Welcome to this week's presentation and conversation
hosted by the
Canadian Association for the Club of Rome,
a Club dedicated to intelligent debate and action on global issues.

Electrification 2.0: Current Status and Future Trends

Our speaker today is Dr. Sheldon Williamson, (Fellow, IEEE) received the Ph.D. degree in electrical engineering from the Illinois Institute of Technology, Chicago. He is currently a Professor with the Smart Transportation Electrification and Energy Research Group, Department of Electrical, Computer, and Software Engineering, University of Ontario Institute of Technology Oshawa, ON. He holds the NSERC Canada Research Chair position in Electric Energy Storage Systems for Transportation Electrification. His current research interests include advanced power electronics, electric energy storage systems, and motor drives for transportation electrification. This presentation will highlight the current status and future opportunities in transportation electrification and other modes of autonomous e-mobility.

The presentation will be followed by a conversation, questions, and observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, and Inuit in Canada) and their descendants.

Website: canadiancor.com
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2023 Feb 01 Zoom #132

Electrification 2.0: Current Status and Future Trends

Sheldon S. Williamson, *Fellow, IEEE*

NSERC Canada Research Chair
Electric Energy Storage Systems for Transportation Electrification

Smart Transportation Electrification and Energy Research (STEER) Group
Advanced Storage Systems and Electric Transportation (ASSET) Laboratory
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@OT_STEER

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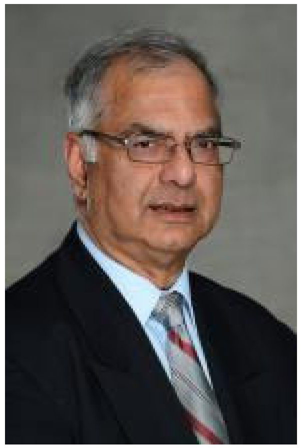
Canadian Association for the Club of Rome / Association canadienne pour le club de Rome

Chaires de recherche du Canada / Canada Research Chairs

Canada

Smart Transportation Electrification and Energy Research (STEER) Group


Tarlochan Sidhu


Vijay Sood


Walid Ibrahim


Mohamed Youssef


Sheldon Williamson

- **150+ graduate research students.**
- **Over 5000 m^2 of research lab space.**
- **12 full-time lab technicians.**

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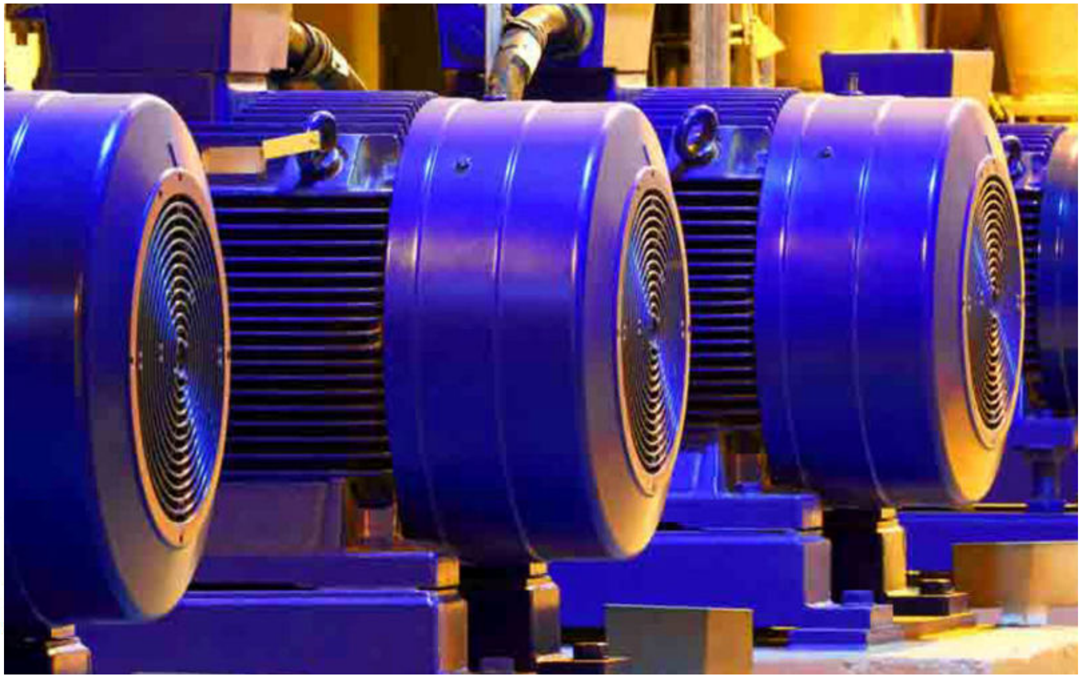
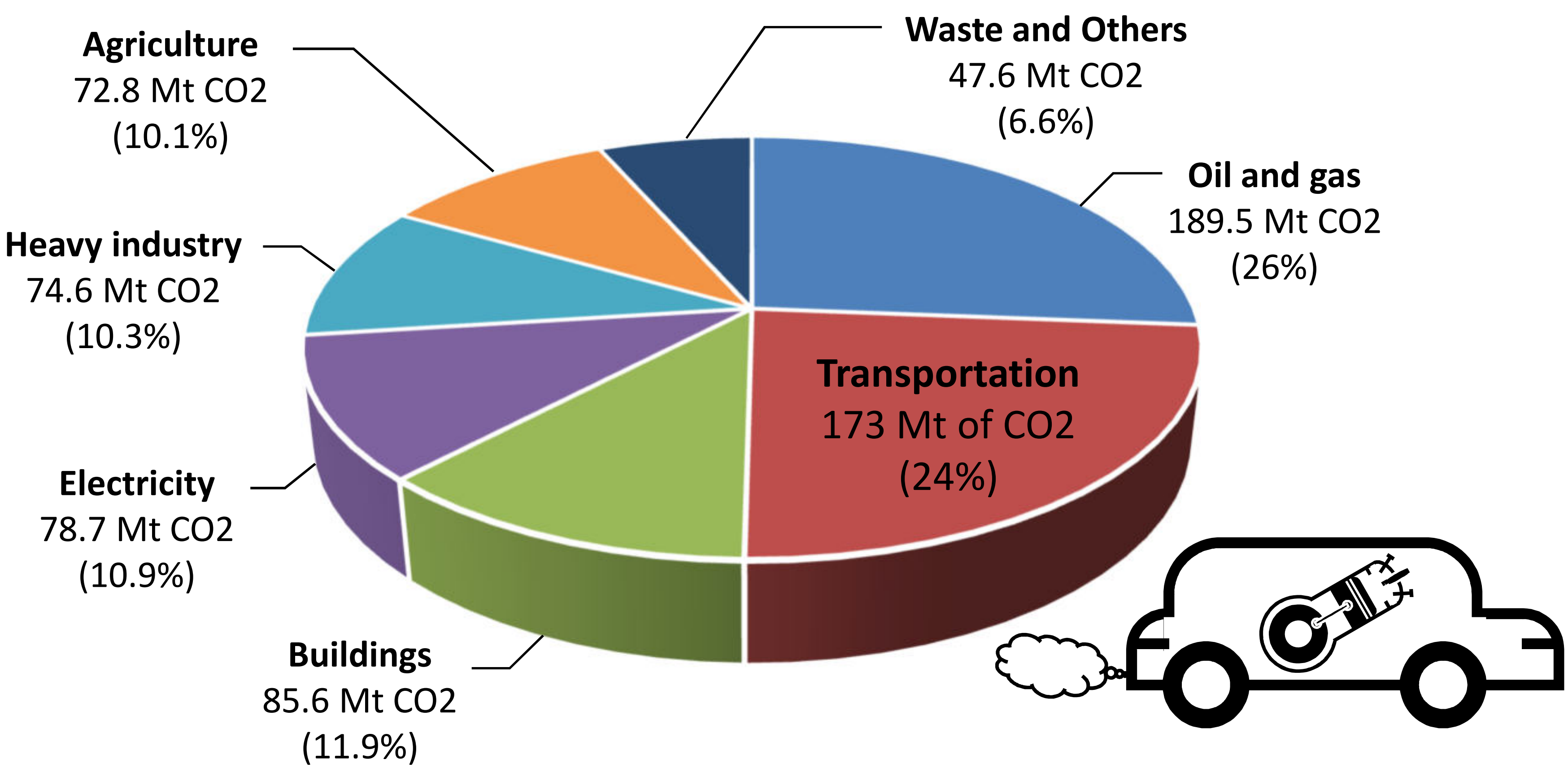
Canada Research Chairs
www.chairs-chaires.gc.ca

Current Research Thrust Areas



Why Electric Transportation?

Greenhouse gas emissions by Canadian economic sector in 2021



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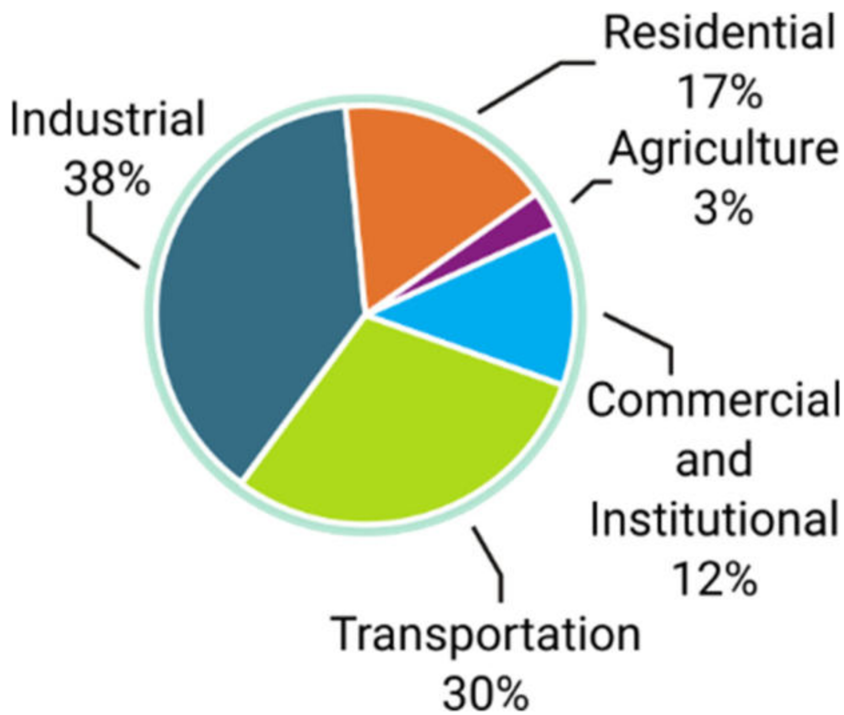
[1] Canadian environmental sustainability indicators: Greenhouse gas missions [Online]. Available: https://www.ec.gc.ca/indicateurs-indicators/F60DB708-6243-4A71-896B-6C7FB5CC7D01/GHGEmissions_EN.pdf

Why Electric Transportation?

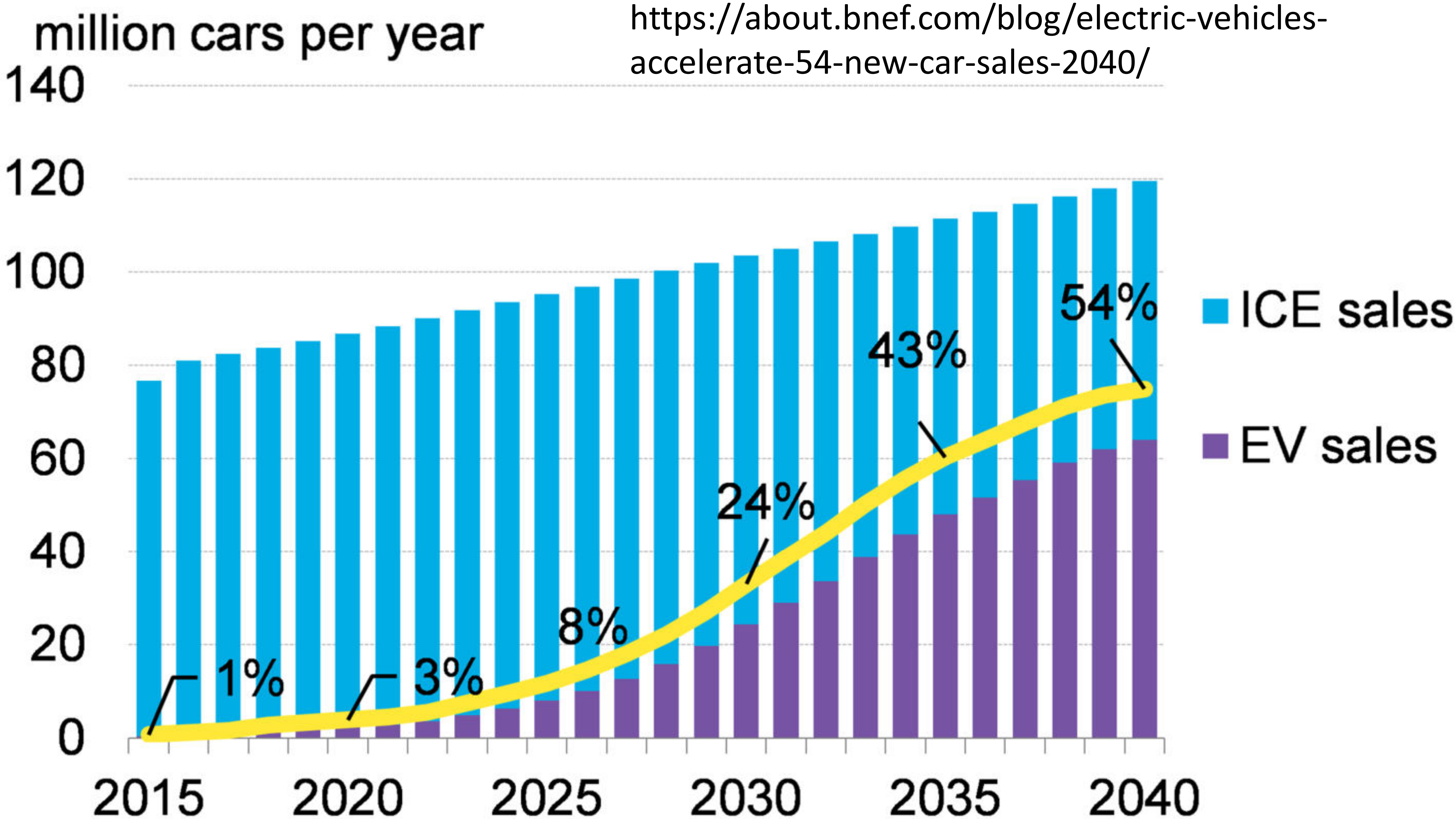
Canada's Energy Use by Sector



[2] Energy Fact Book, Natural Resources Canada

Why Electric Transportation?

https://about.bnef.com/blog/electric-vehicles-accelerate-54-new-car-sales-2040/



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Key Challenges

1. Limited range: 100-500 km
2. Long charging time: 4-8 hours
3. Limited charging infrastructure
4. Limited battery cycle life: 500-1000 cycles
5. Safety issues
6. High initial cost

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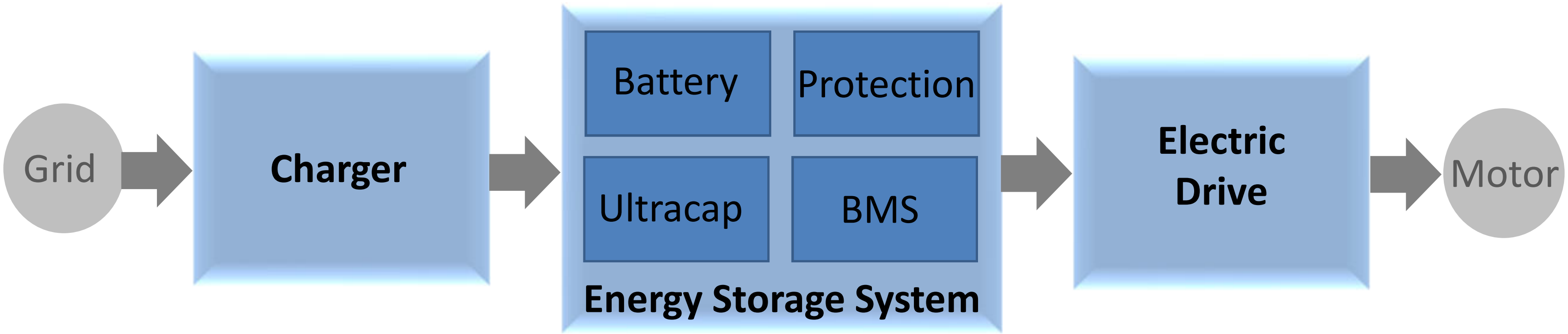
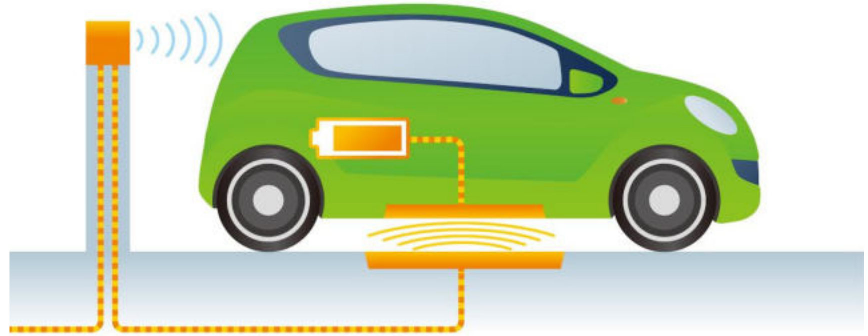
Research Focus Areas within the STEER Group



1. EV charging technologies
2. Battery energy management
3. Electric drives for EVs

EV Charging Methods



Wired Chargers

- On-board (AC)
  <20 kW
  Slow
- Off-board (DC)
  >20 kW
  Fast

Wireless Chargers

- Inductive
  - Magnetic induction
  - Magnetic resonance
- Capacitive

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Ultrafast Charging

Type	Chemistry	C-rate	Time	Temperature	Charge termination
Slow charger	Ni-Cd, PbA	0.1C	14h	0ºC to 45ºC (32ºF to 113ºF)	Continuous low charge or fixed timer. Subject to overcharge. Remove battery when charged.
Rapid charger	Ni-Cd, Ni-MH, Li-ion	0.3-0.5C	3-6h	10ºC to 45ºC (50ºF to 113ºF)	Senses battery by voltage, current, temperature and time-out timer.
Fast charger	NiCd, NiMH, Li-ion	1.0 C	1h+	10ºC to 45ºC (50ºF to 113ºF)	Same as a rapid charger with faster service.
Ultra-fast charger	Li-ion, Ni-Cd, Ni-MH	1-10 C	10-60 minutes	10ºC to 45ºC (50ºF to 113ºF)	Applies ultra-fast charge to 70% SOC; limited to specialty batteries.

