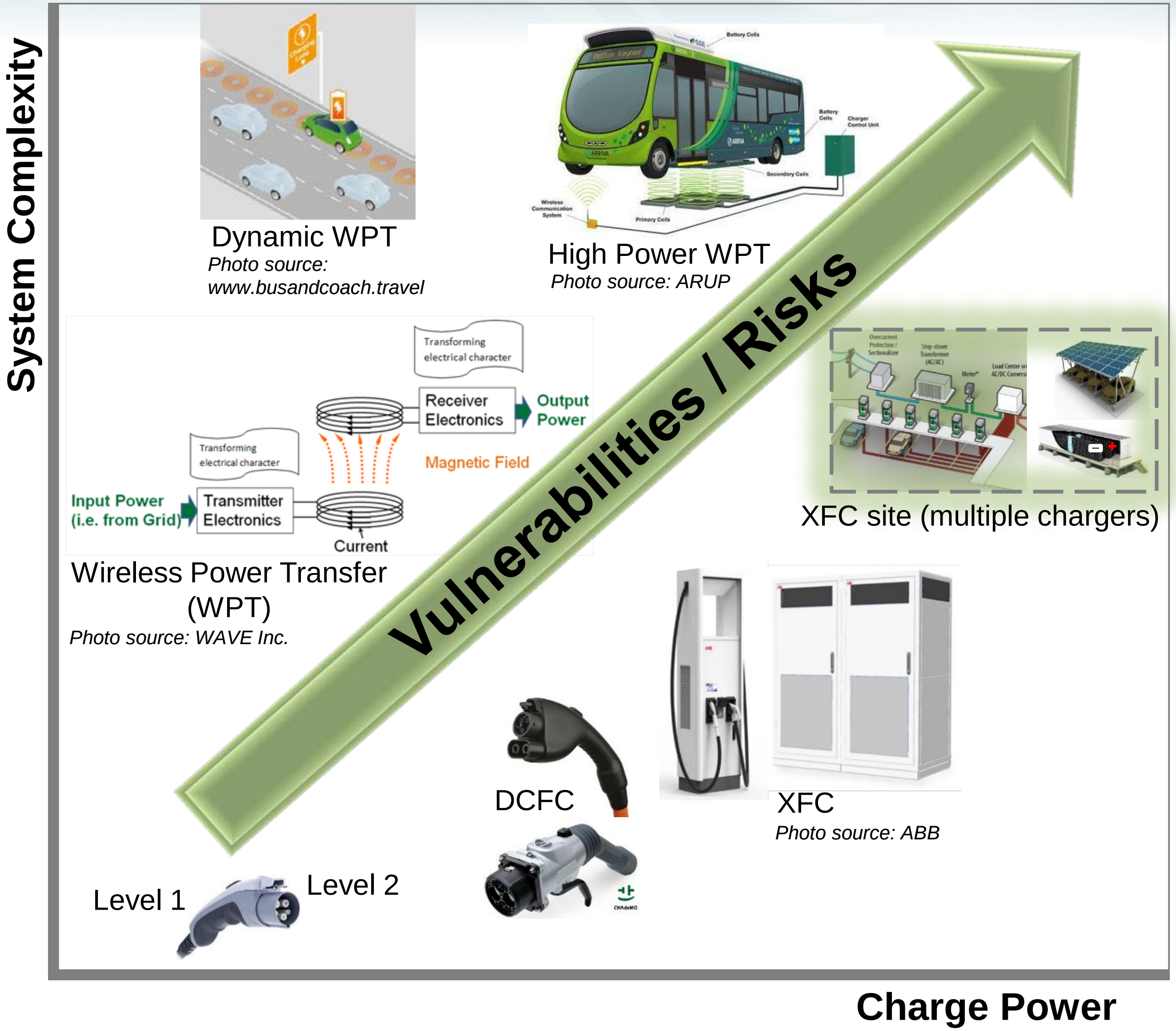
- Simultaneously turn off all power electronics modules
- Response of the DCFC:
  - Full power (50 kW) to standby power (~300W)
    - 0.020 seconds (-2.6 MW/sec)
- No impact to grid from a single DCFC shut down
- Potential impact to grid if simultaneously shut down of 100’s of DCFC
  - ? What about 350 kW XFC





