Electric Vehicle (EE60082)

Lecture 16: Charger part1

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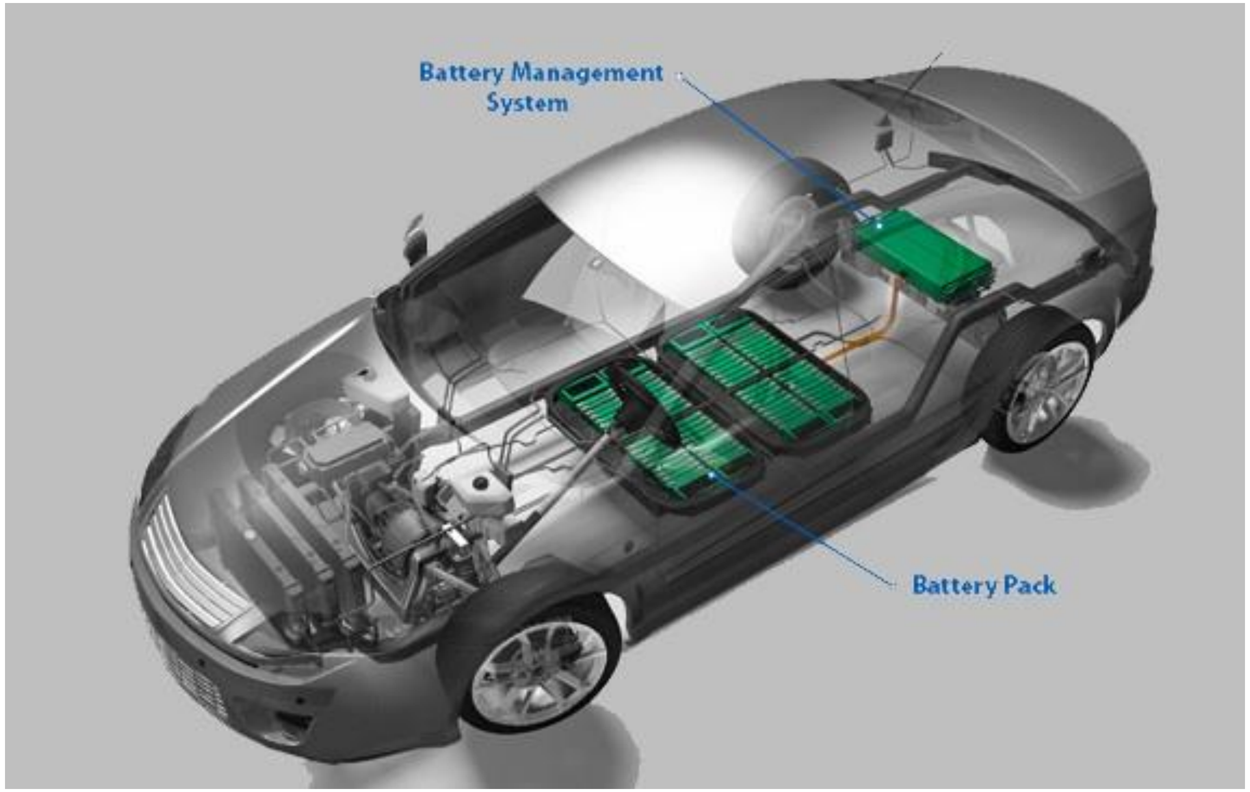
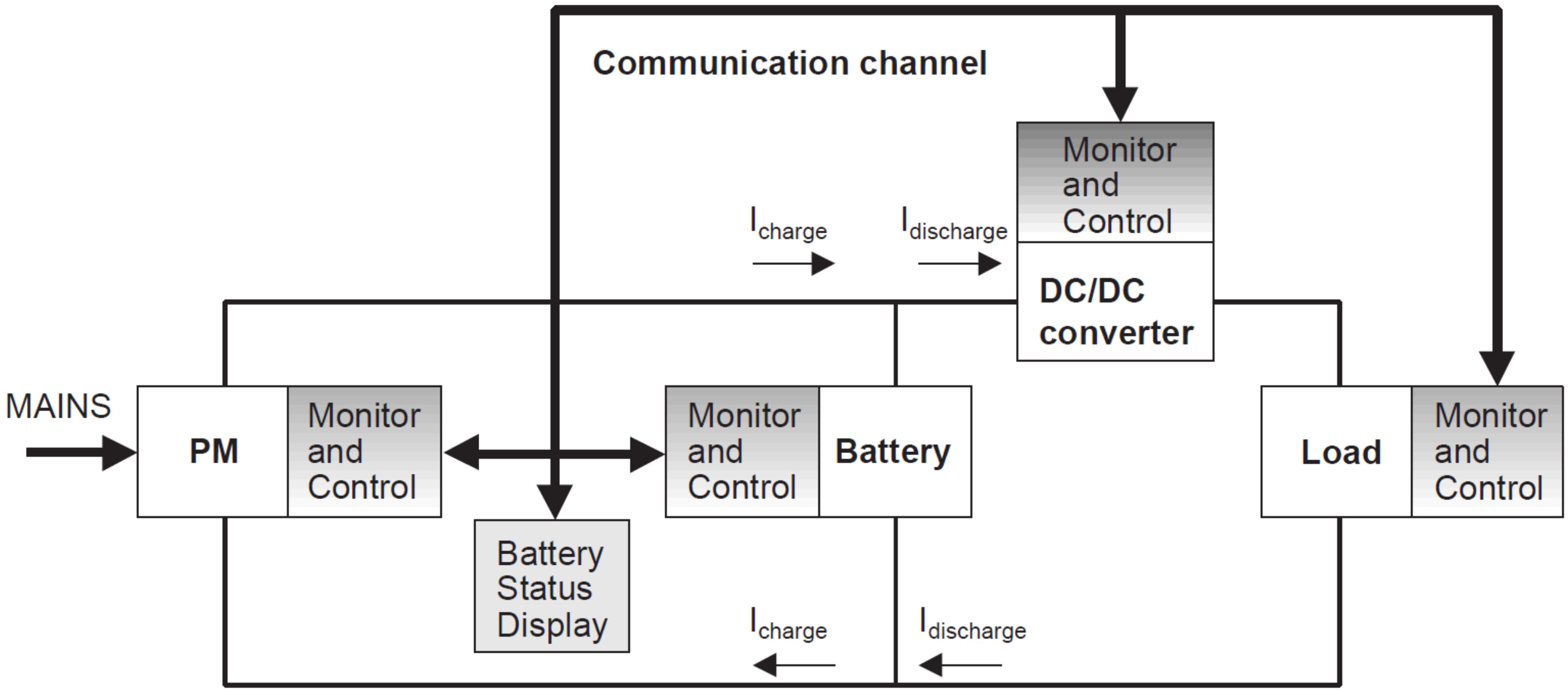
Battery Management System (BMS) (recap)

A generic definition of BMS:

- BMS is combination of all the parts of the system that performs one or more of the following functions for the battery pack,
  - Control
  - Monitor
  - Protect
  - Communicate



A generic BMS (recap)