DC Fast Charging Systems

SAE J1772 AC and DC Charging Standards

Charge Method	Nominal Supply Voltage (V)	Maximum Current (A)	Branch Circuit Breaker Rating (A)	Output Power Level (kW)
AC Level 1	120 V AC, 1-phase	12 A	15 A	1.08
	120 V AC, 1-phase	16 A	20 A	1.44
AC Level 2	208 to 240 V AC, 1-phase	16 A	20 A	3.3
	208 to 240 V AC, 1-phase	32 A	40 A	6.6
	208 to 240 V AC, 1-phase	≤ 80 A	Per NEC 635	≤ 14.4

Charge Method	Supplied DC Voltage Range (V)	Maximum Current (A)	Power Level (kW)
DC Level 1	200-450 V DC	≤ 80A DC	≤ 36 kW
DC Level 2	200-450 V DC	≤ 200A DC	≤ 90 kW
DC Level 3	200-600 V DC	≤ 400A DC	≤ 240 kW

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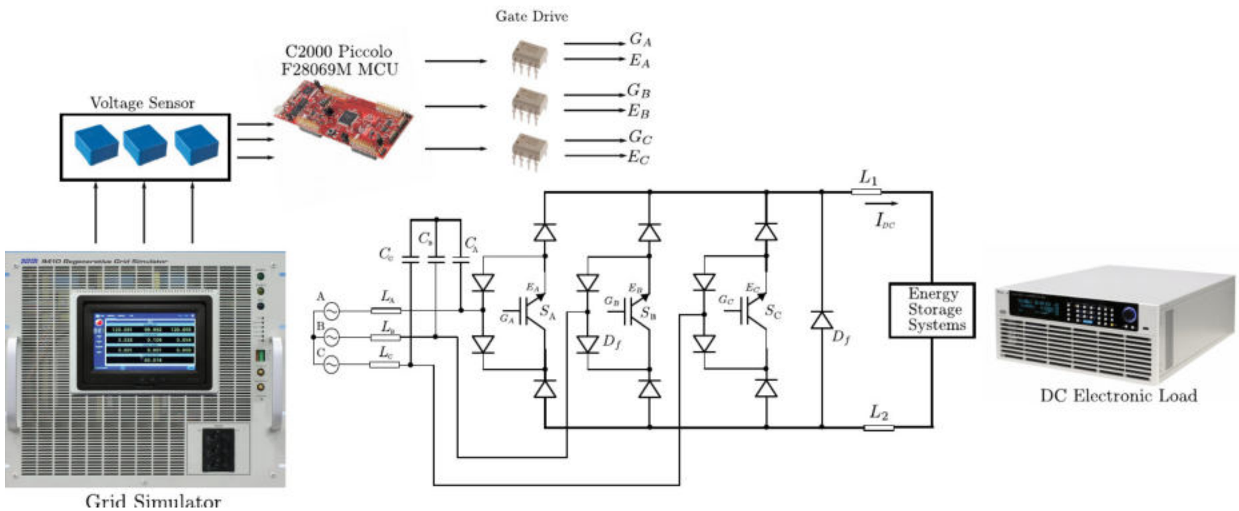
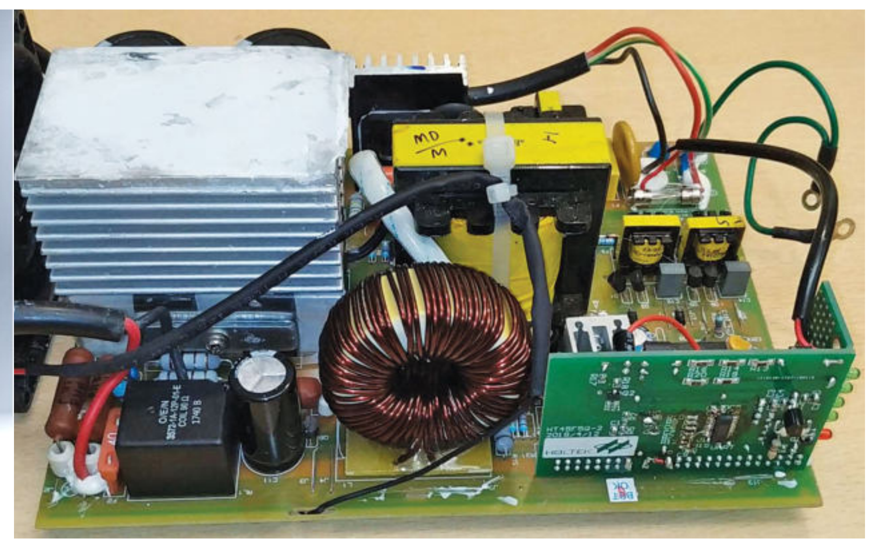
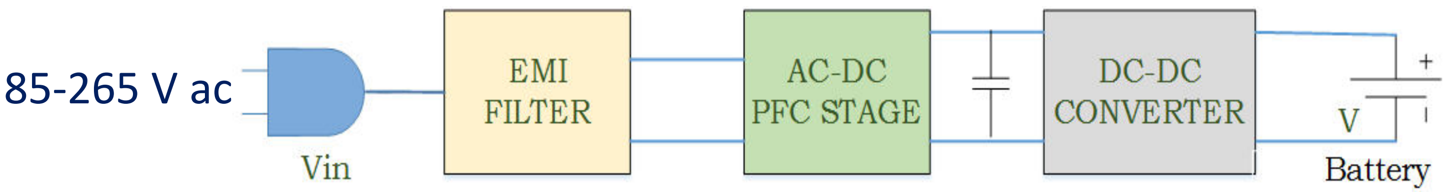
Design of a 25 kW DC Fast Charger



Janamejaya Channegowda
PhD (2020)



Universal 6.6 kW On-board Battery Charger



Conventional
Fixed dc link

Proposed
Variable dc link

Conventional
36-72 V dc
72-150 V dc
200-450 V dc

Proposed
50-1000 V dc

AVJS Praneeth
PhD (2021)

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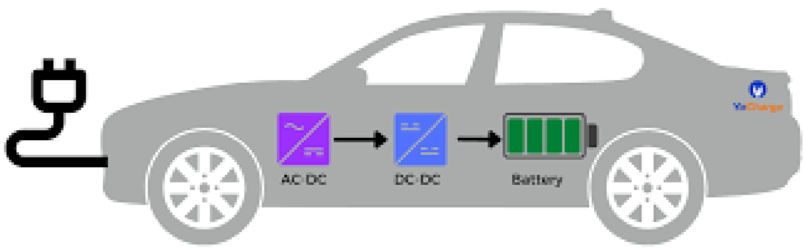
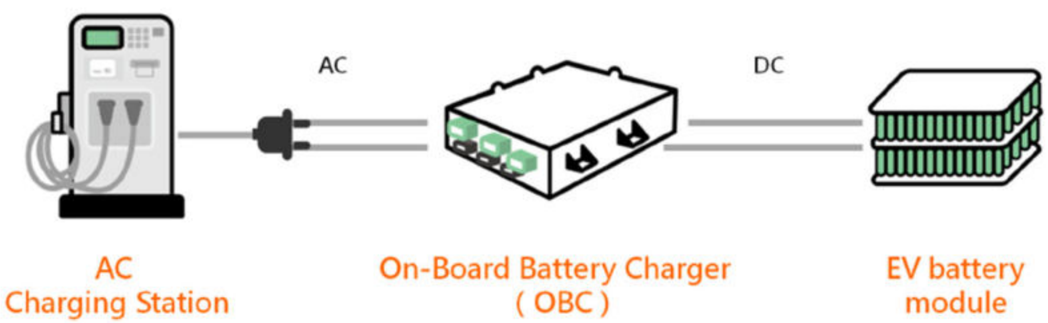
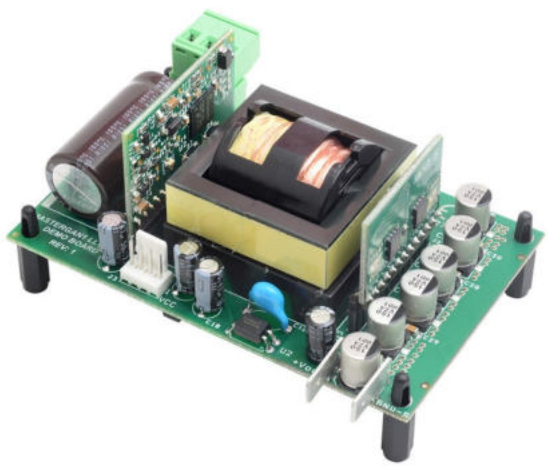
Universal 6.6 kW On-board Battery Charger

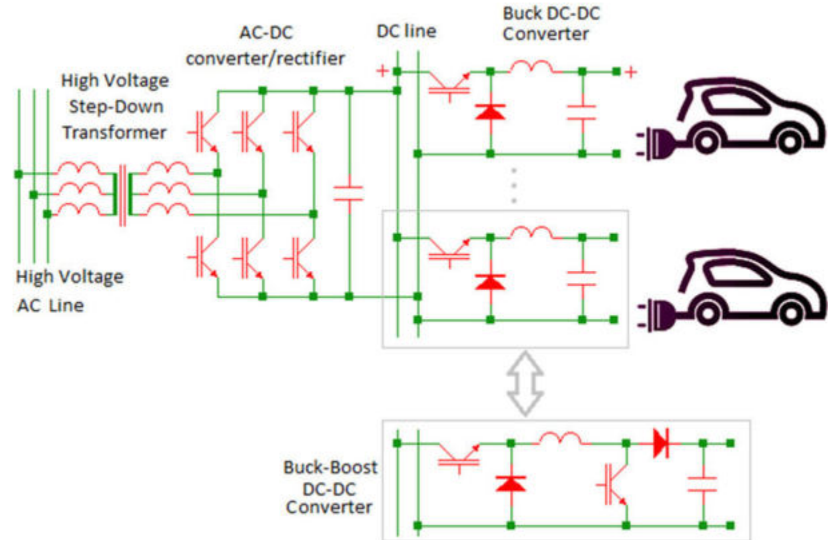


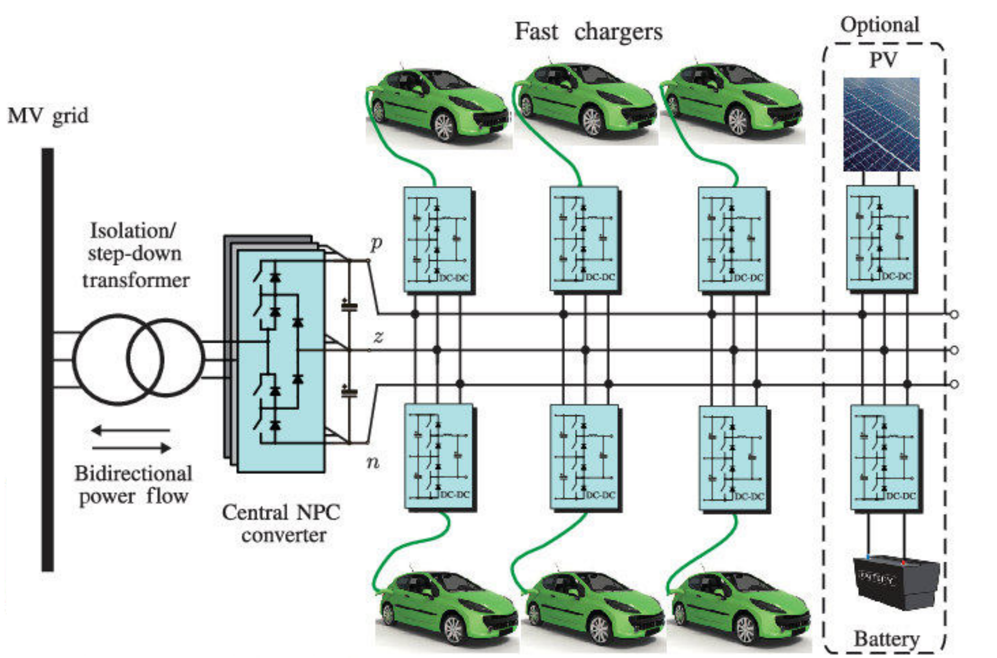


Jaya Sai Praneeth Ammanamanchi Venkata, Lalit Patnaik, Najath Abdul Azeez, Sheldon S. Williamson, "Wide-output voltage range on-board battery charger for electric vehicles," **U. S. Patent No. 11518262, Dec. 06, 2022**.

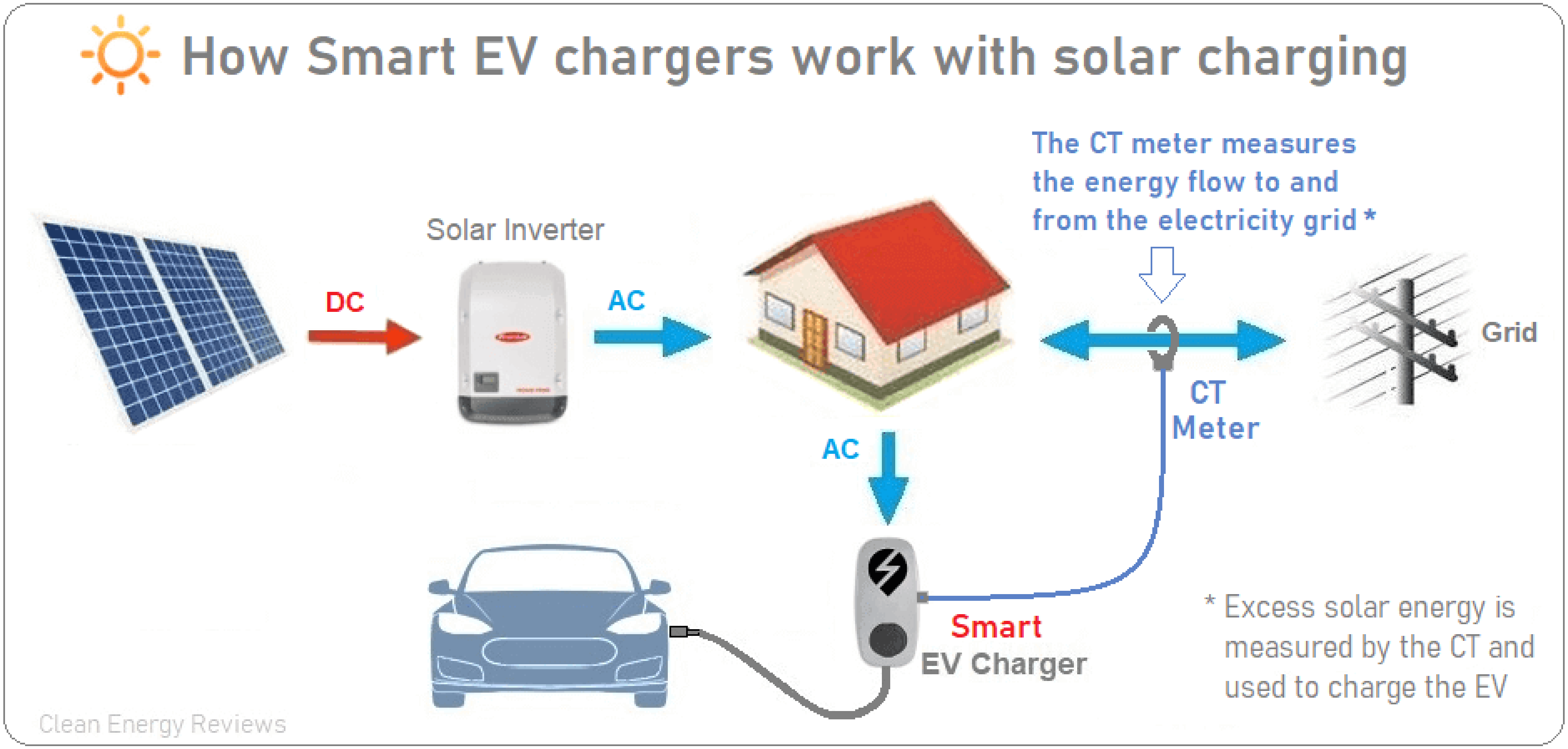
Ongoing Work on AC Onboard Chargers and DC Offboard Fast Chargers







Solar/EV/Grid Integrated Charger/Inverter (Including V2G/V2H/V2X)



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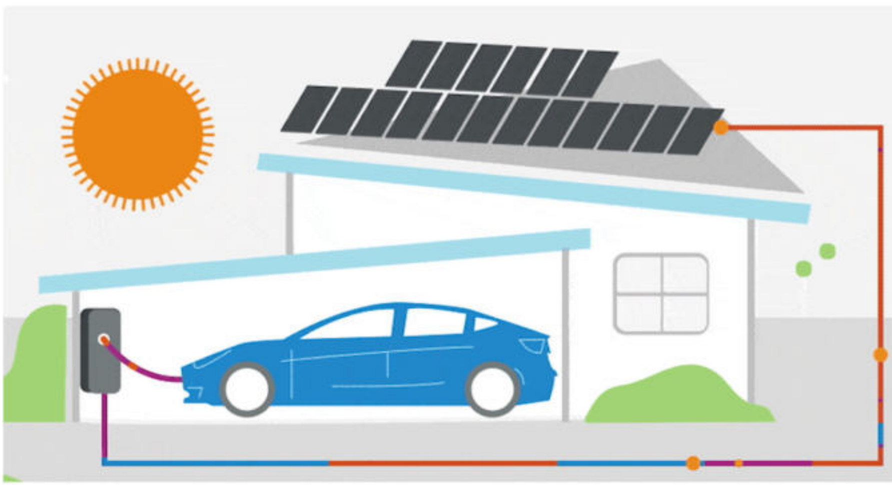
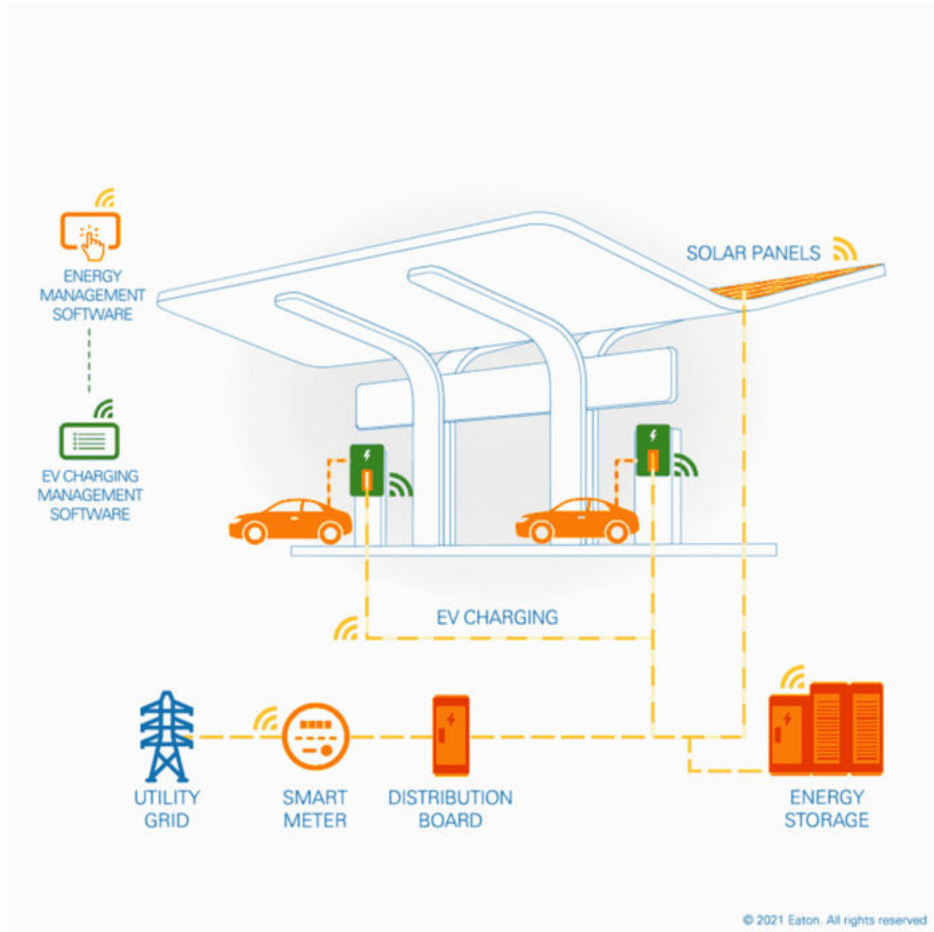
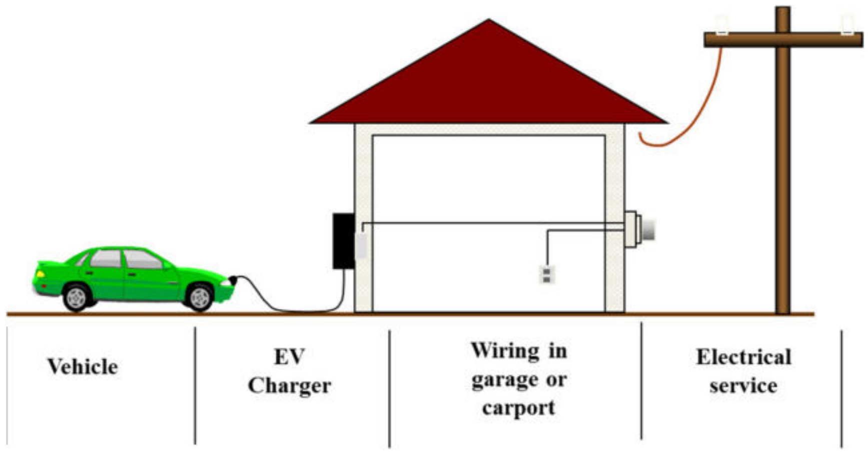
Solar/EV/Grid Integrated Charger/Inverter (Including V2G/V2H/V2X)