Future Advancement:
High Power and Complexity

- Increased vulnerabilities and risk with increased charge power and system complexity
- Increased System Complexity
  - Advanced Control System of modular components
  - Multiple communication pathways
- Increased Charge Power
  - Potential increased grid interaction impacts
  - Increased safety risks



Wireless Charging (WPT) & Xtreme Fast Charging (XFC)

- XFC: Higher power
  - 350 kW (500A / 1000VDC) or higher
  - Liquid cable & connector cooling system
  - Multiple standards still required (CCS, CHAdeMO, GB/T, overhead charging, etc.)
  - Likely co-located with several XFC at charge depot (>1 MW demand on grid)

- WPT: Higher complexity controls
  - Controls communication is wireless (from ground assembly to vehicle assembly) 802.11p & 802.11n
  - Foreign object detection system
  - Vehicle approach, pairing, and alignment system

Photo source: Electrify America

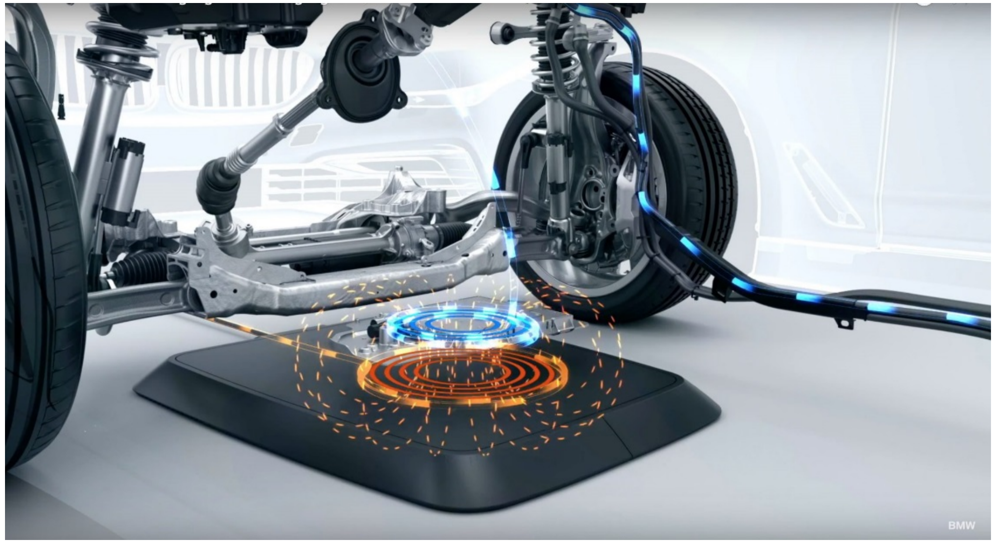


Photo source: companycartoday.co.uk

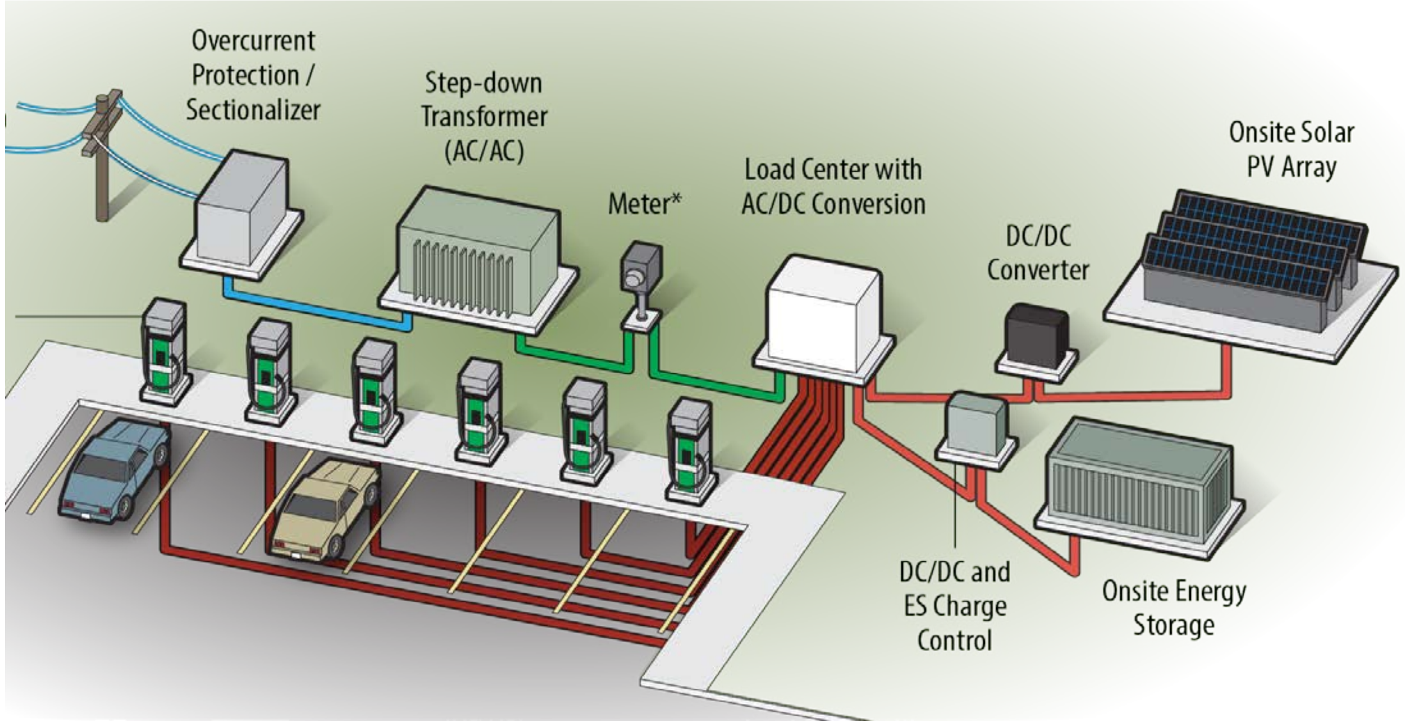
Lessons Learned: Guidelines for improved security / robustness

- Communication and Controls Security (internal and external)
  - Encryption for external communications, verification of information origin
  - Unique keys (not the same key for all chargers deployed)
  - Remove external jacks, disable JTAG, and secure boot loaders
  - Secure remote firmware updates capable with firmware integrity verification
  - Communication message freshness verification (identify replay attacks)
  - Segmentation of control systems (GUI, power electronics, vehicle interface, energy management)
  - Log events for security forensics
- Physical security