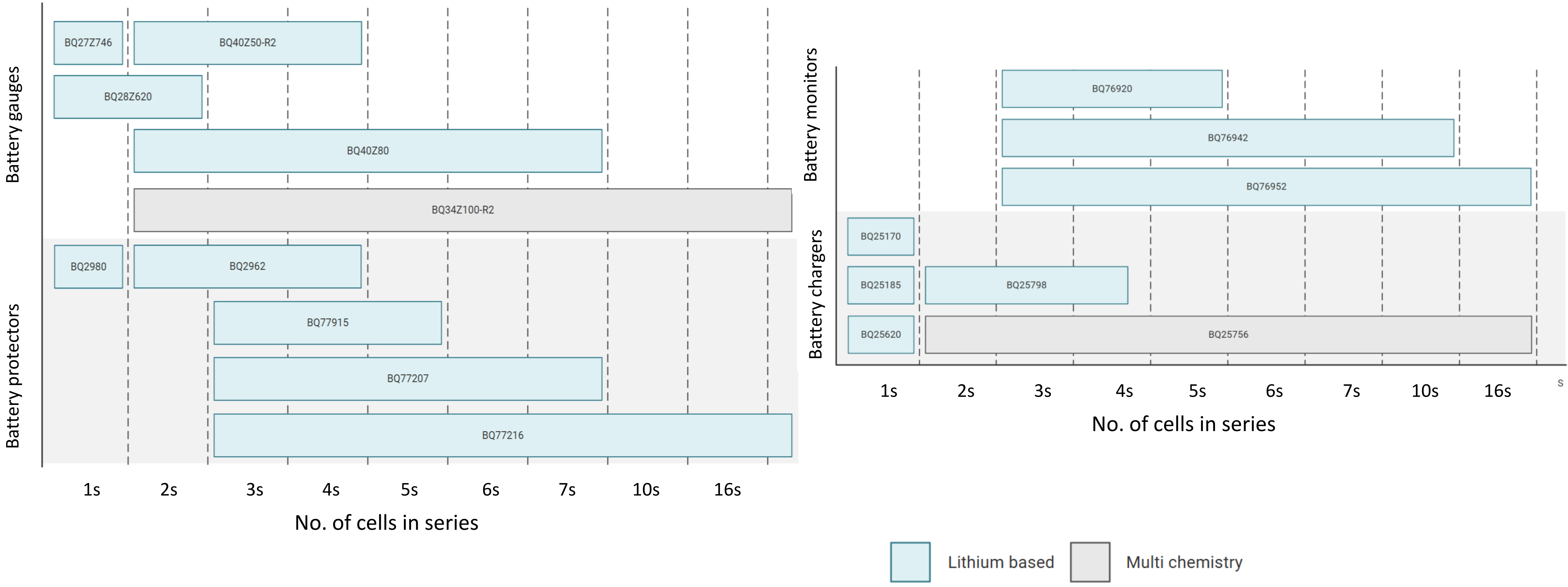


Functions of a BMS (recap)

- Number of functions of a BMS depends on the application
- More functions mean higher cost

- BMS functions depend on the following factors
  - The cost of the portable product: cost of the BMS should be small compared to the product cost
  - The features of the portable product: high-end product has more features that need the BMS to be more sophisticated
  - Type of product: Products with high energy demand and frequent use needs more sophisticated BMS
  - Type of battery: some types of cell chemistries need more care and extra protection features

BMS ICs (from TI) (recap)



Functions of BMS for EV (recap)

Main goals of BMS
- Control battery charging and discharging
- Ensure safe operation
- Maximize battery utilization
- Prolong battery life

Challenges of fast charging for BMS
- Higher and faster voltage unbalance
- Higher power loss and cell temperature, leading to cell degradation
- Complicated thermal management

Charge/discharge Control
- Charge with desired profile
- High efficiency energy conversion

Measure and monitor
- Cell voltage, current, temperature
- Collect data for analysis, prediction, and decision making

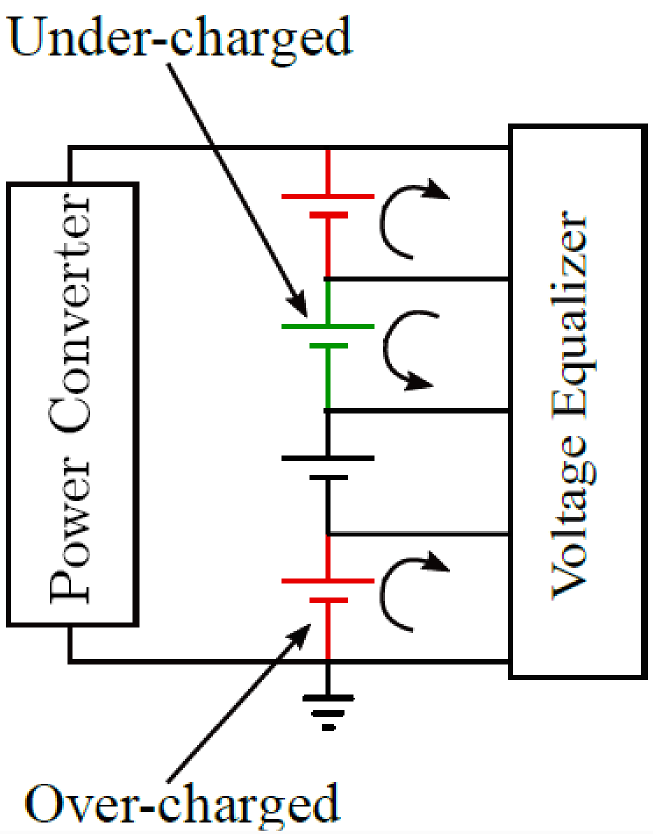
Protect and bypass
- Detect over-current, over-voltage, over-temperature
- Detect faulty cell and bypass

Cell balancing
- Fast active cell balancing
- Multi-cell to multi-cell balancing with high efficiency

Communication
- Status report
- Data collection
- Charging control

Thermal management
- Embedded cooling in battery pack
- Maintain safe temperature during fast charging

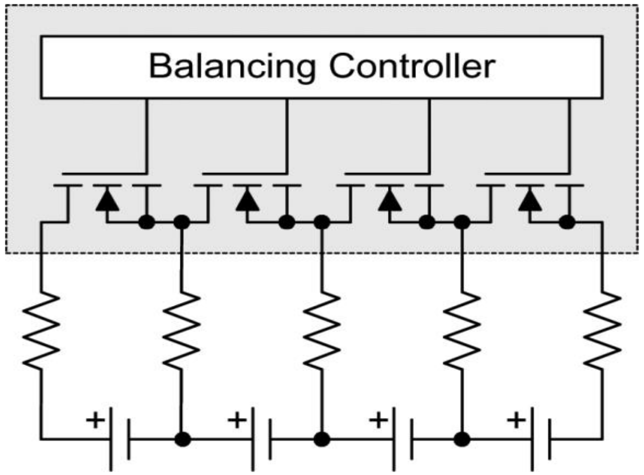
Cell balancing (recap)



Voltage equalization:

- Voltage equalizer equalizes cell voltages
- Over-charged cells are discharged
- Under-charged cells are charged
- Over-charge and over-discharge of any cell is avoided.

Passive Resistor Balancing (recap)