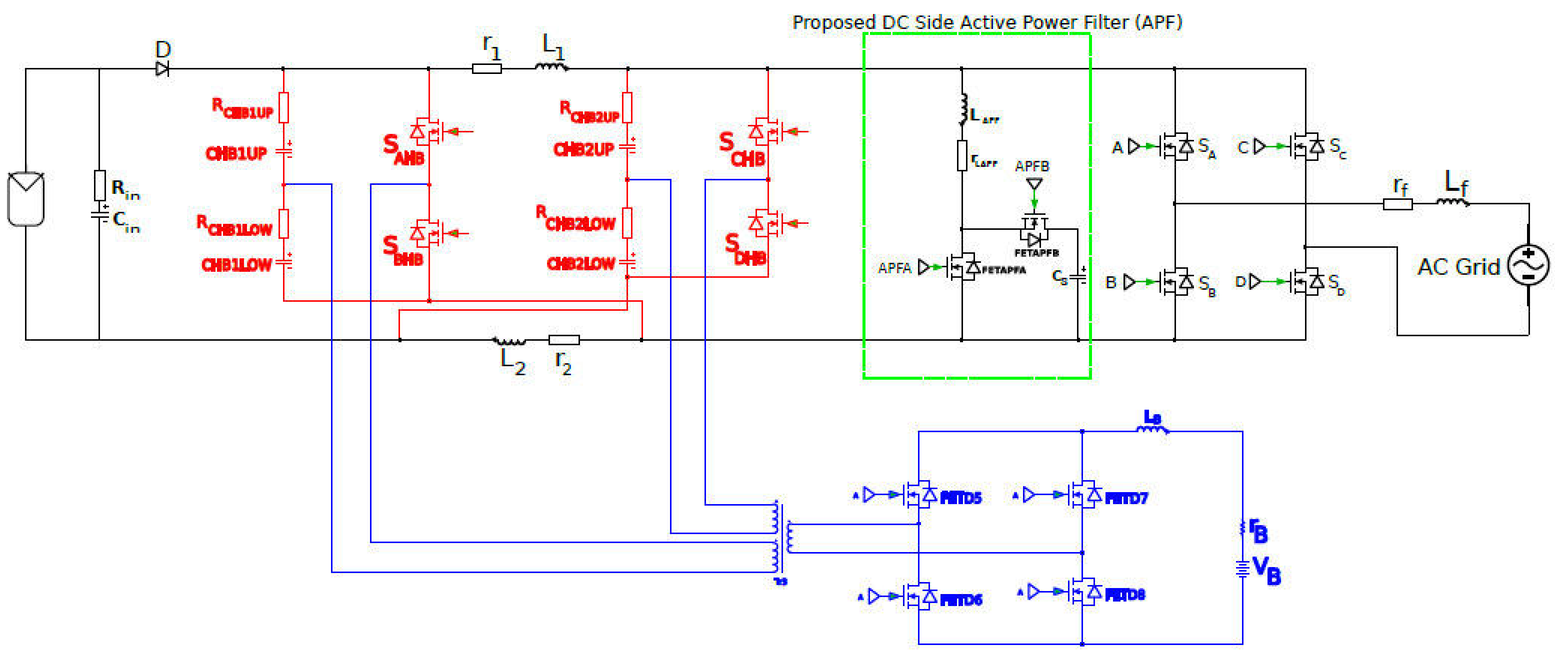




Single-Stage PV-Grid Inter-connected Z-source Inverter for DC Fast Charging (5.0 kW Prototype)



Siddhartha Singh
PhD Candidate



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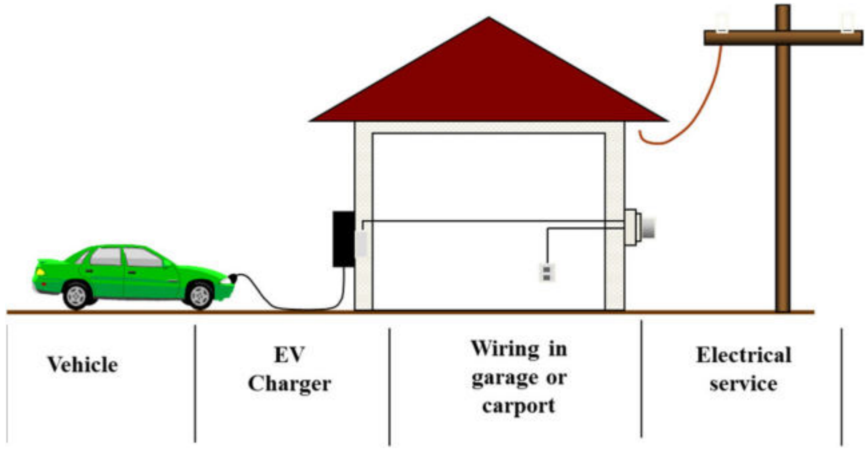
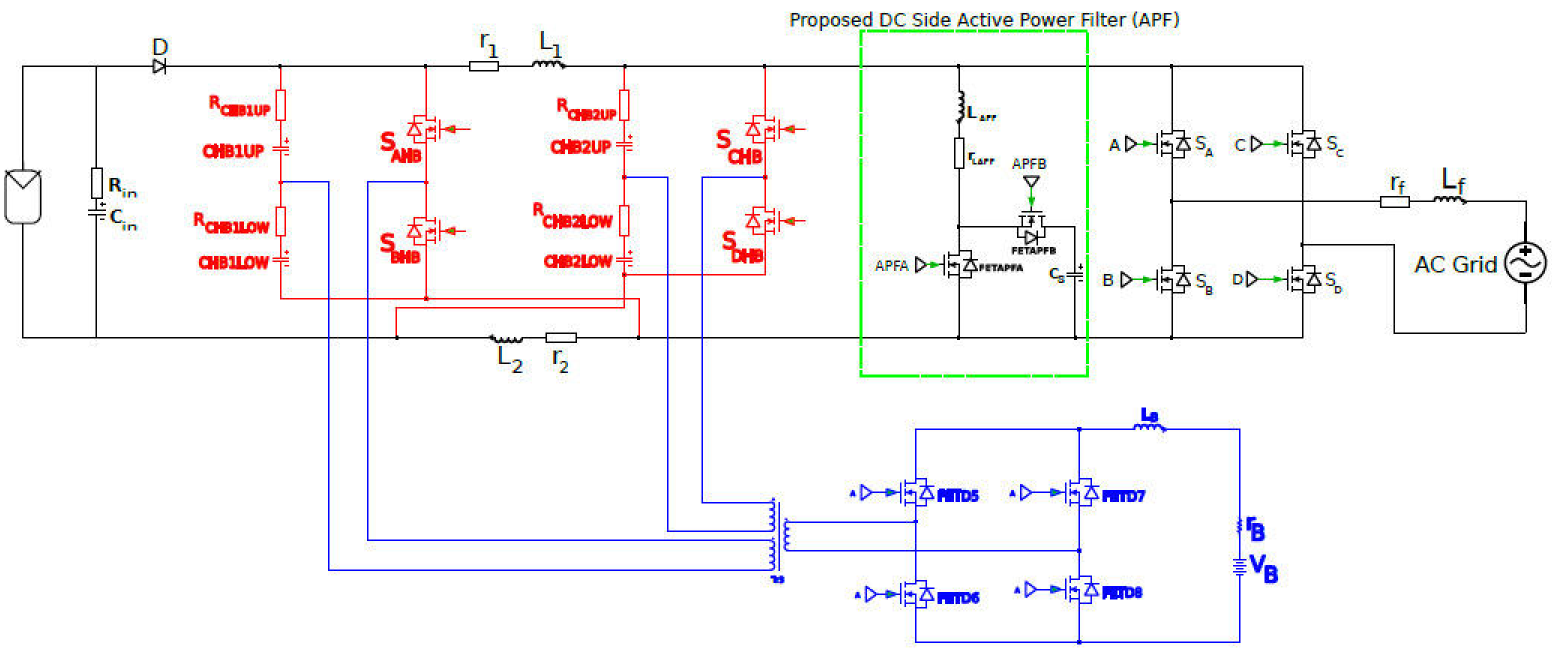
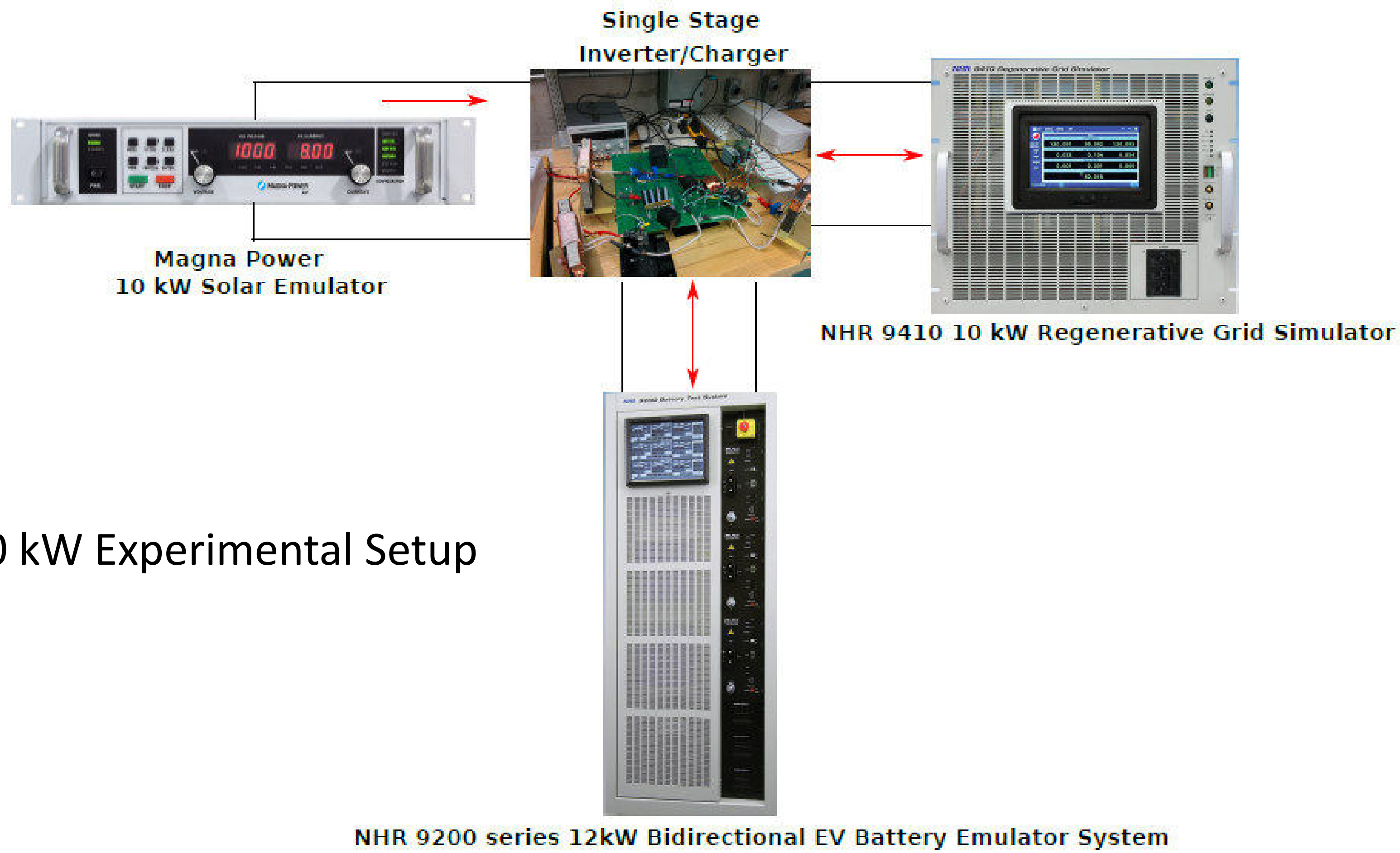


Siddhartha Singh
PhD (2021)



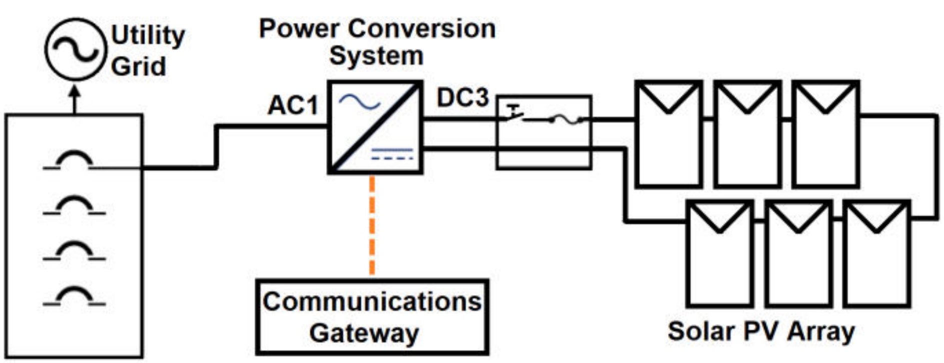
Single-Stage PV-Grid Inter-connected Z-source Inverter for DC Fast Charging (5.0 kW Prototype)

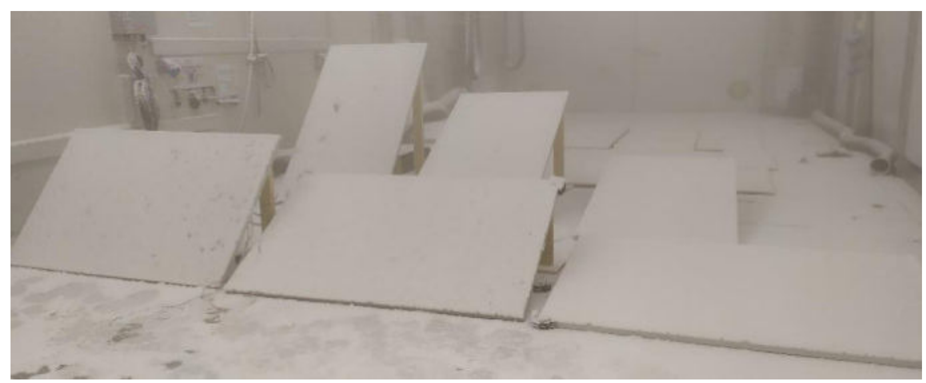


5.0 kW Experimental Setup

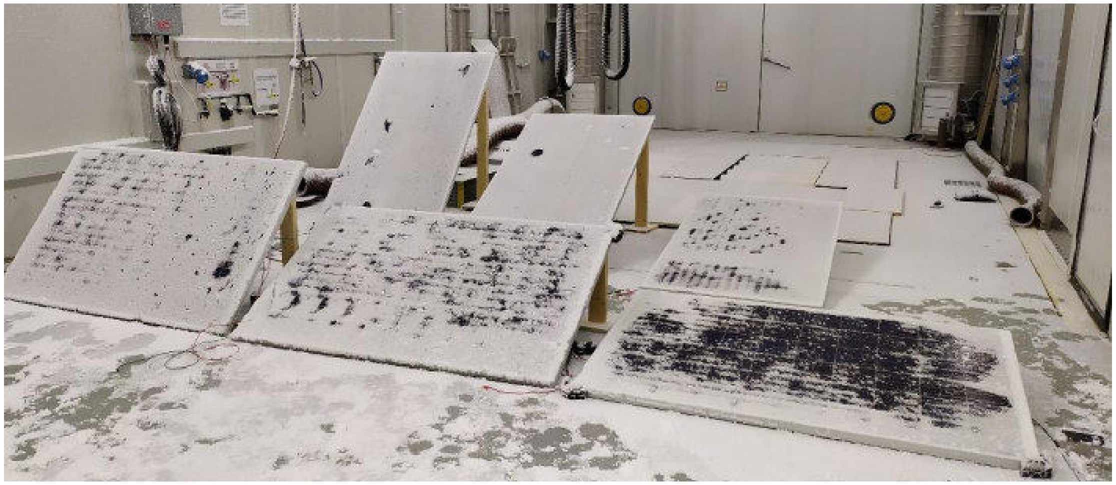
Active Snow Removal from PV Panels + EV Charging

Sandra Aragon Aviles
Master's (2022)

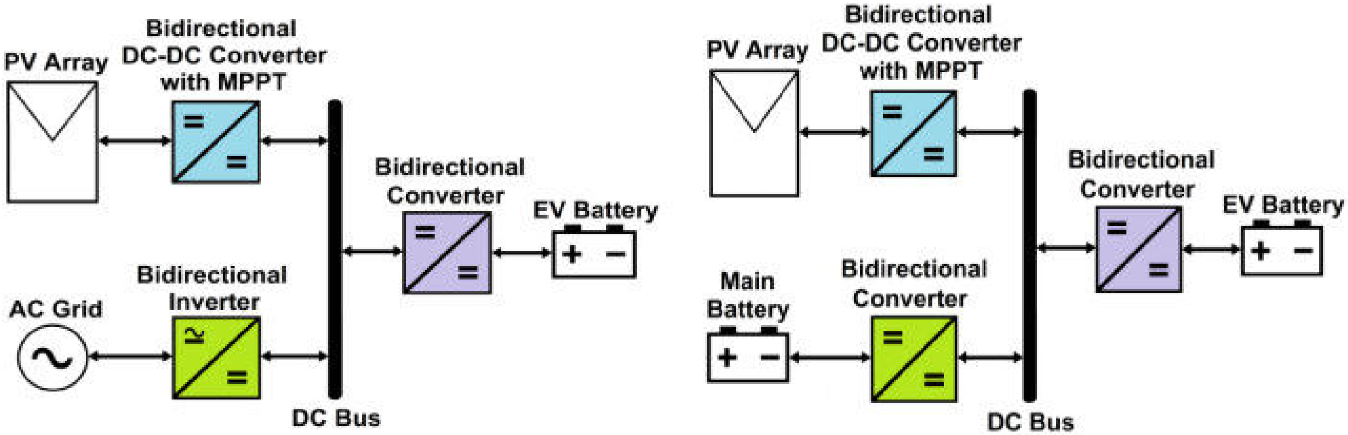




Active Snow Removal from PV Panels + EV Charging



Sandra Aragon Aviles
Master's (2022)