  - Recognition of physical access (open door) or physical manipulation
  - Tamper resistant enclosure
- Procedural
  - Manufacturer software and hardware quality assurance program

Potential Mitigation Solutions and Strategies

- Decouple DCFC load transients from grid
  - Local Energy Storage
    - Charger site DC bus with DER
      - a.k.a. “DC-as-a-service”

- DCFC internal performance monitor
    - Electrical performance and characteristics
    - Monitor communication for anomalies



Next Steps:

- Develop methodologies for cyber secure engineering design of charging systems
  - Internal controls and communications
  - External communication and security
- Quantify impacts of malicious events on electric gird networks
  - Decreased Power Quality
  - Coordinated large step change in power
- Evaluation and analysis of:
  - Xtreme Fast Charging system
    - Modular designs
  - Wireless charging system
    - Wireless communications (802.11p, 802.11n)
      - Automated power transfer control
    - Safety systems
      - Live object detection, Foreign object detection, vehicle alignment and pairing

Summary

- **Cyber security** of high power charging infrastructure
  - Consequence driven, Cyber-informed Engineering (CCE) process
  - Develop cyber-informed engineering methodologies and mitigation strategies
- **Identified risks and threats**
  - Internal power electronics controls able to be maliciously manipulated
  - High priority threats / risks when coordinated attack
- **Identified vulnerability impacts**
  - Poor power quality
  - Coordinated, sudden change in load
- **Potential mitigation strategies and solutions**
  - Local energy storage
  - Security monitor within charger system