Energy of high-voltage cells is consumed by resistors

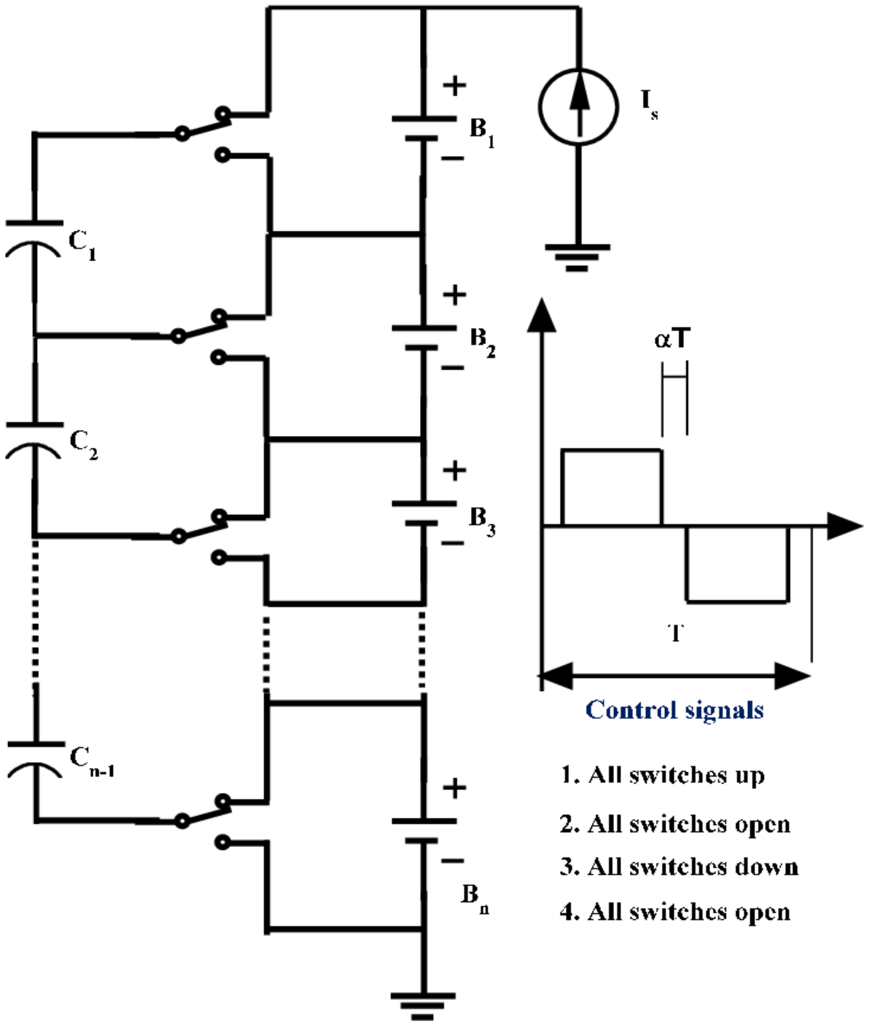
Loss of energy due to balance

Hard to manage heat

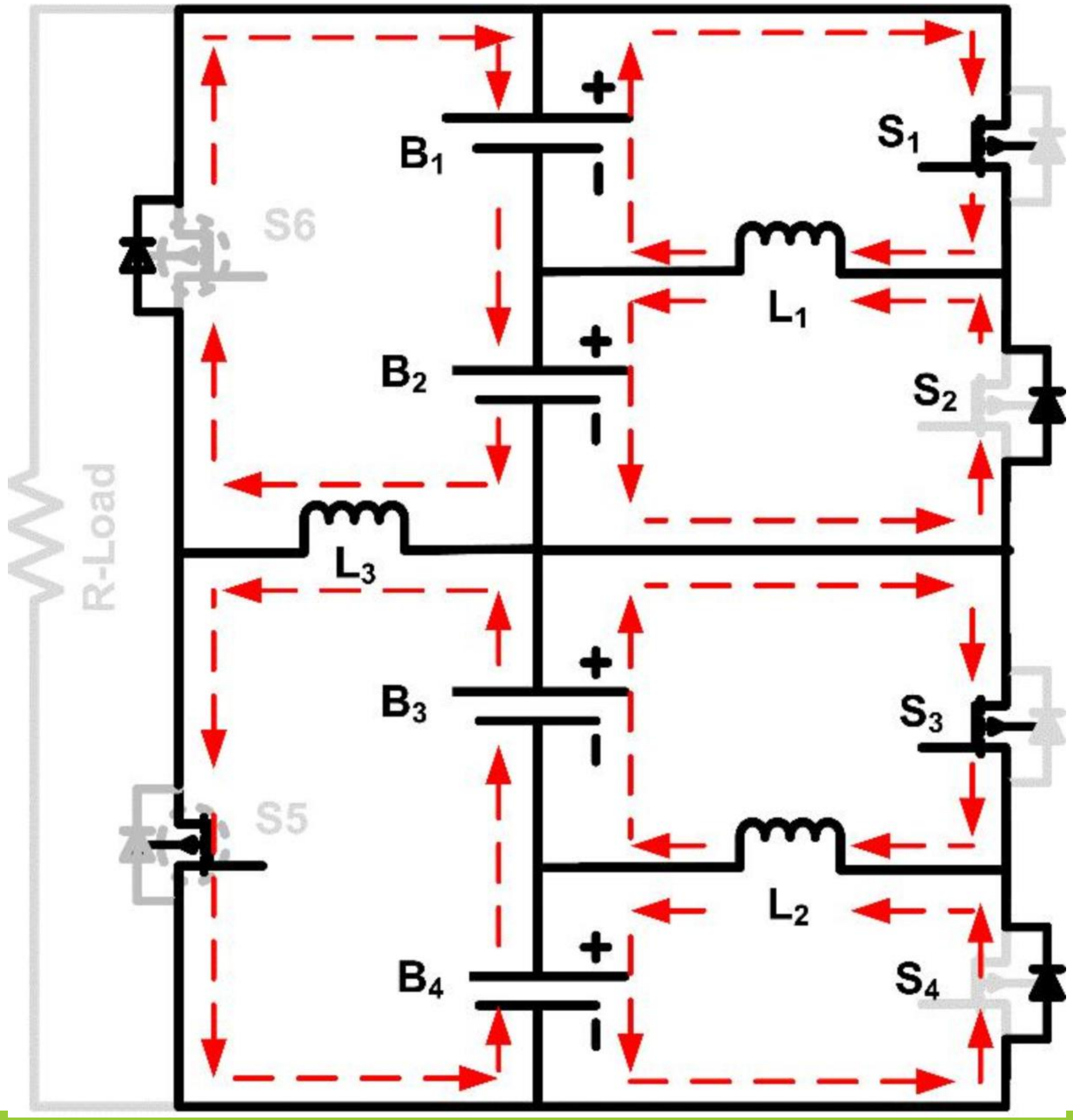
Can only balance the over-voltage cell

N. H. Kutkut, "Life cycle testing of series battery strings with individual battery equalizers," white paper, Power Designers, Inc., 2000. Available: http://t2rerc.buffalo.edu/products/2003_powercheq%20testing.pdf

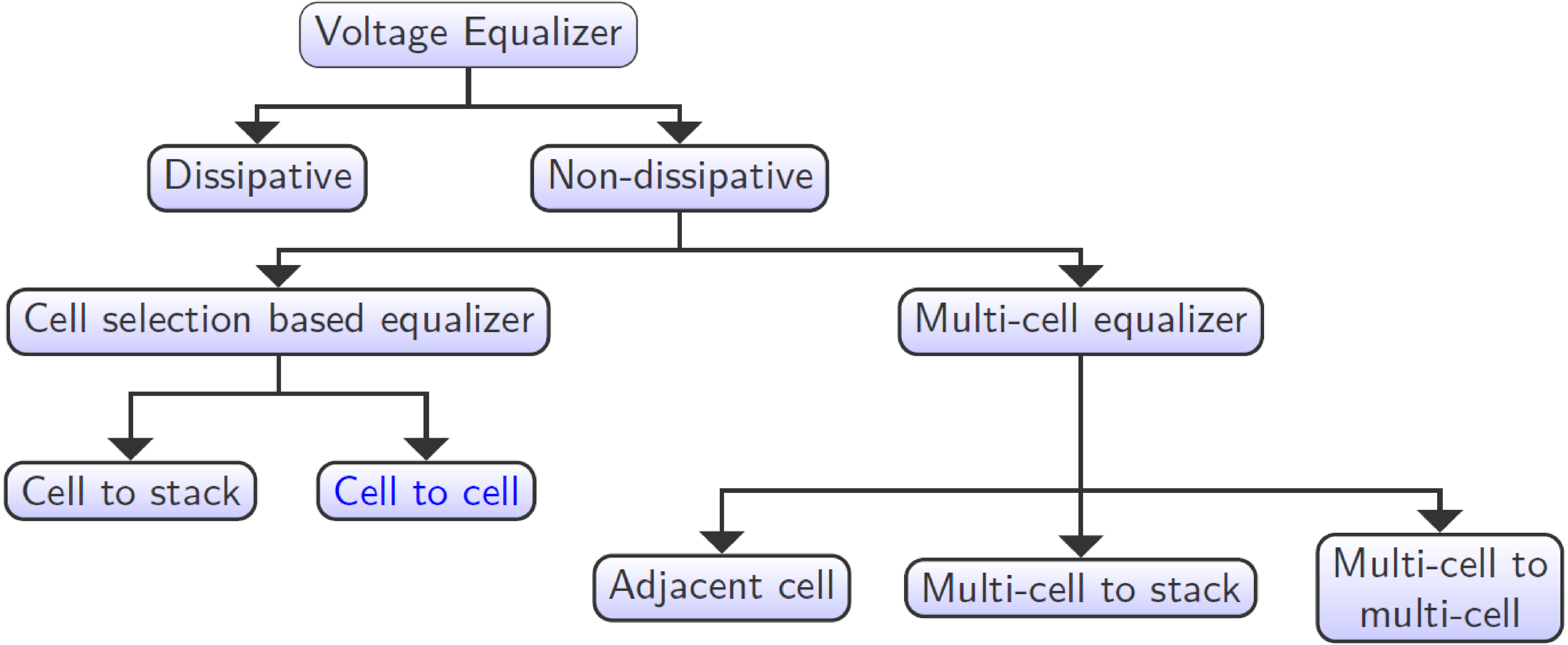
Active balancing: capacitive charge transfer (recap)