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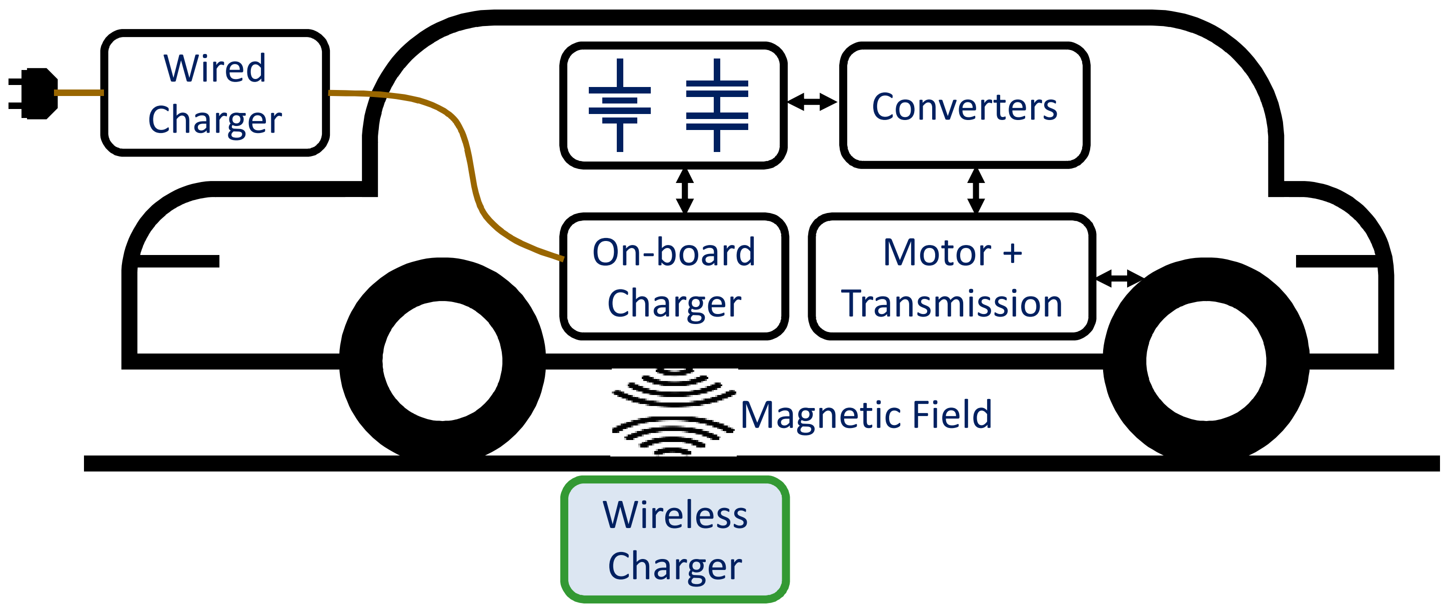
Wireless Charging



- ❑ Driving range extension
- ❑ Battery volume reduction
- ❑ Battery life span increase
- ❑ Convenience
- ❑ Weather proof

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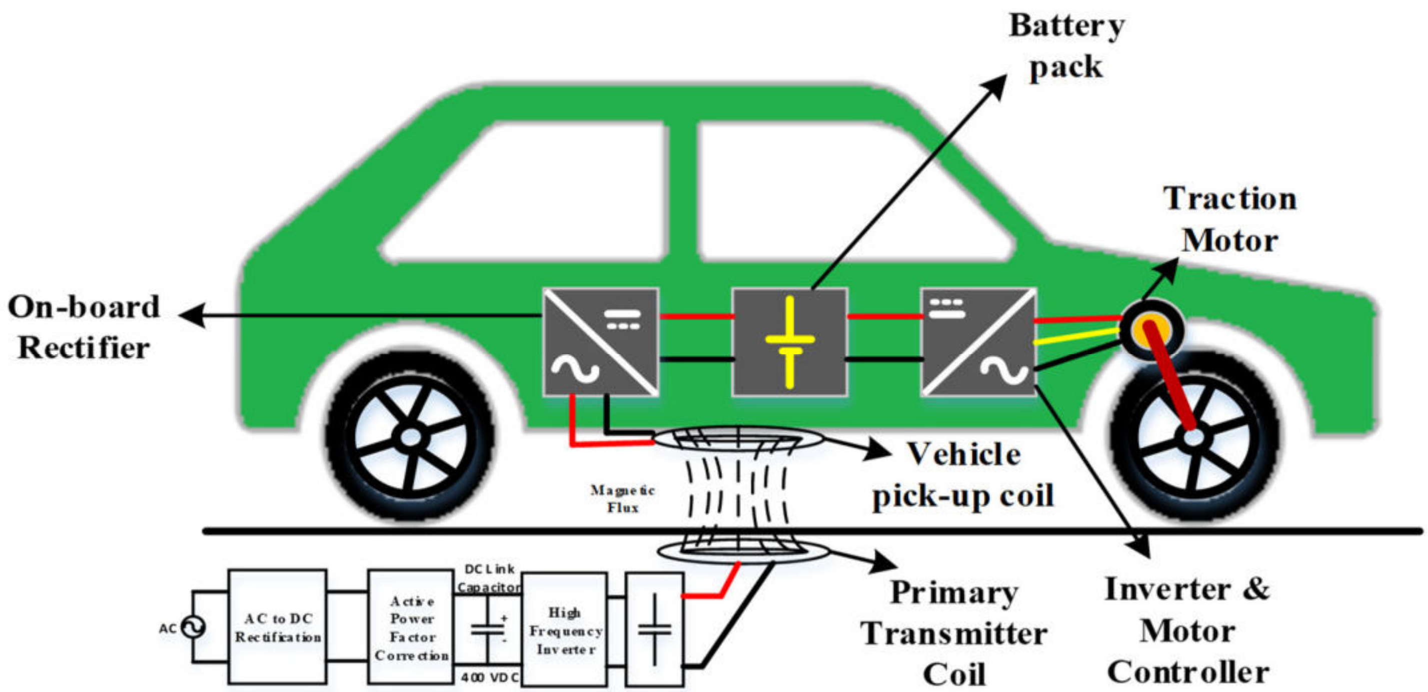
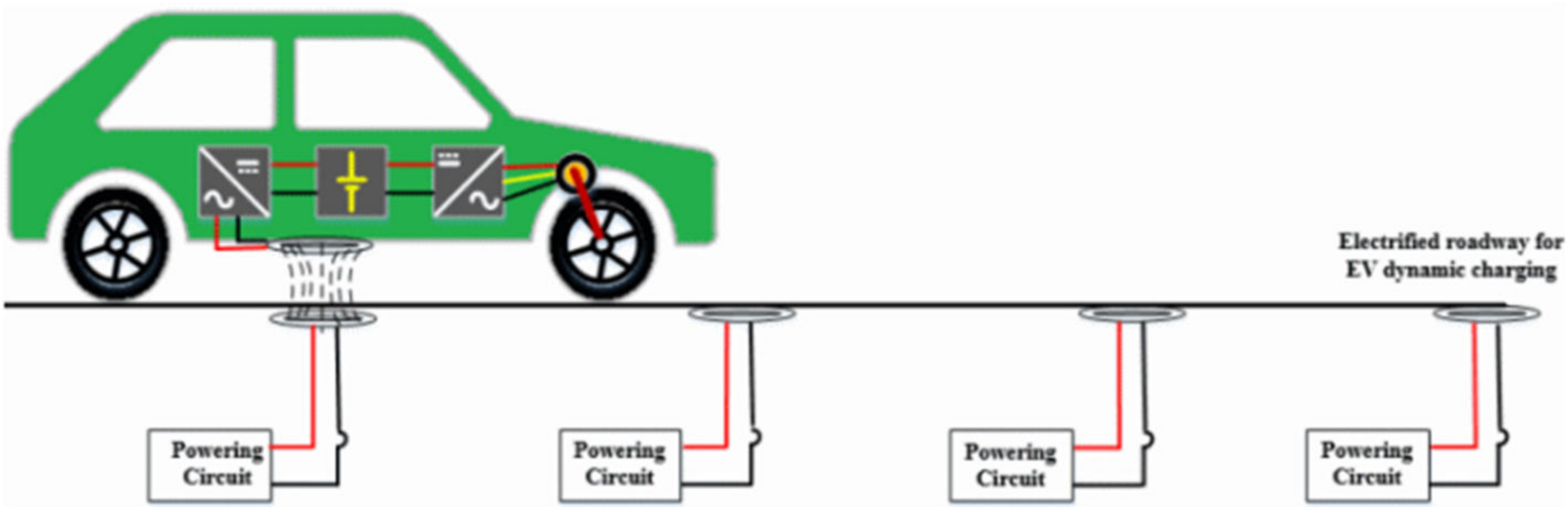
Static Wireless Charging + SAE J2954 Standards



SAE J2954 WPT Charging Standards

Classification	WPT1	WPT2	WPT3	WPT4
Frequency band	81.39 kHz – 90 kHz (typical 85 kHz)			
Power Levels	3.7 kW	7.7 kW	11 kW	22 kW
Status	Specified	Specified	In process	In process

Dynamic (In-motion) Wireless Charging



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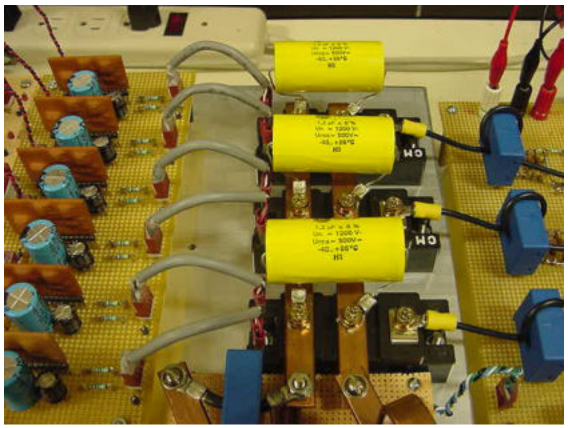
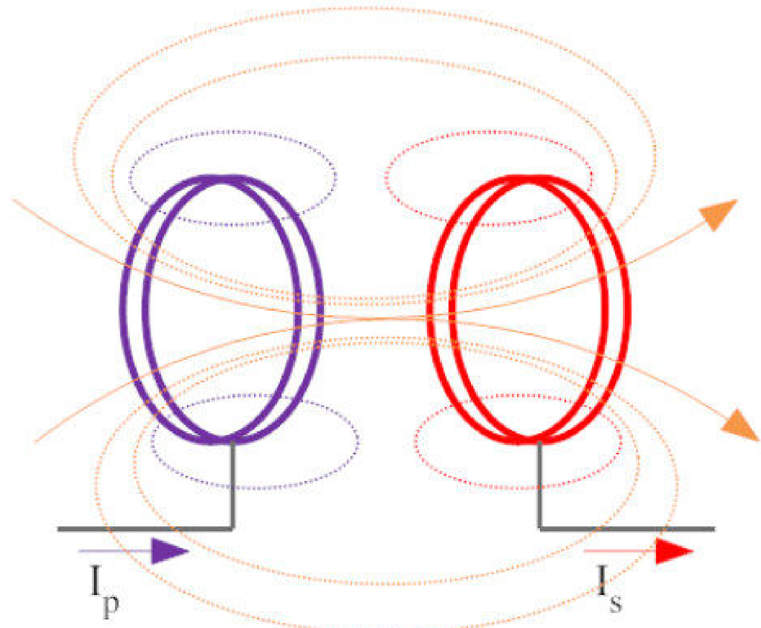
Dynamic (In-motion) Wireless Charging (E-autonomy)

Inductive Power Transfer (IPT) Fundamentals

- Advances in power electronics have positively impacted inductive power transfer (IPT) technology.





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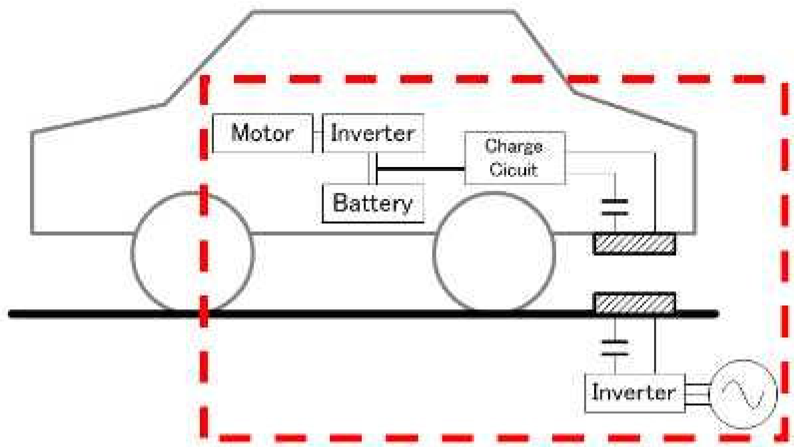
Inductive Power Transfer (IPT) Fundamentals

- IPT technology is an effective alternative for charging EVs.



Ref: 2011 ANSYS, Inc

- IPT technology has been proven for low-power applications.

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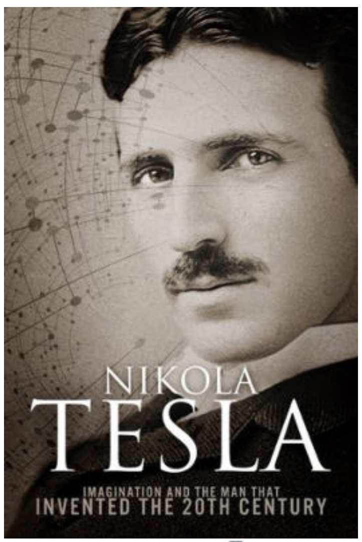
Inductive Power Transfer (IPT) Fundamentals

- IPT has been researched for higher-power applications as well.



SIEMENS

CONDUCTIX wampfler
DELACHAUX GROUP

QUALCOMM

Evatran
energy without limits

BOMBARDIER

WiTricity

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Static Wireless Charging Standards for EVs

Society of Automotive Engineers (SAE J2954) Standard

Classification	WPT1	WPT2	WPT3	WPT4
Frequency band	81.39 kHz – 90 kHz (typical 85 kHz)			
Power Levels	3.7 kW	7.7 kW	11 kW	22 kW
Status	Specified	Specified	In process	In process

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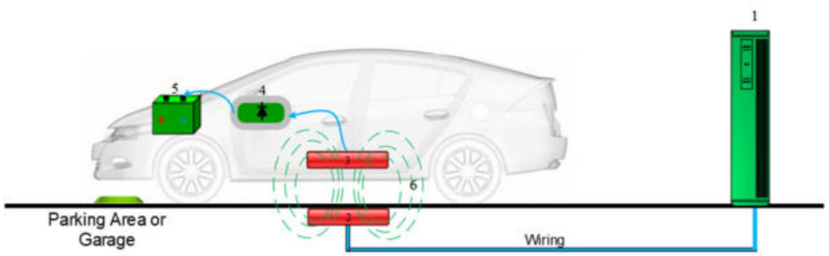
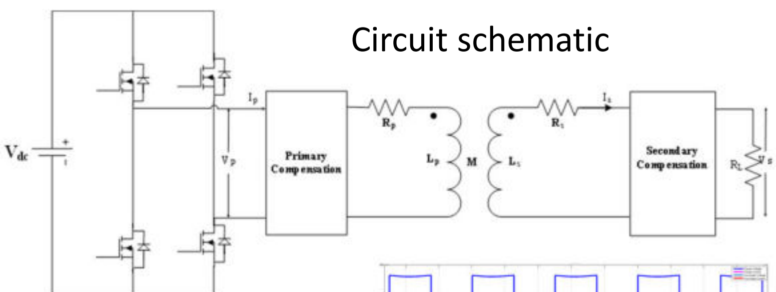
[3] SAEJ2954 technical information report (TIR) 2016 [Online]. Available: http://standards.sae.org/wip/j2954/

Design of Archimedean Coil Wireless Charger

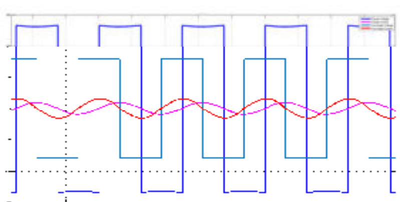


Conceptual diagram for wireless charging of EV

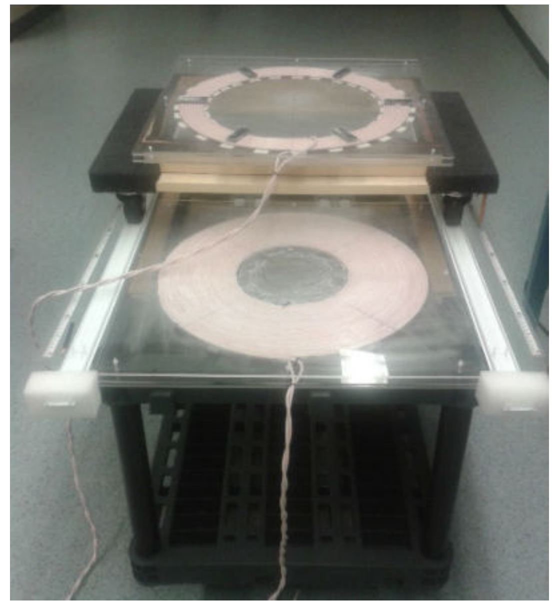
1. Power Supply with controller
2. Transmitter Coil
3. Receiver Coil
4. Converter
5. Energy Storage
6. Wireless Energy Transfer



Circuit schematic

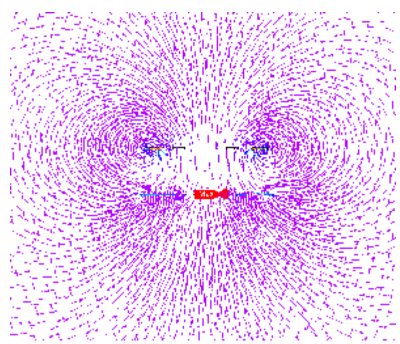


Results



Coils for 3.6 kW wireless charger

Dr. Kunwar Aditya
PhD (2016)



FEA analysis

Parameters	Values
Nominal Output Power	3.6 kW
Operating Frequency	40 kHz
Nominal Air Gap	16 cm
Input Voltage	240 V ac

Parameters of designed coils

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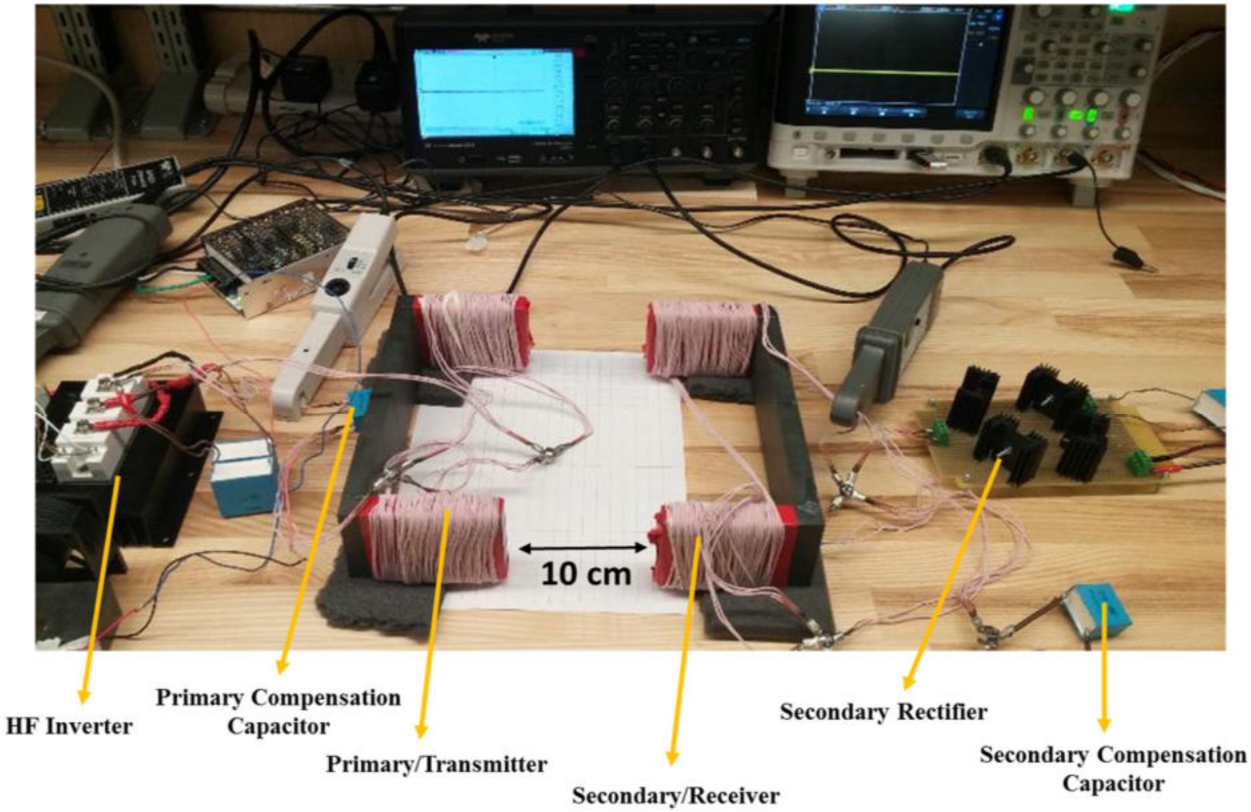
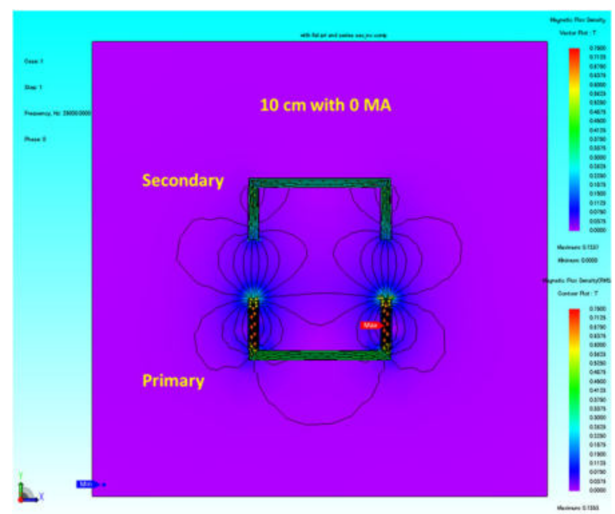
Design of Ferrite-core-based Wireless Charger