Active balancing: inductive charge transfer (recap)



Classification of cell balancers: based on energy transfer paths (recap)

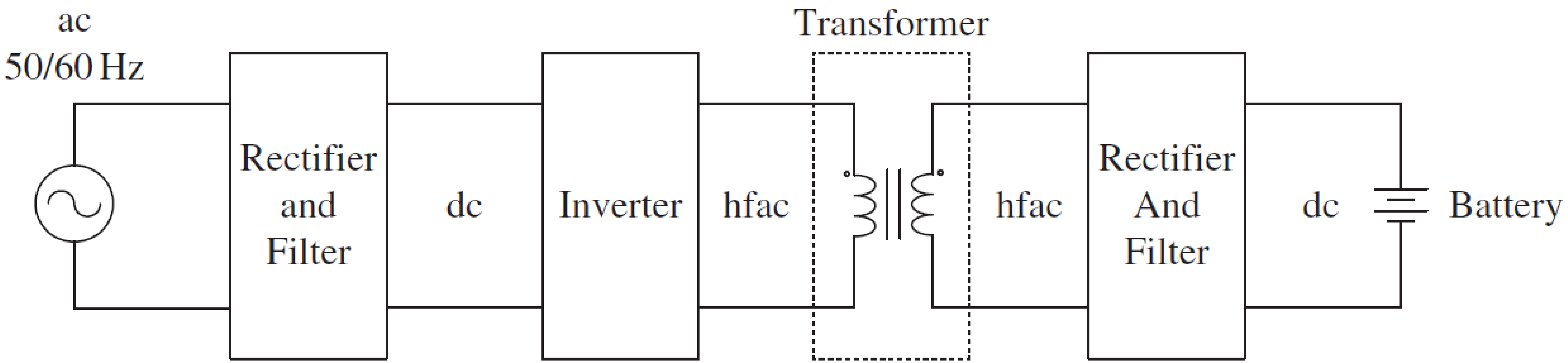


Module 4: EV chargers

Basic requirements for a charger

- Available power sources
  - 50/60 Hz single phase grid at home
  - 50/60 Hz three phase grid at charging stations

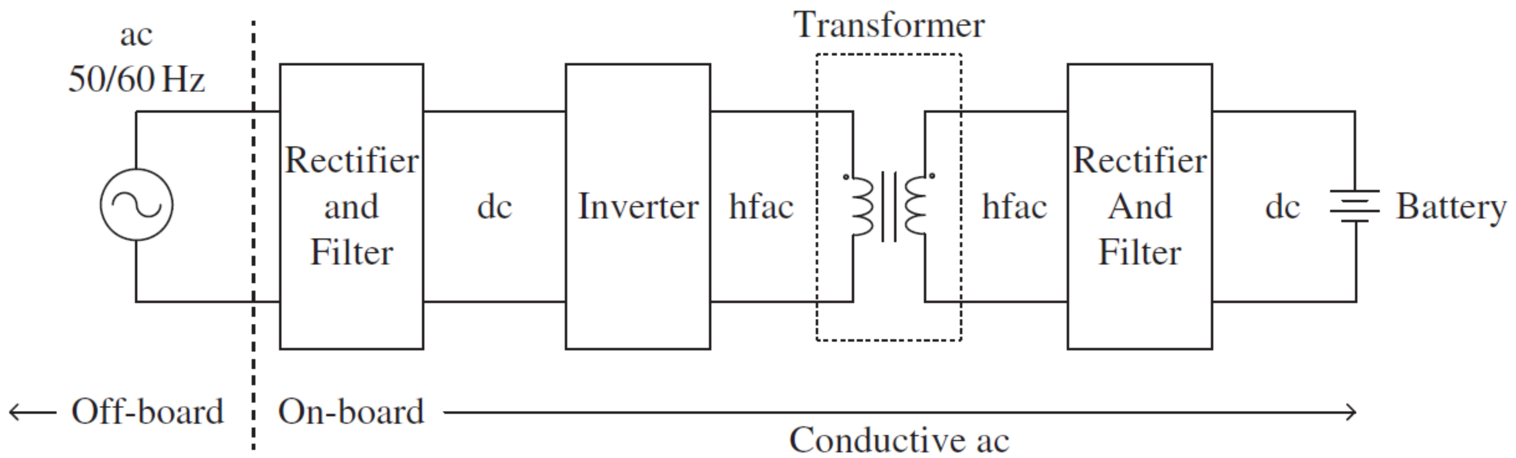
- Minimum requirements are
  - Controllable DC source
  - Isolation for safety



Charger architectures

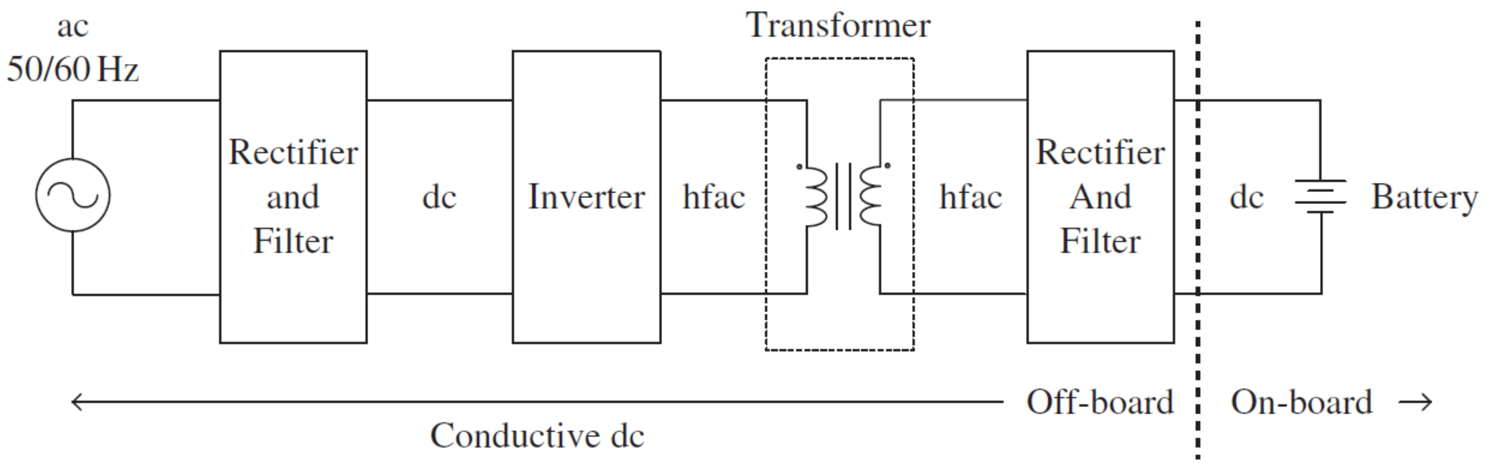
On-board charger

- Low power
- Slow charging
- Home charger
- Called AC charger



Off-board charger

- Medium to high power
- Fast charging
- Charging stations
- Called DC charger



Standards for EV chargers

1. International Standards

- **IEC 61851** – Electric vehicle conductive charging system
  - Defines different charging modes (Mode 1, 2, 3, 4)
  - Covers safety, communication, and performance requirements
- **IEC 62196** – Plugs, socket-outlets, vehicle connectors, and inlets
  - Defines connector types (Type 1, Type 2, CCS, CHAdeMO, etc.)
- **ISO 15118** – Vehicle-to-Grid (V2G) communication interface
  - Covers secure communication between the EV and charger
- **IEC 60364-7-722** – Electrical installations for EV charging
  - Safety regulations for charging stations

3. European Standards (CEN/CENELEC)

- **EN 61851** – European adaptation of IEC 61851
- **EN 62196** – European standard for charging connectors

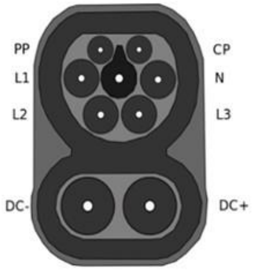
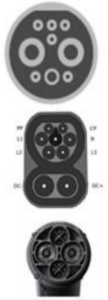
2. US Standards (SAE & UL)

- **SAE J1772** – Standard for AC charging connectors (Type 1)
- **SAE J2847** – Communication between EVs and chargers
- **SAE J2954** – Wireless charging standard
- **UL 2202** – Safety standard for DC fast chargers
- **UL 2594** – Safety standard for EV supply equipment

4. Indian Standards (BIS & ARAI)

- **IS 17017** – Standard for EV charging system
- **IS 17017-1** – General requirements
- **IS 17017-2-2** – DC fast charging system
- **IS 17017-2-3** – AC charging system
- **AIS-138** – Standards for EV conductive charging

Charger standards around the world

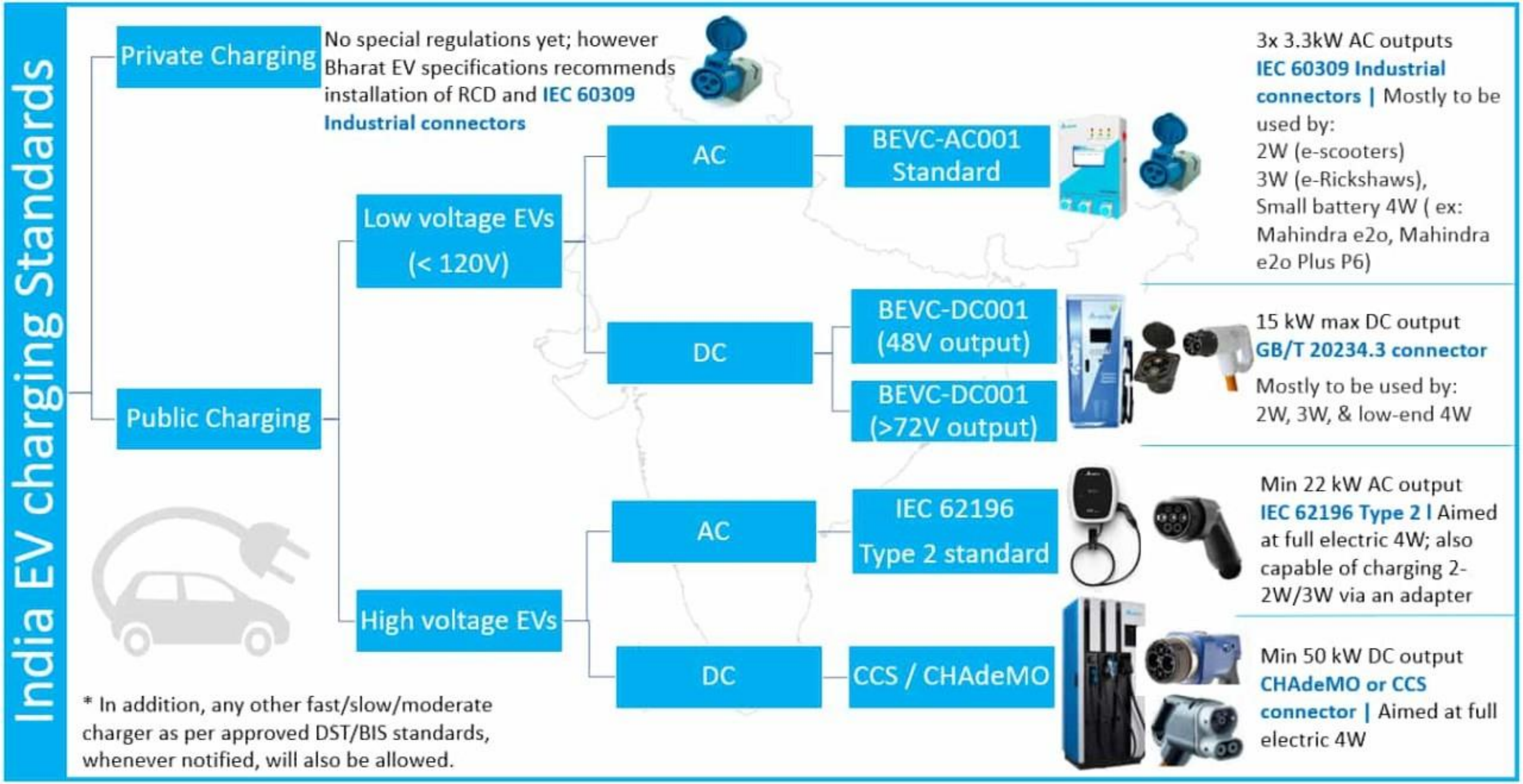
Type of Charging	North America	Japan	EU & rest of the market	China	All markets except EU	India
AC Type1: 1-3kW Type2: 3-22kW						
Plug Name	J1772 (Type 1)	J1772 (Type 1)	Mennekes (Type 2) IEC62196-2	GB/T		Commando (Type-1): IEC60309 Mennekes (Type-2): IEC62196-2
DC 10-400kW						
Plug Name	CCS1	CHAdeMO	CCS2	GB/T	TESLA	GB/T, CCS2, CHAdeMO

Charger categories in US

	Level 1	Level 2	DC Fast Charging
Connector Type[2]	J1772 connector 	J1772 connector 	CCS connector  CHAdeMO connector  Tesla connector 

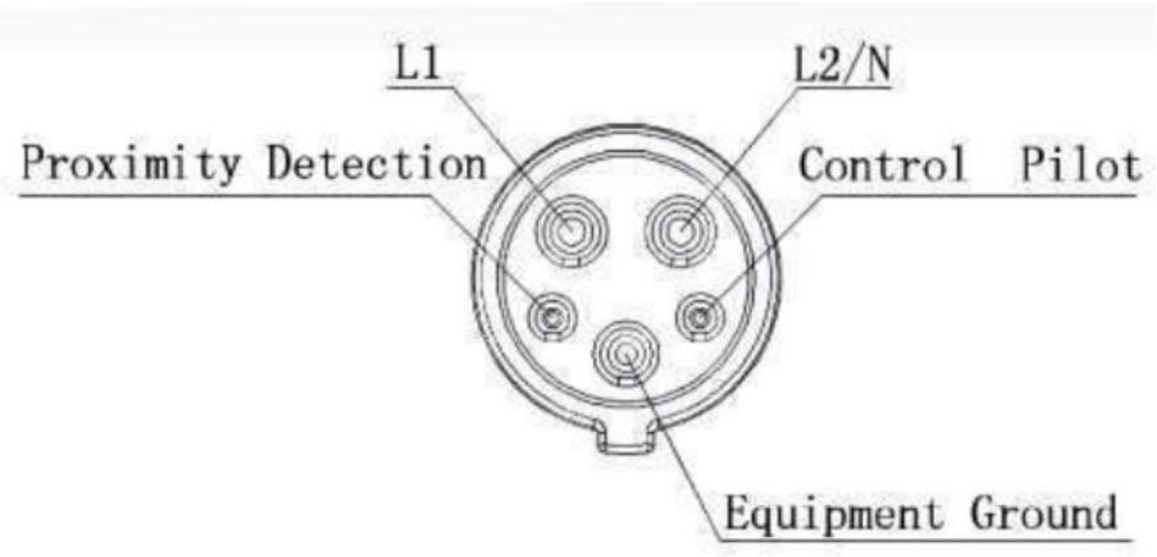
	Level 1	Level 2	DC Fast Charging
Voltage[3]	120 V AC	208 - 240 V AC	400 V - 1000 V DC
Typical Power Output	1 kW	7 kW - 19 kW	50 - 350 kW
Estimated PHEV Charge Time from Empty[4]	5 - 6 hours	1 - 2 hours	N/A
Estimated BEV Charge Time from Empty[5]	40 - 50 hours	4 - 10 hours	20 minutes - 1 hour[6]
Estimated Electric Range per Hour of Charging	2 - 5 miles	10 - 20 miles	180 - 240 miles
Typical Locations	Home	Home, Workplace, and Public	Public