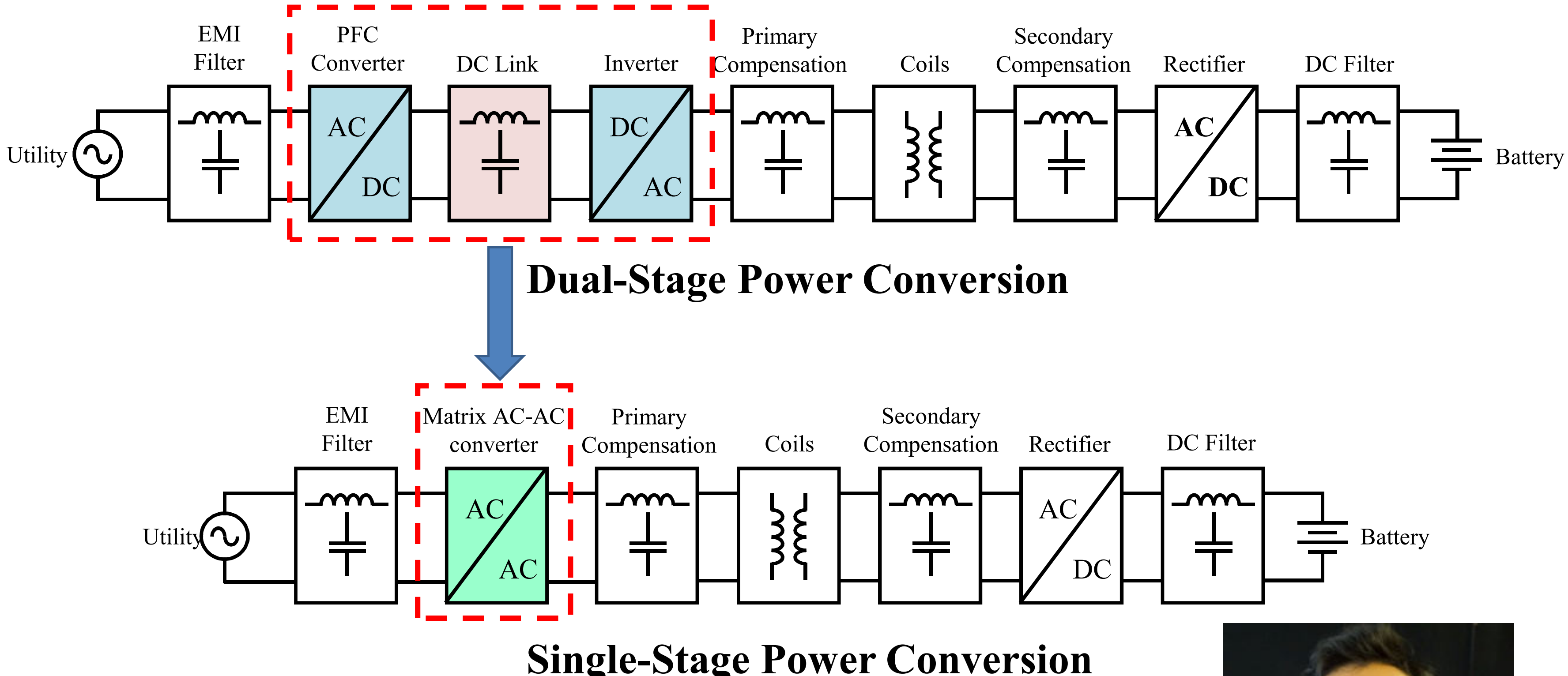
1kW prototype and test bench layout

Vamsi K Pathipati
MASc (2016)



FEA analysis

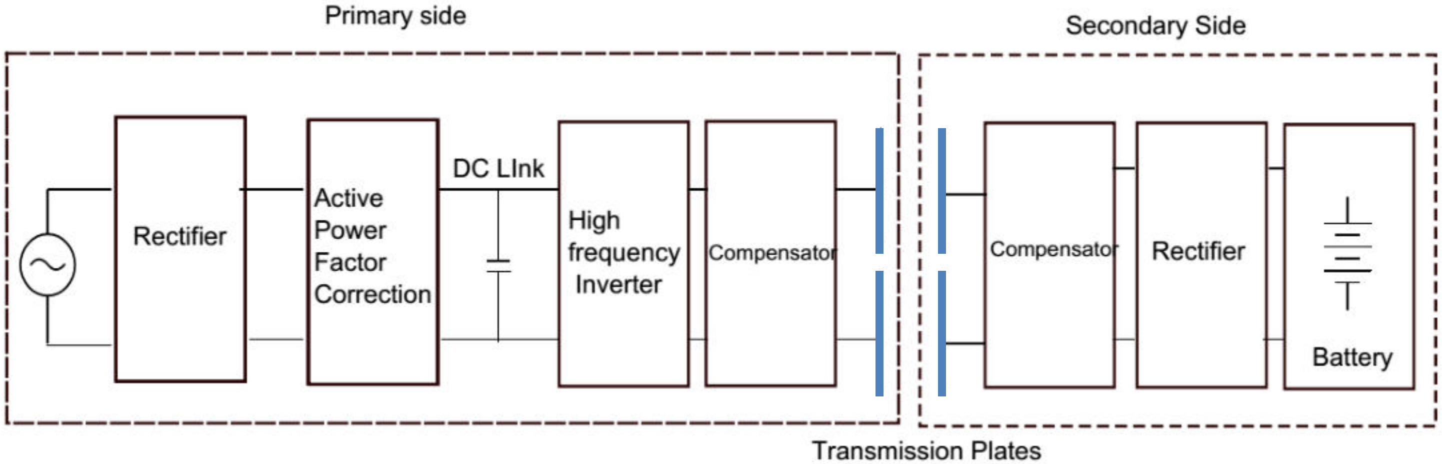
Matrix AC-AC Converters for Wireless Charging



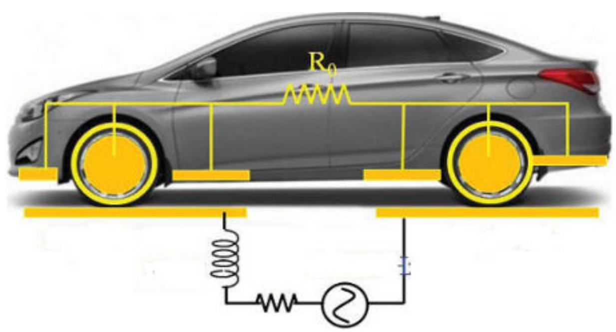
Phuoc Sang Huynh
PhD Student

Contactless Capacitive Power Transfer

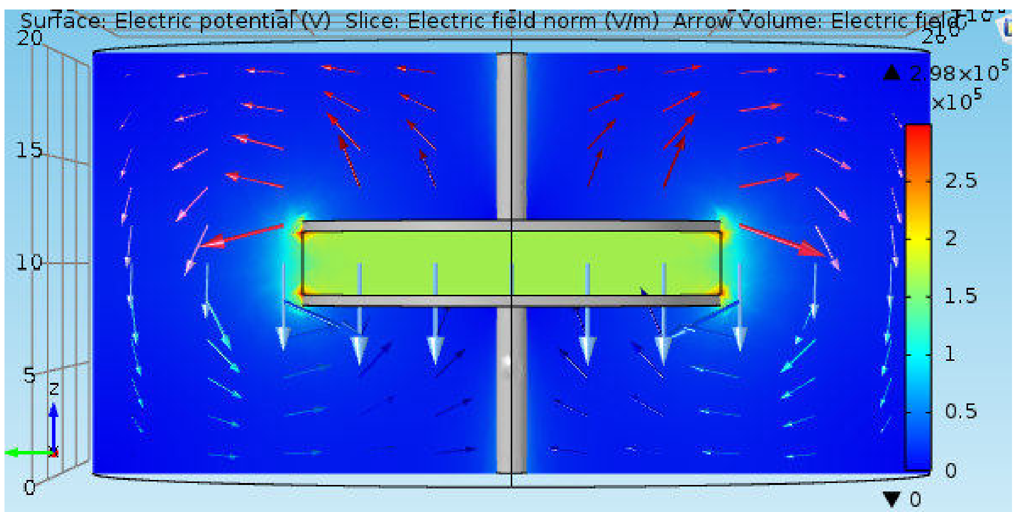
Block Diagram of the CPT System



Deepak Rozario
MASc (2016)



Application of the CPT charging system



FAE analysis for CPT charging

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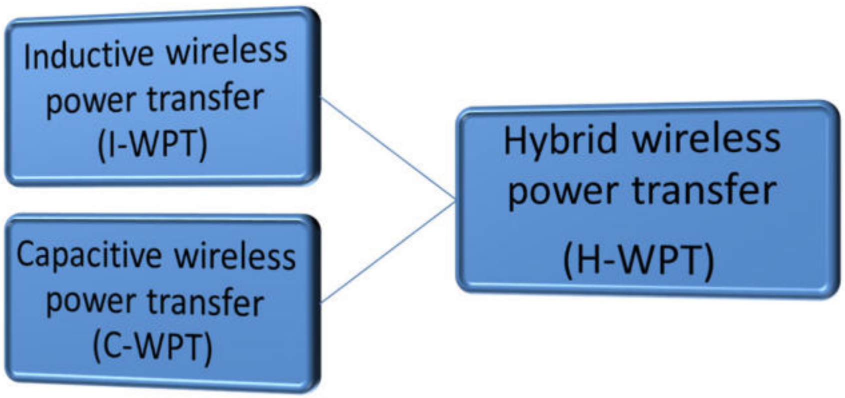
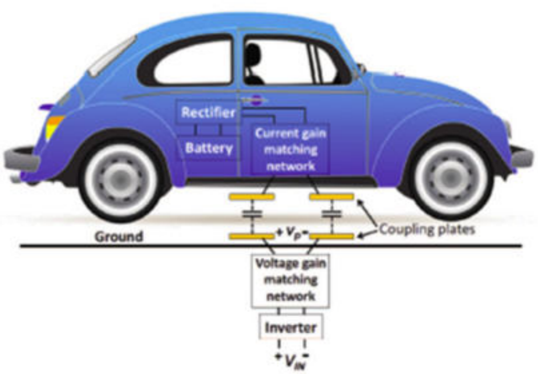
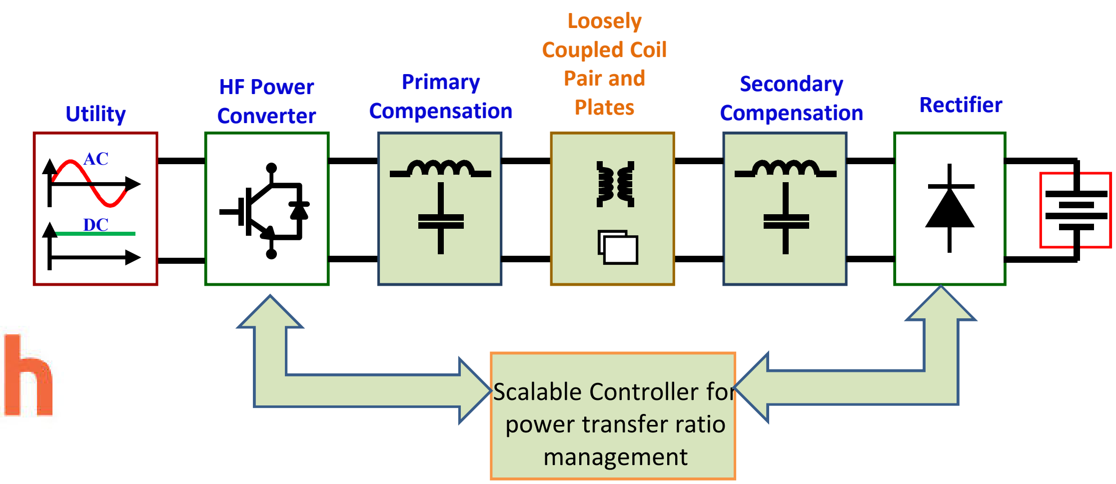
Hybrid Wireless Charging with Controllable Power Sharing



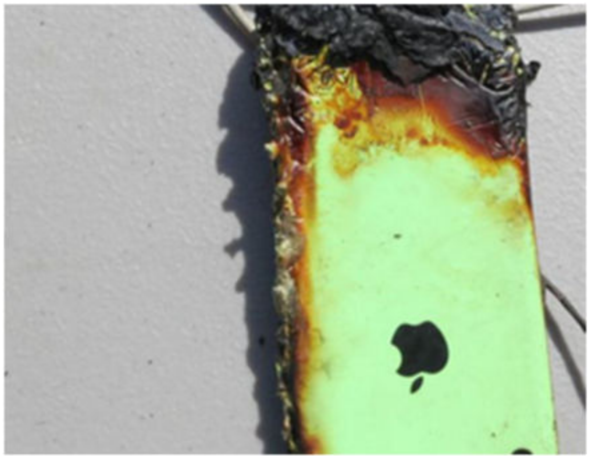
- Expected DC-DC Efficiency (>95%) by adjusting the power transfer ratio
- Medium air gap
- Unity power factor
- Misalignment tolerance (High)
- Metal barrier resistant
- Redundancy
- Reliability
- Limiting EMI exposure by proper shielding

Deepa Vincent
PhD Student





Li-based Battery Energy Storage Systems: Current Status and Issues (big picture)



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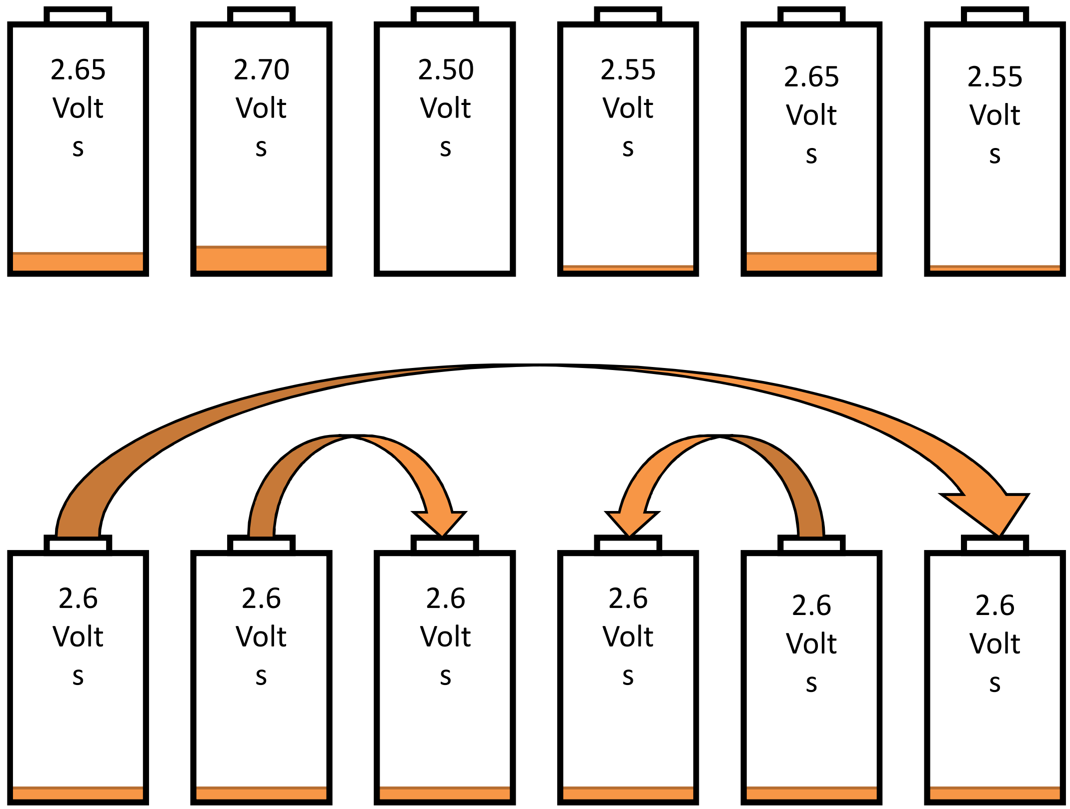
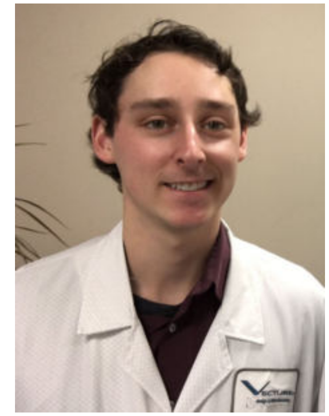
Active Cell-balancing Under Aggressive Discharge Conditions