Charger categories in India



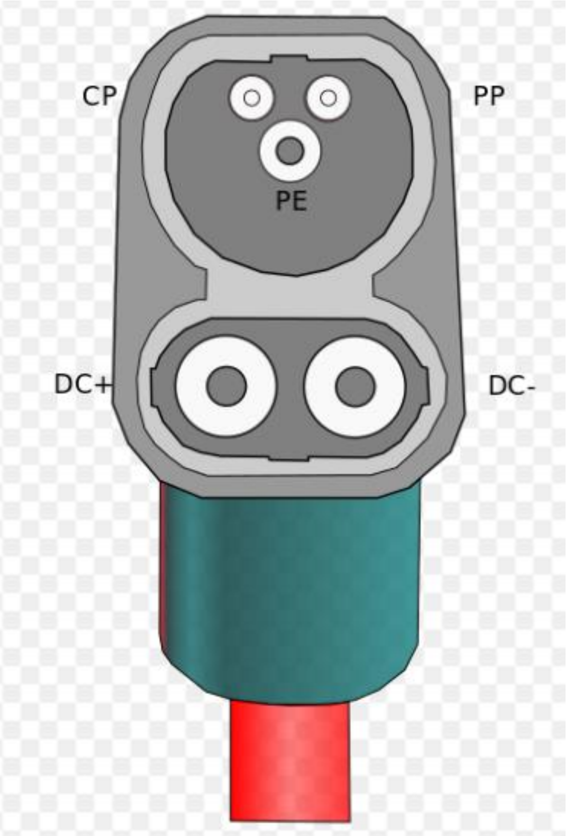
SAE J1772 (AC)


ChargePoint
Network


L1
L2/N
Proximity Detection
Control Pilot
Equipment Ground

Combined Charging Systems (CCS)

DC charger: Bypassing OBC, directly to battery



DC charger connector

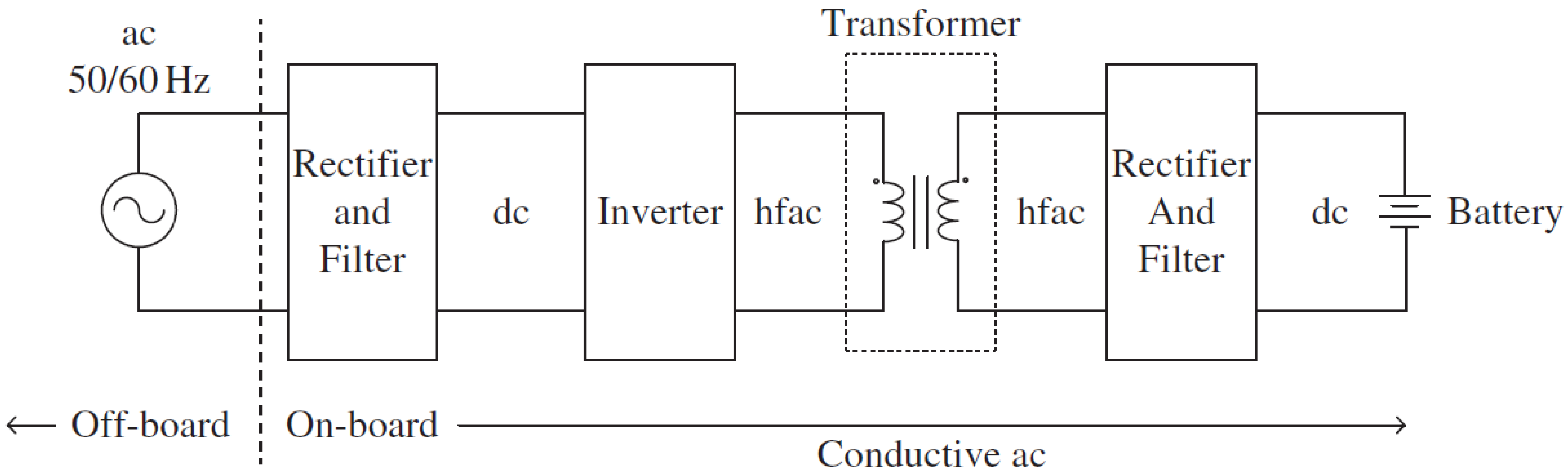
CCS

Combined Charging Systems (CCS)

On-board charger

Topology

- On-board charger (OBC)
  - power supplied from single phase grid
  - AC/DC rectification needed
  - isolation needed for safety



OBC Requirement

- Cost sensitive; ($ > PD> η)
- Automotive qualified parts;
- $-40^{o}C \sim +85^{o}C$ ambient, water cooled;
- Protection installed;
- Mechanical vibration.