Conventional approach

Proposed approach



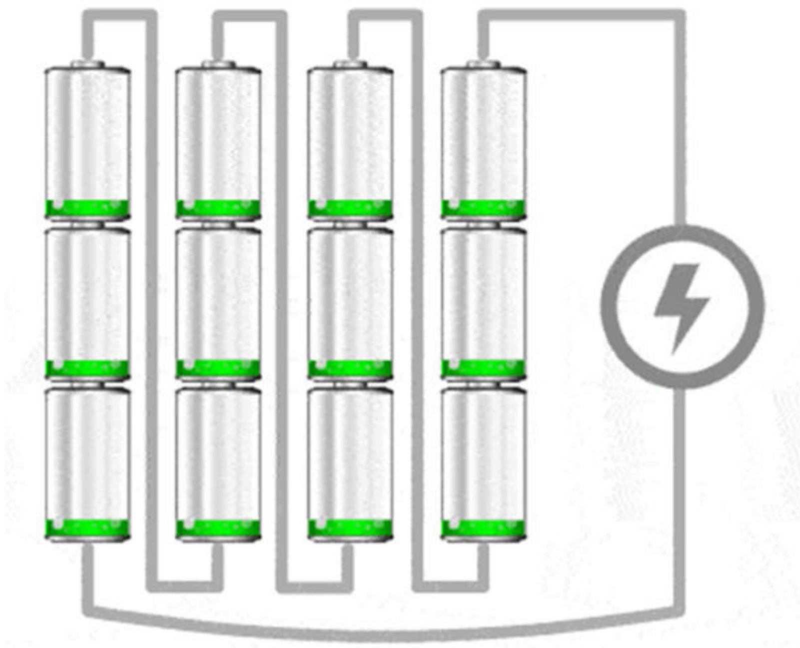


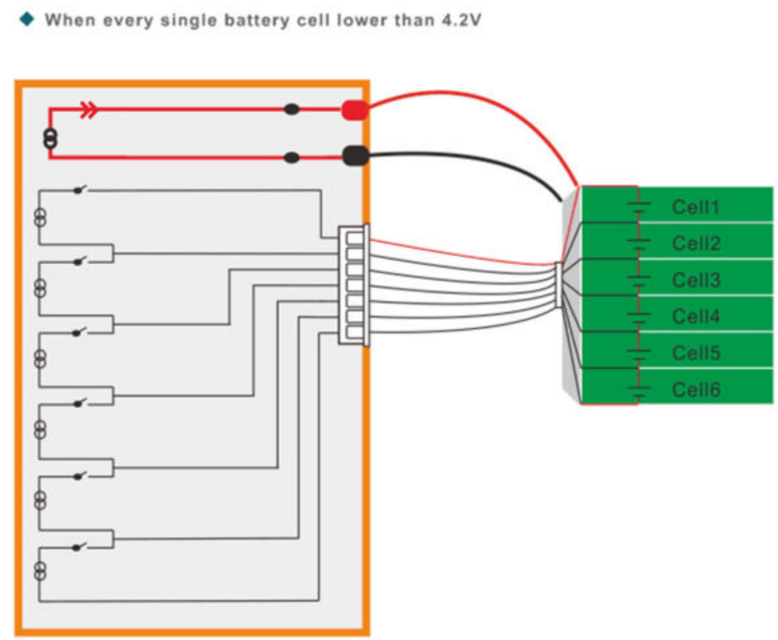
David Capano
MASc Student

OntarioTech UNIVERSITY

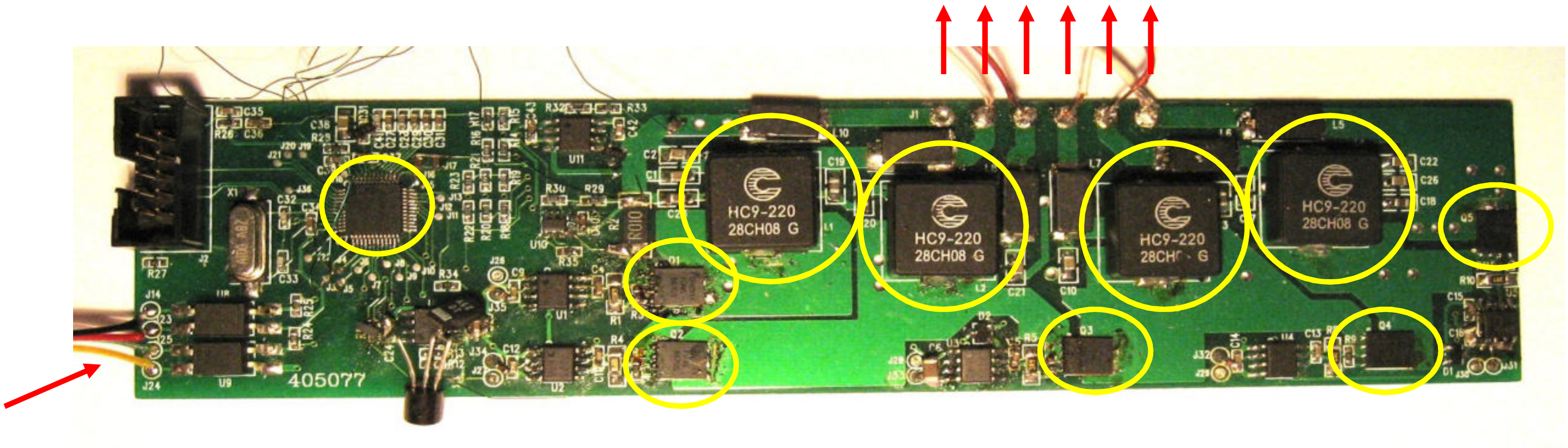
- Discharge rate > 10C
- Racing applications

Cell Balancing/SOC Estimation





Equalizer Prototype



- ➢Microcontroller
- ➢MOSFETs
- ➢Inductors
- ➢To 5 battery cells in series
- ➢Communication Bus

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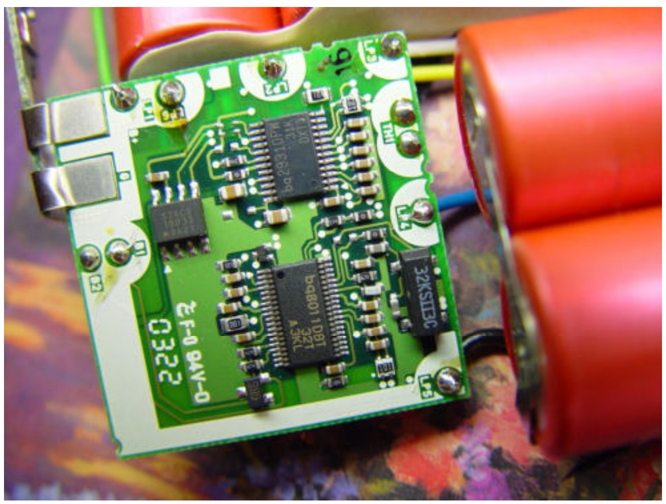
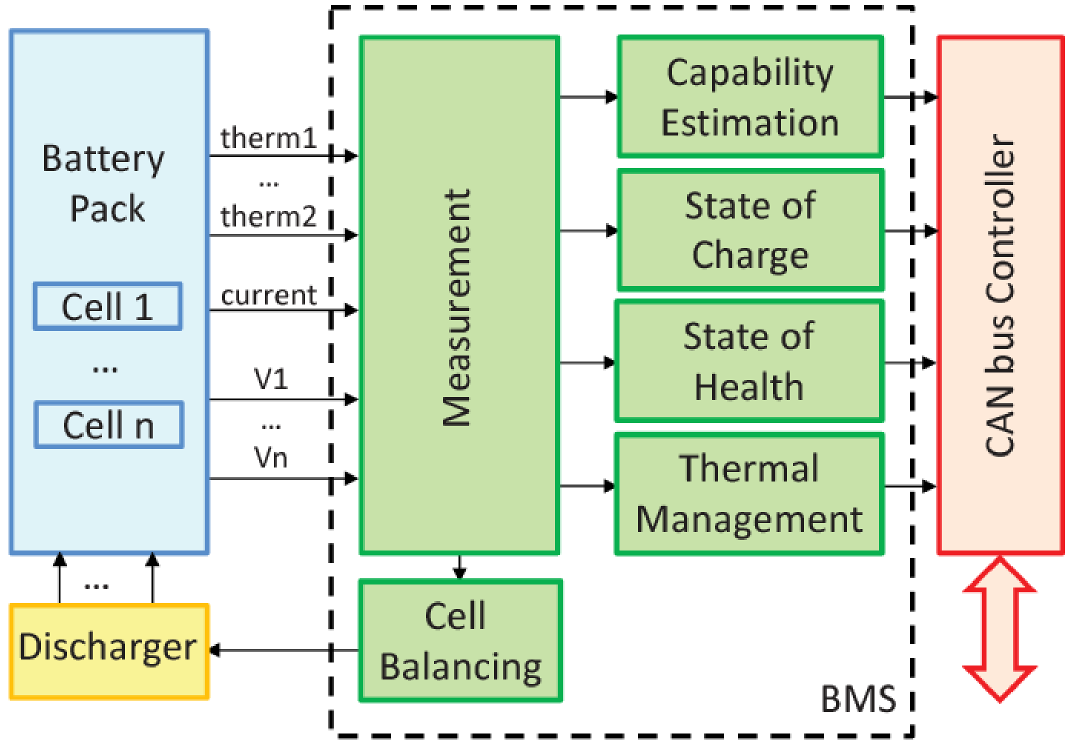
Smart Battery Management Systems

1. **Reducing battery size by 50-60%;**
2. **Extending calendar life by ~200%;**
3. **Within 5% of the battery pack cost.**





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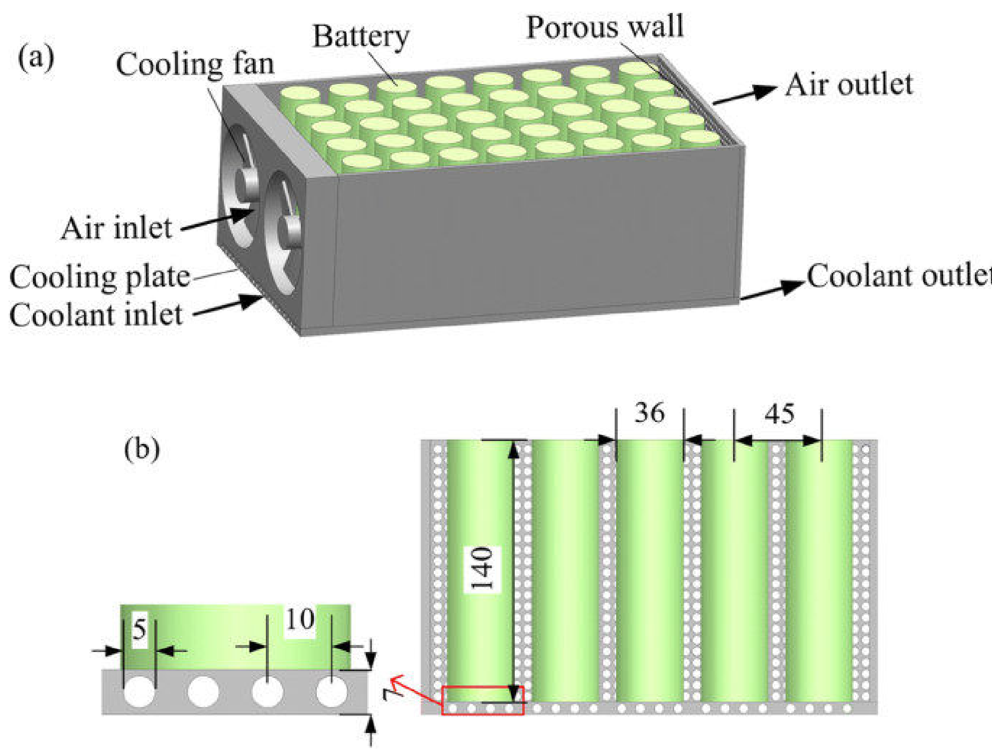
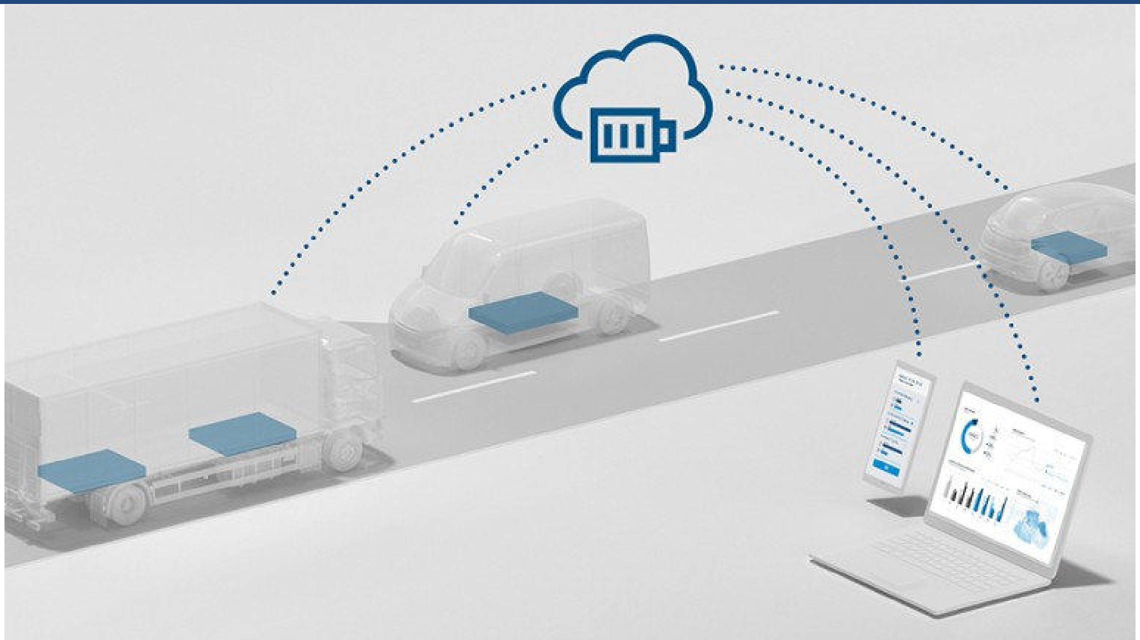
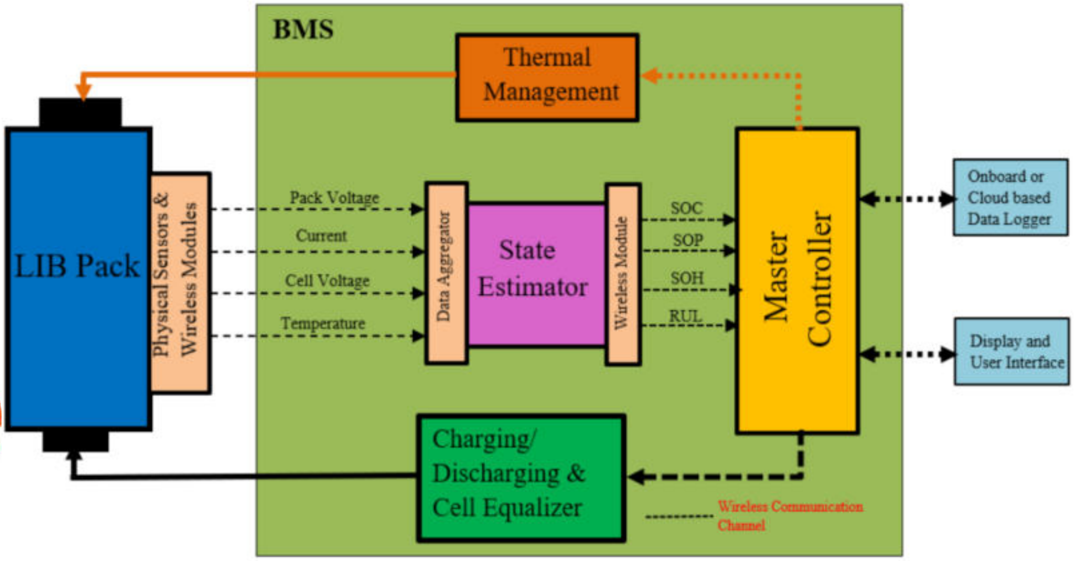
EV Battery 2nd Life and Beyond

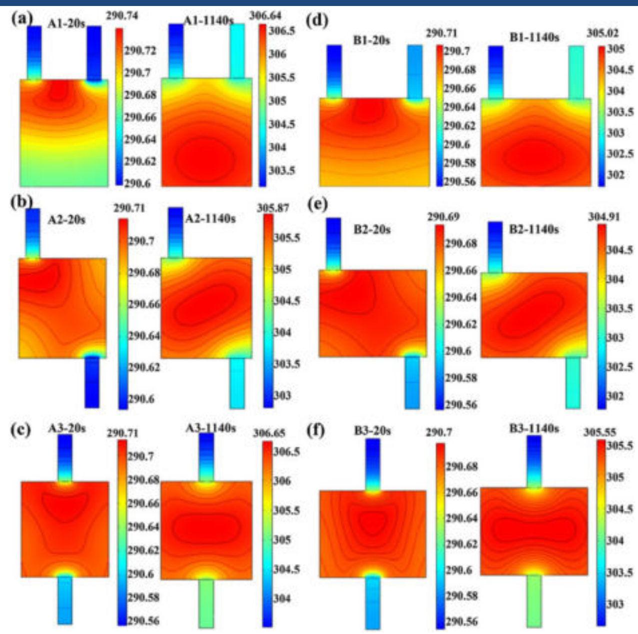


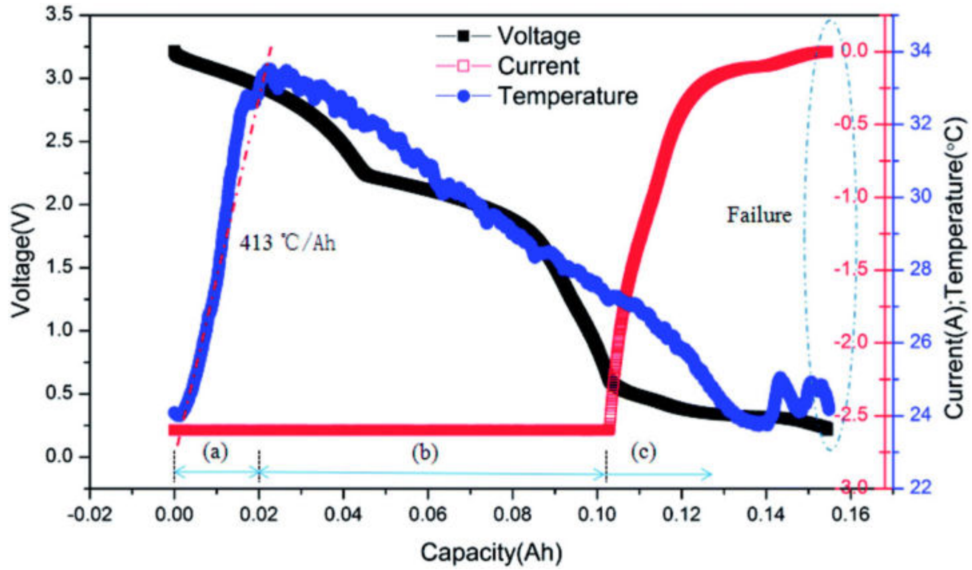
Battery Digital Twin + Wireless Cloud-based BMS