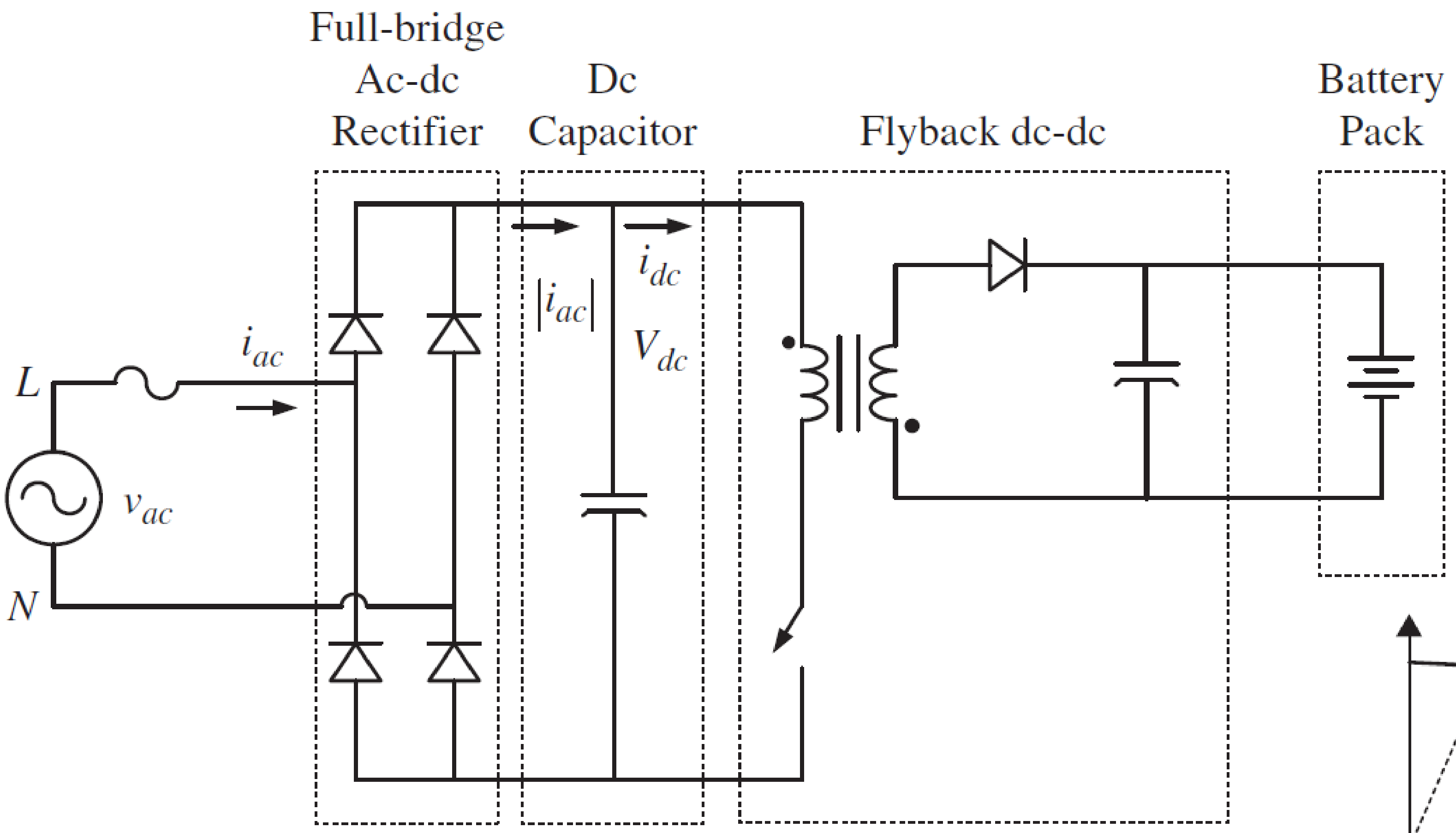
OBC Specs example

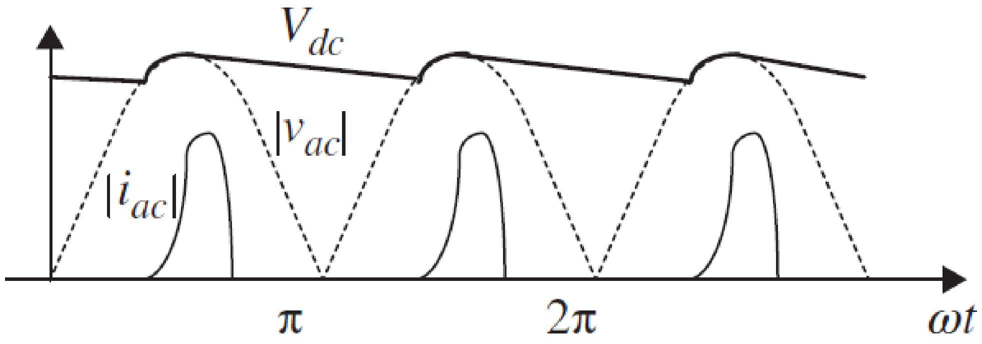
- Power Factor at rated power: > 0.99
- Grid-side Current THD < 5%
- Efficiency estimate ~ 94%
- Output voltage ripple: <2%
- Output current ripple: <5%
- Operating temperature range: -40^{o}C~100^{o}C
- Operating voltage range: 85VAC~240VAC
- Output voltage range: 200VDC~450VDC

- Rated charging power: 6.6kW
- Voltage mode / Current mode: CC & CV Charging
- Ambient: 70^{o}C.
- Power density: (>2kW/L)

- Bidirectional power flow (plus)

Charger with diode bridge rectifier





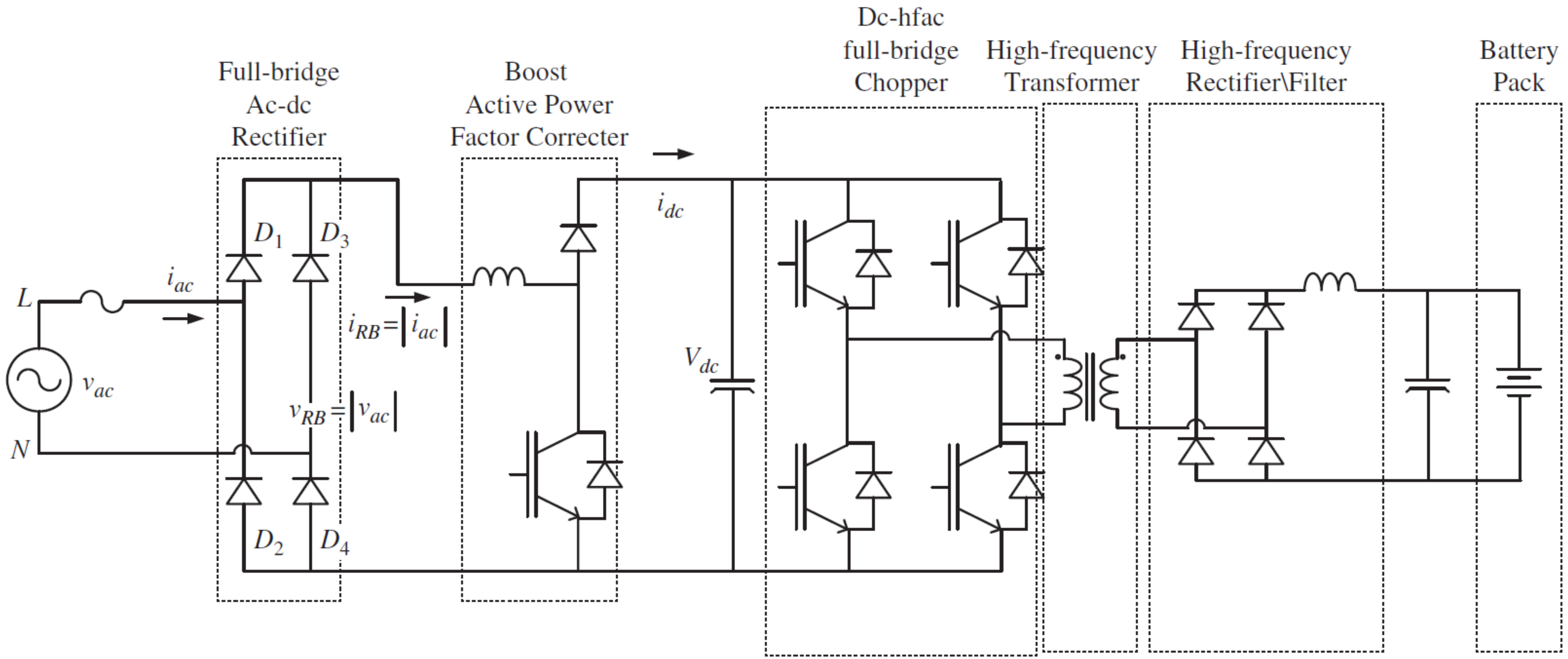
THD requirements

- IEC 61851-21-2 governs the conductive charging system for electric vehicles (EVs) and specifies power quality requirements, including harmonic distortion limits

- EV chargers ≤ 16 A per phase (Low Power AC Charger) must comply with IEC 61000-3-2 Harmonic current limits
  - Total Harmonic Distortion (THD) is typically limited to ≤ 8%.