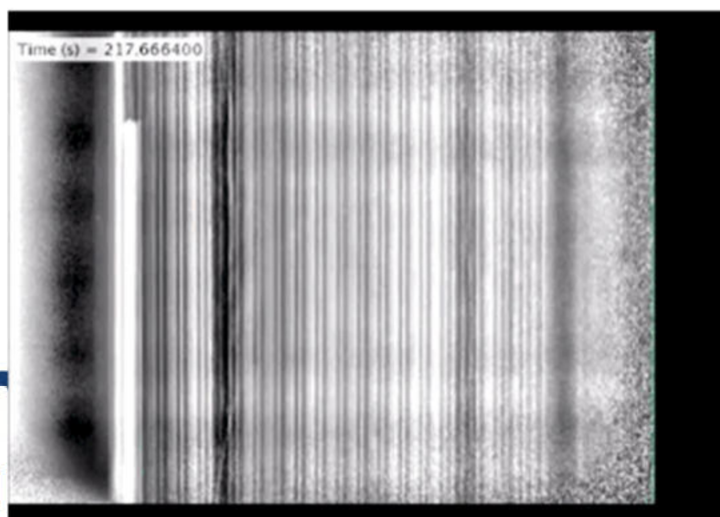


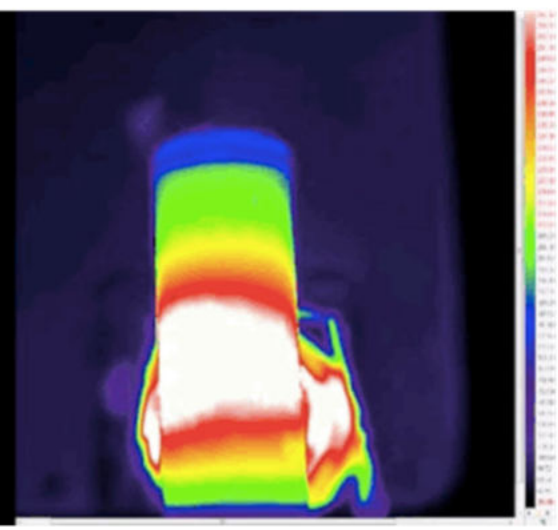


Health-conscious Fast Charging Algorithms

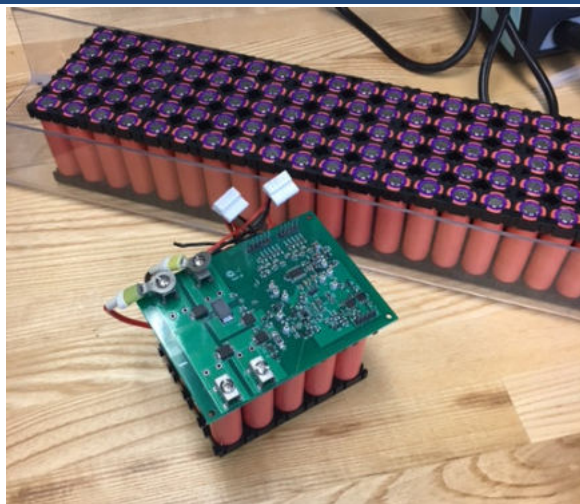


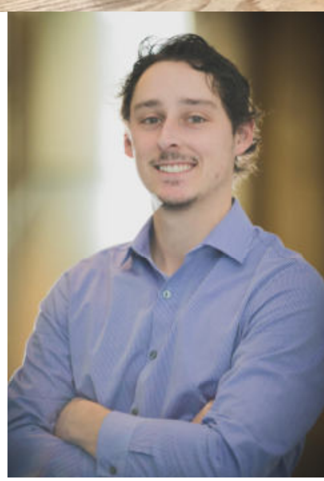


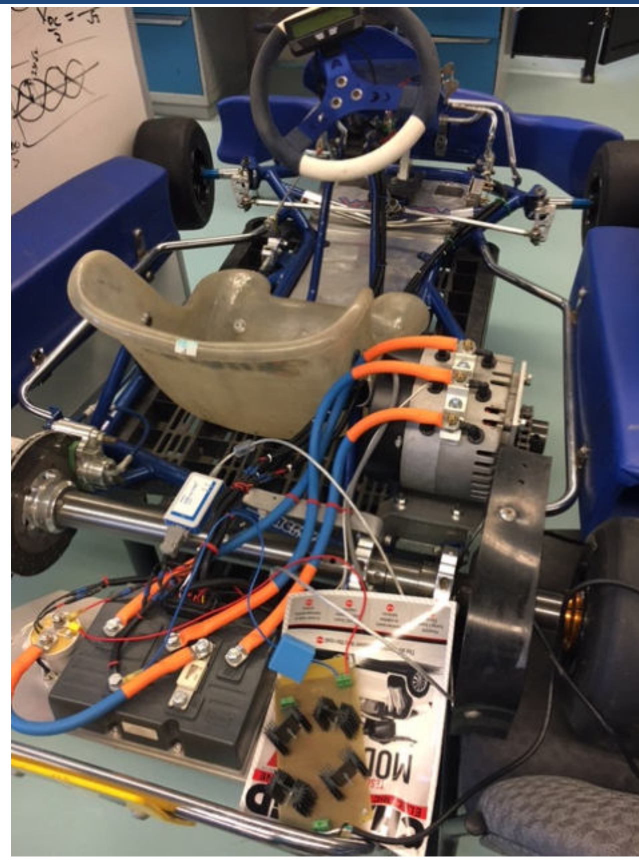




Energy Management for E-racing







LiFePO$_4$ battery energy management under aggressive usage (SAE Formula Electric® Race Car Series)

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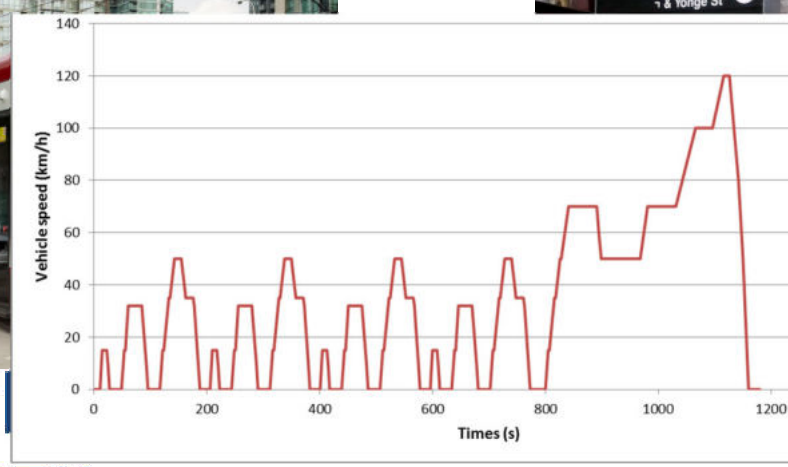
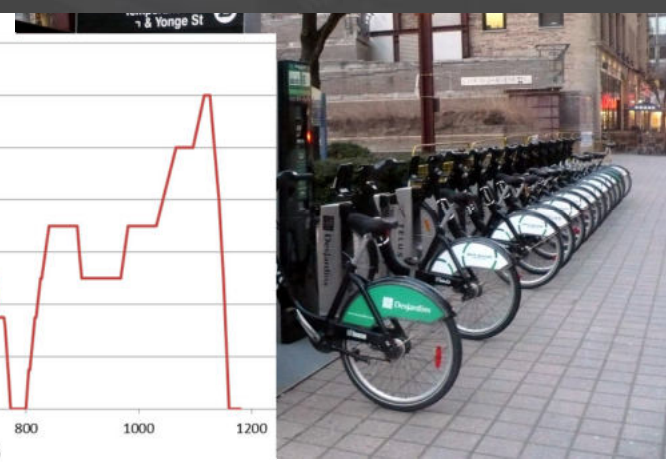
FORMULA SAE ELECTRIC

ace

Ultracapacitors (UC) for Electric Mass Transit

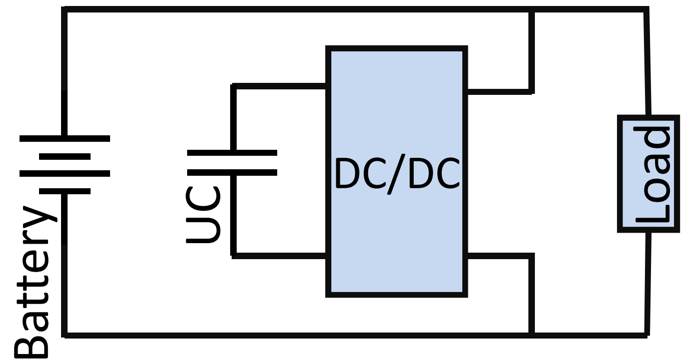




Bank Switching of Ultracapacitors for Hybrid Energy Storage Systems

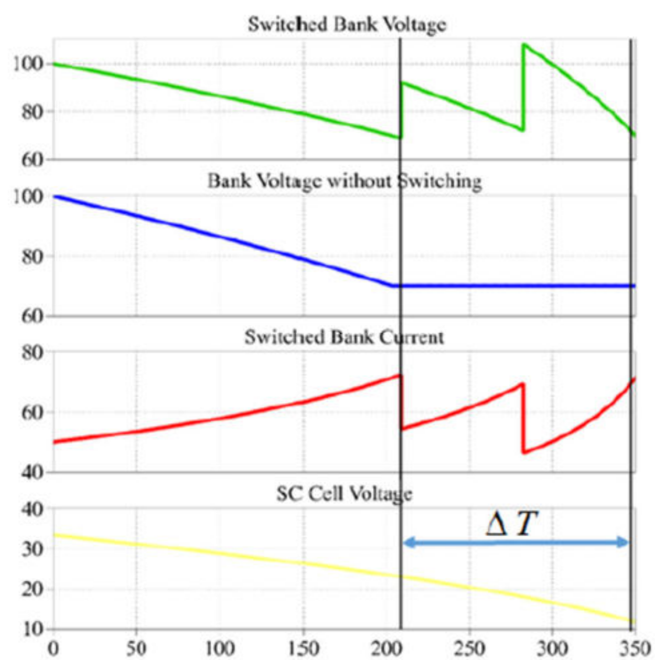
Ultracapacitor
High power

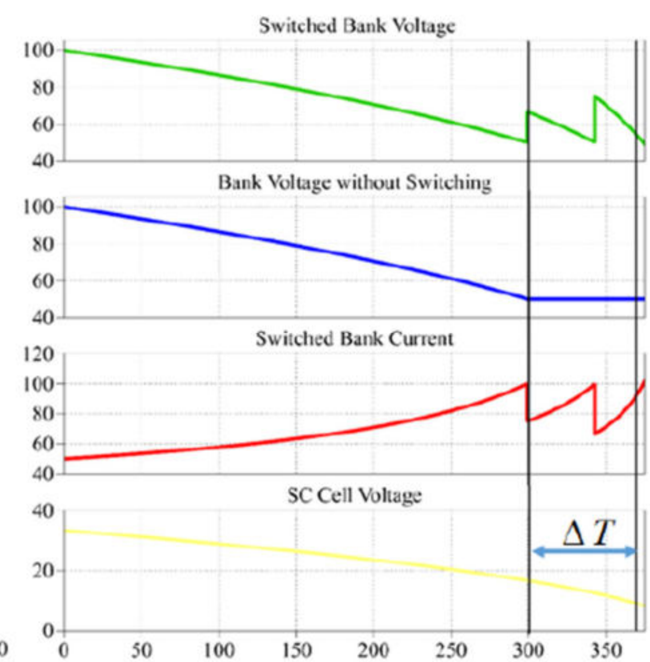
Battery
High energy



Navbir Sidhu
MASc (2017)

Case study using
DRT Route 401





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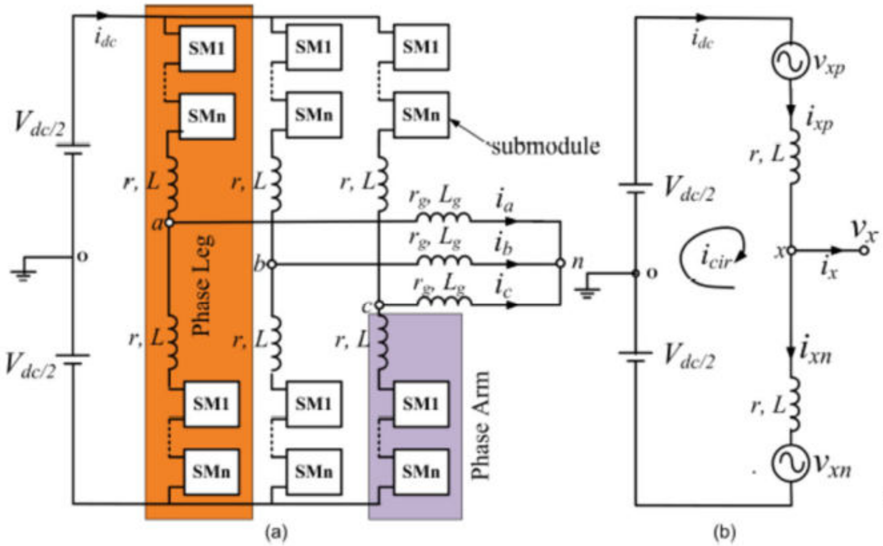
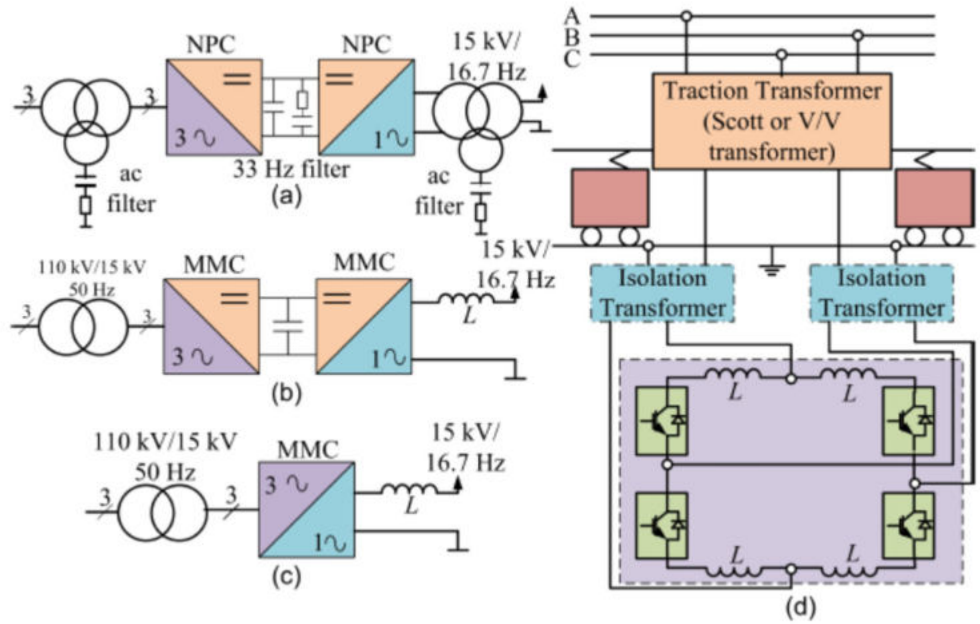
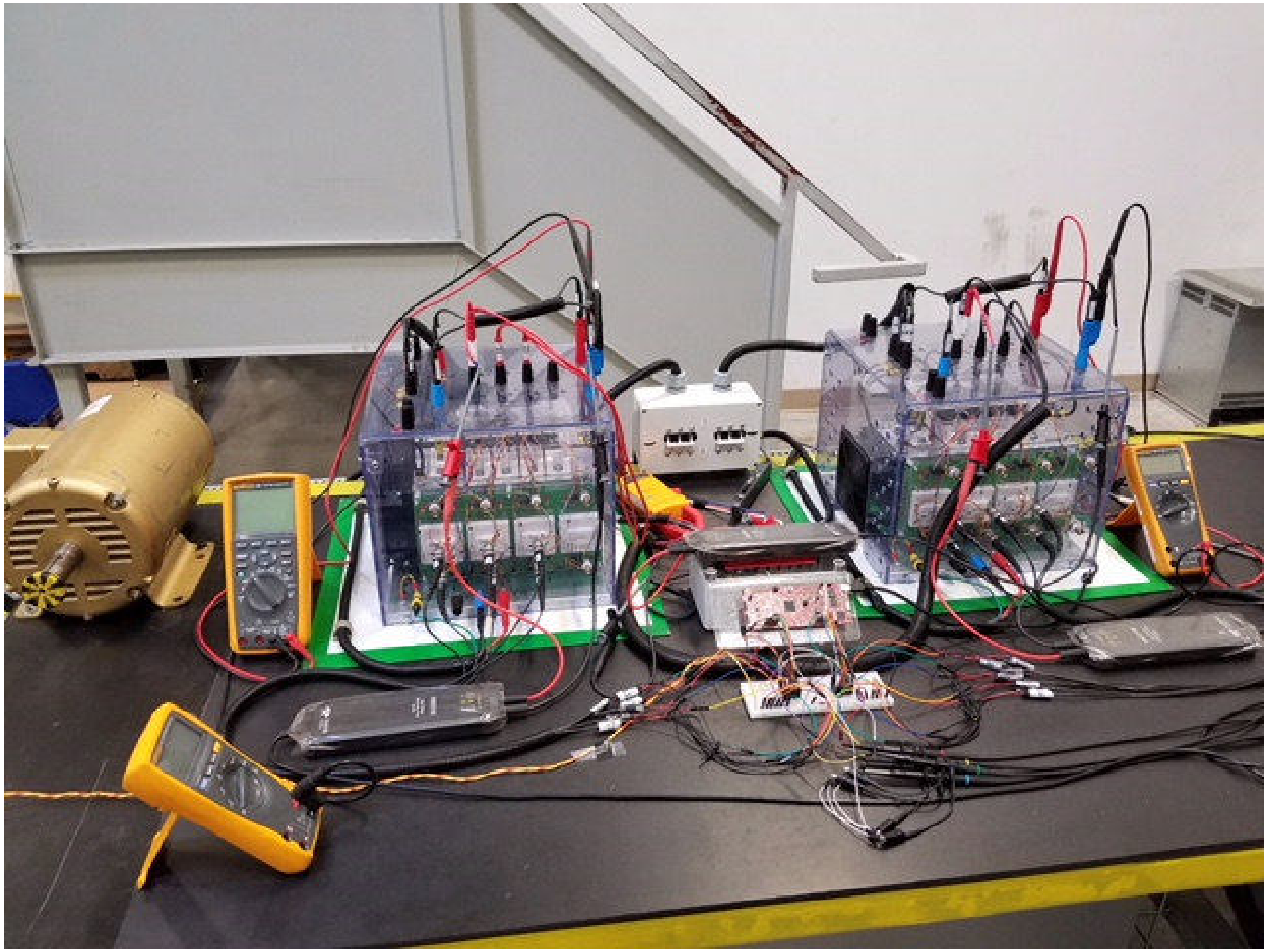
Modular Multilevel Converters for High-power Traction



Deepak Ronanki
PhD (2021)

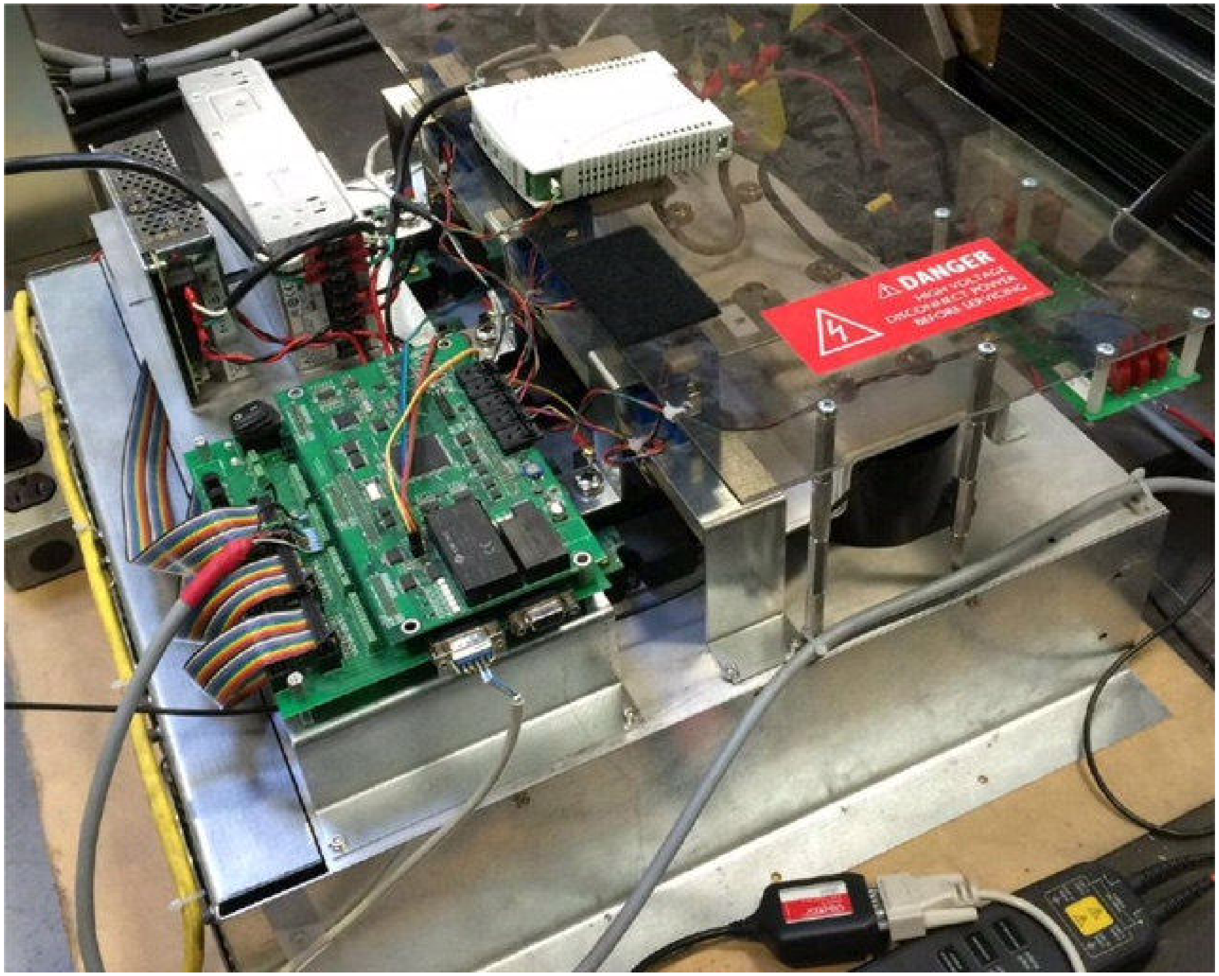


Modular Multilevel Converters for High-power Traction



Rishi Menon
PhD (2020)

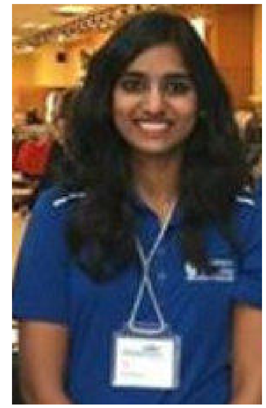
Electric Traction Machine Emulator

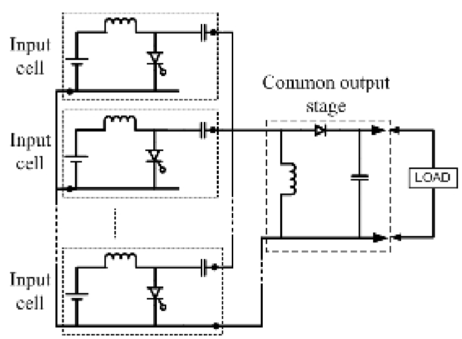


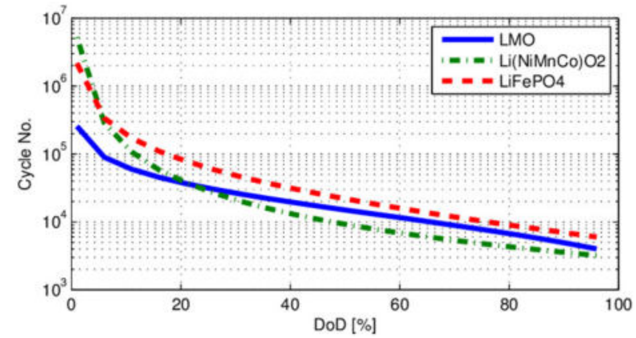
Arvind Kadam
PhD (2022)

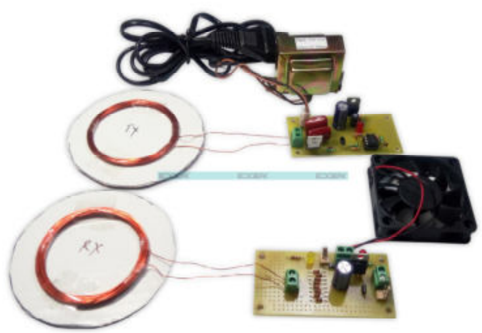
Other Ongoing Projects







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UCs for E-buses (Fast Charging + On-board Power Management)

- **UC bank life estimation for mass e-transit;**
- **UC power management electronics;**
- **UC fast charging converters (≥ 250 kW).**

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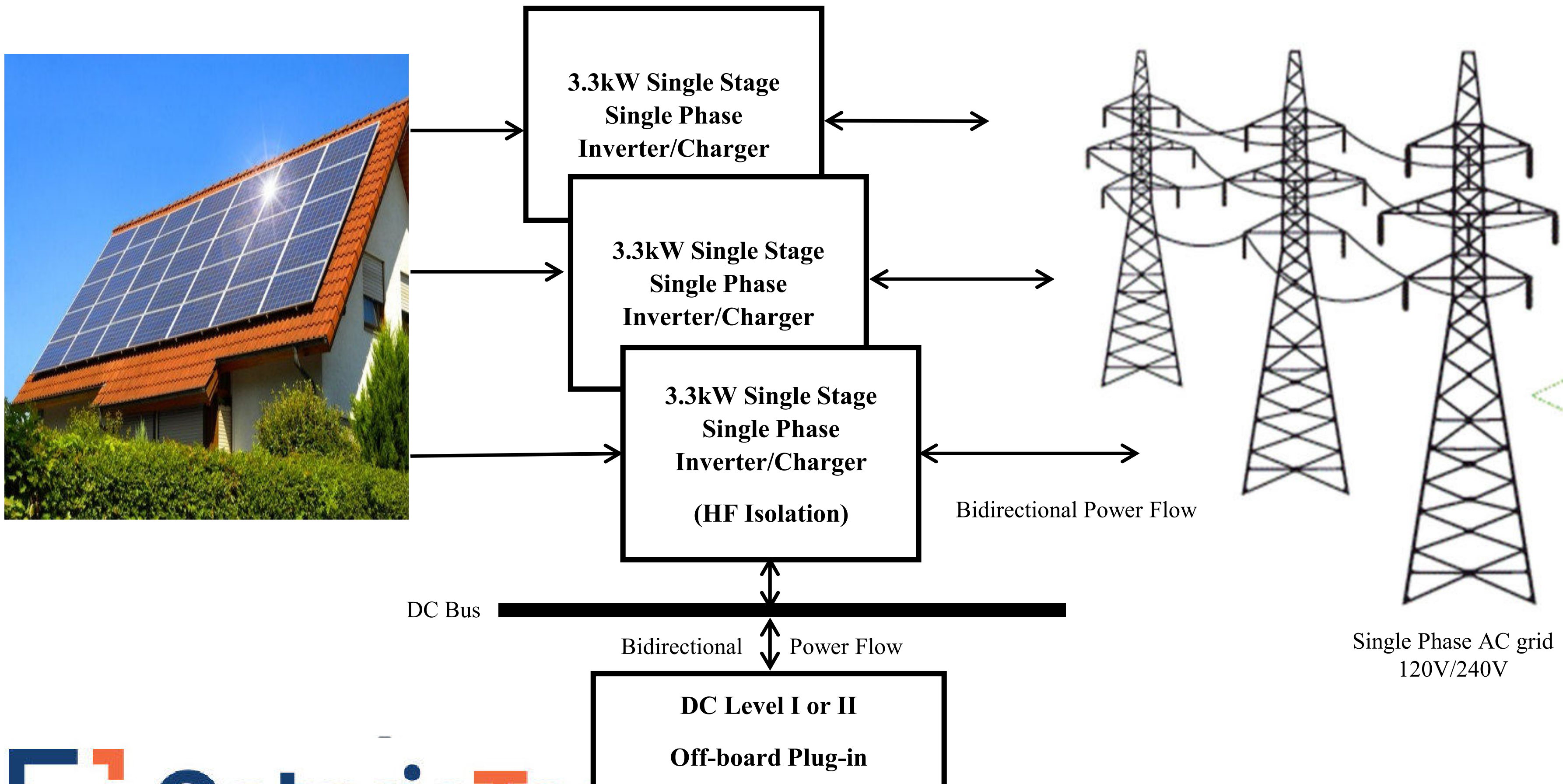
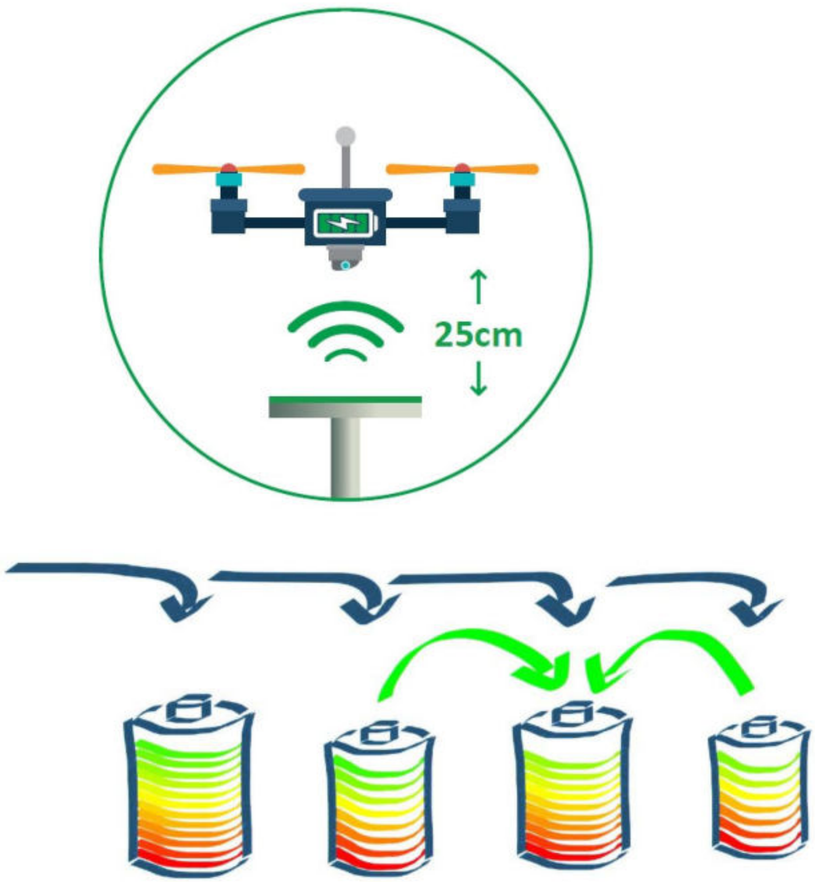
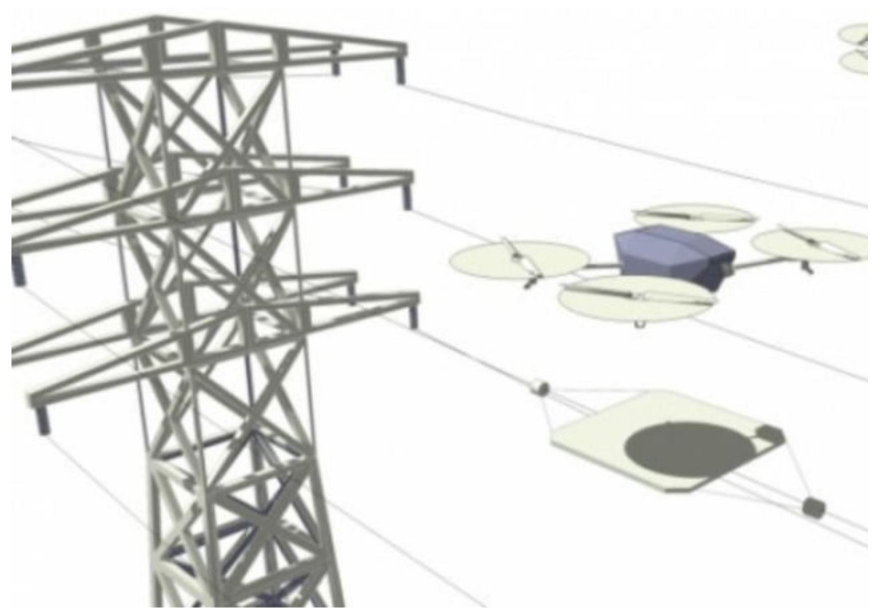
PV/EV/Grid Interface

- Modular 10.0 kW single-stage, 1-phase Inverter/Charger systems for Level 1 or Level 2 DC charging system.



E-drones (Range Extension)





Sky Guys

ONTARIO POWER GENERATION

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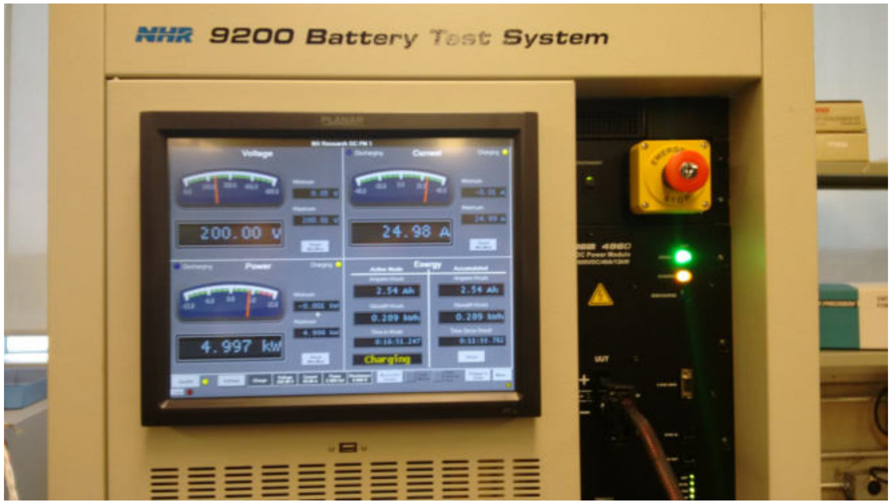
Défense nationale National Defence

Canada Research Chairs
www.chairs-chaires.gc.ca

Automotive Center of Excellence (ACE)



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Automotive Center of Excellence (ACE)

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Microgrid and Innovation Research Park

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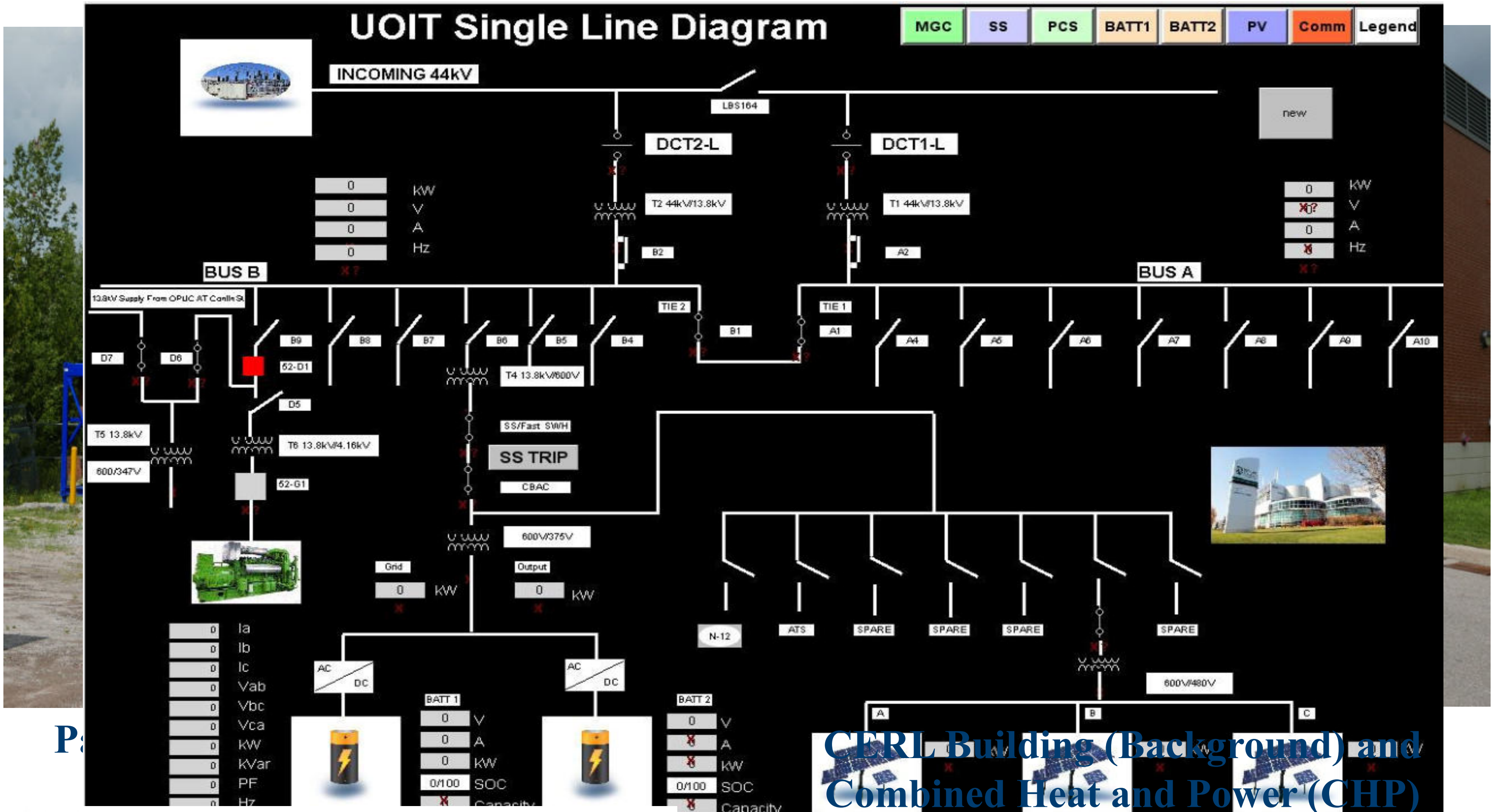
Ontario MINISTRY OF ENERGY

Oshawa PUC Networks Inc.

hydro one

Panasonic

Microgrid and Innovation Research Park



P...

CERL Building (Background) and Combined Heat and Power (CHP) Building (Foreground)

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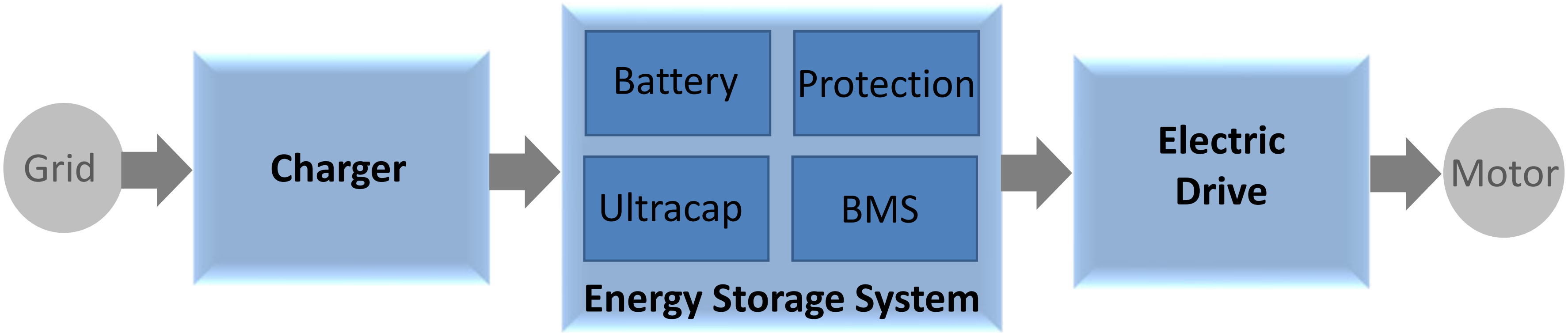
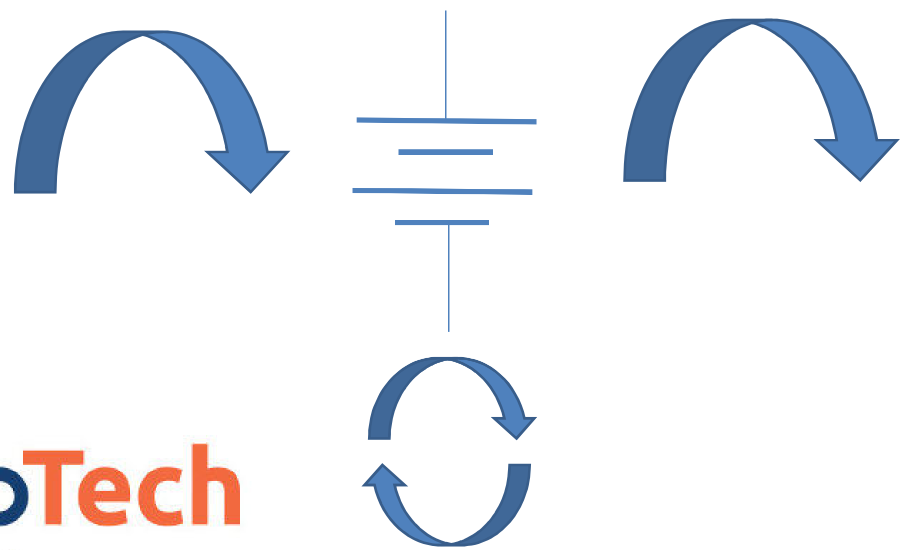
Research Focus Areas at STEER Group





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ONTARIO TECH

RIDGEBACKS

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