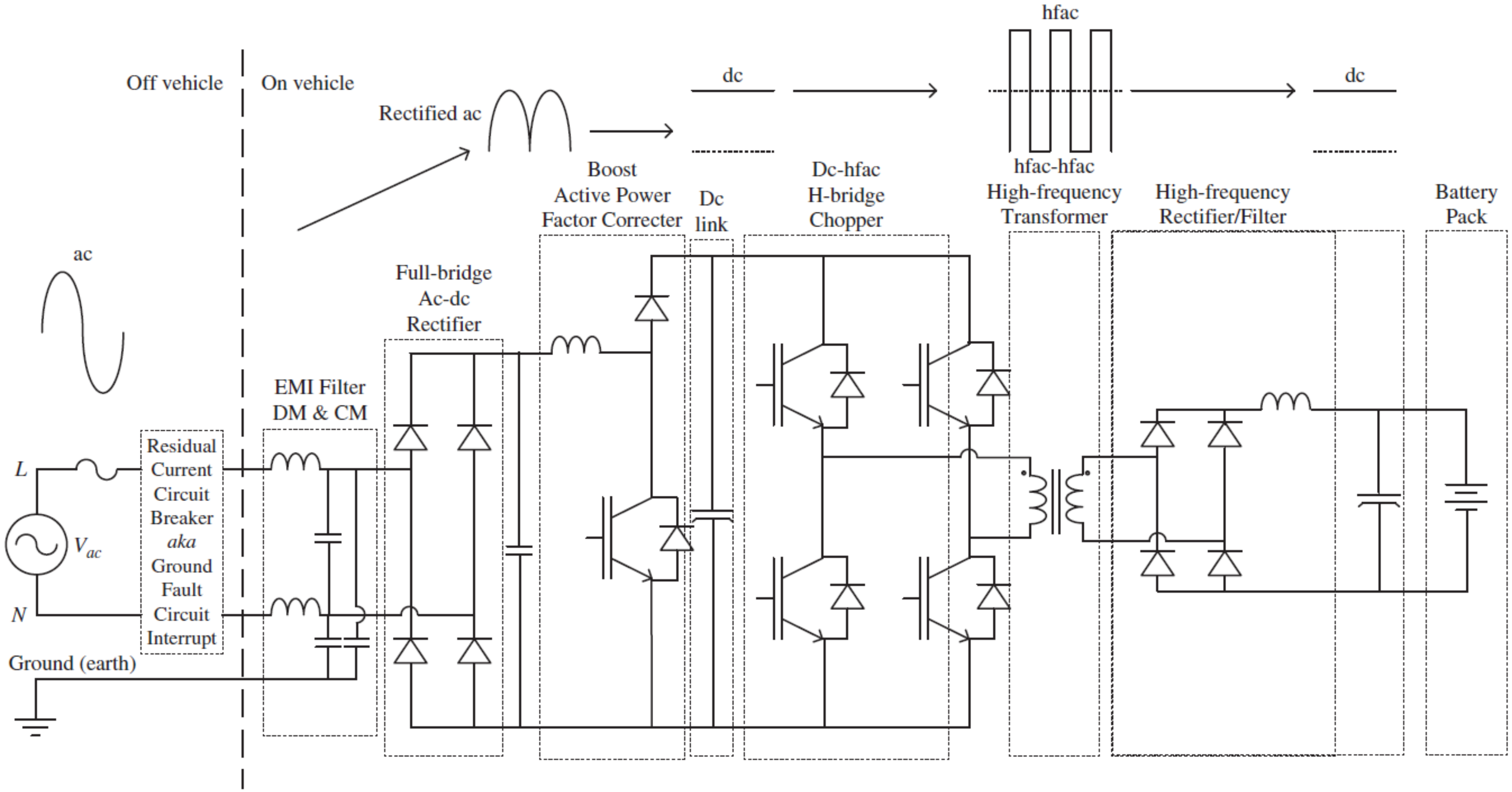
- EV chargers > 16 A and ≤ 75 A per phase (Higher Power AC/DC Chargers) must comply with IEC 61000-3-12
  - Individual harmonic limits are set for odd and even harmonics.
  - THD is typically limited to ≤ 5% for high-power chargers.

Charger with Power Factor Correction (PFC)

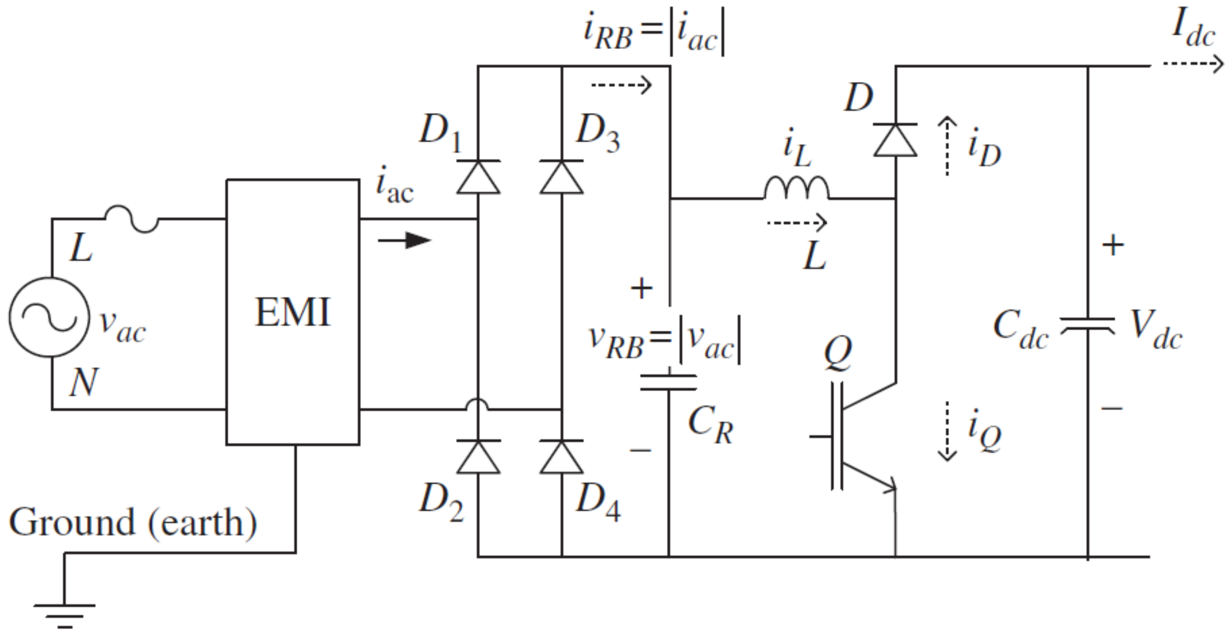


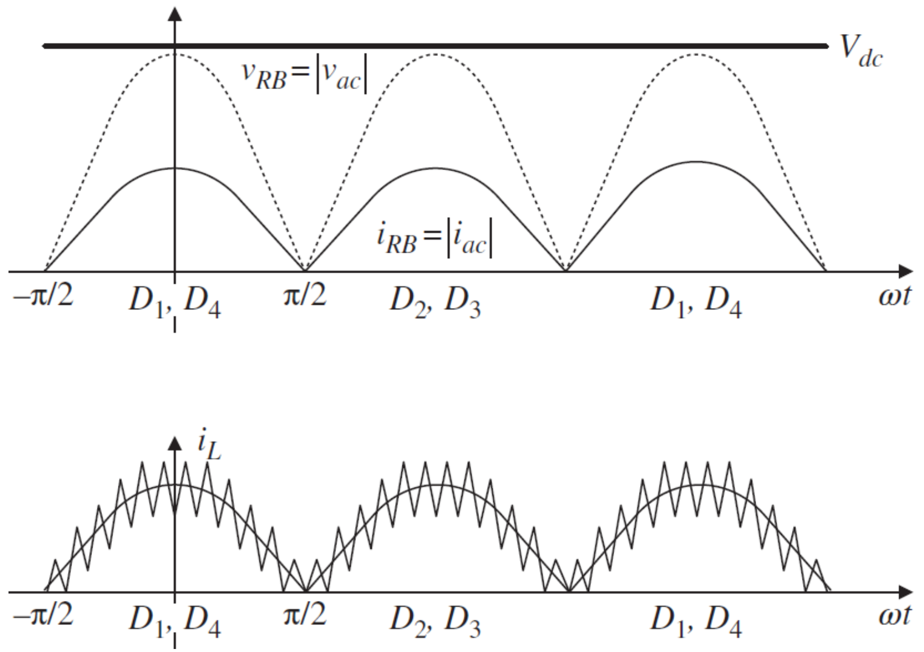
Charger with PFC and EMI filter

- Standard to follow: CISPR 25 for on-board charger



PFC stage design





$$v_{ac}(\theta) = \sqrt{2}V_{ph}\cos\theta$$

$$i_{ac}(\theta) = \sqrt{2}I_{ph}\cos\theta$$

$$v_{RB}(\theta) = \sqrt{2}V_{ph}|\cos\theta|$$

$$i_{RB}(\theta) = \sqrt{2}I_{ph}|\cos\theta|$$

DC current from PFC

- AC power

$$p_{ac}(\theta) = v_{ac}(\theta) \times i_{ac}(\theta) = \sqrt{2}V_{ph}\cos\theta \times \sqrt{2}I_{ph}\cos\theta = 2V_{ph}I_{ph}\cos^2\theta$$

$$P_{ac} = V_{ph}I_{ph}$$

- DC power

$$p_D(\theta) = V_{dc} \times i_D(\theta)$$

- Power balance

$$p_D(\theta) = p_{ac}(\theta)$$

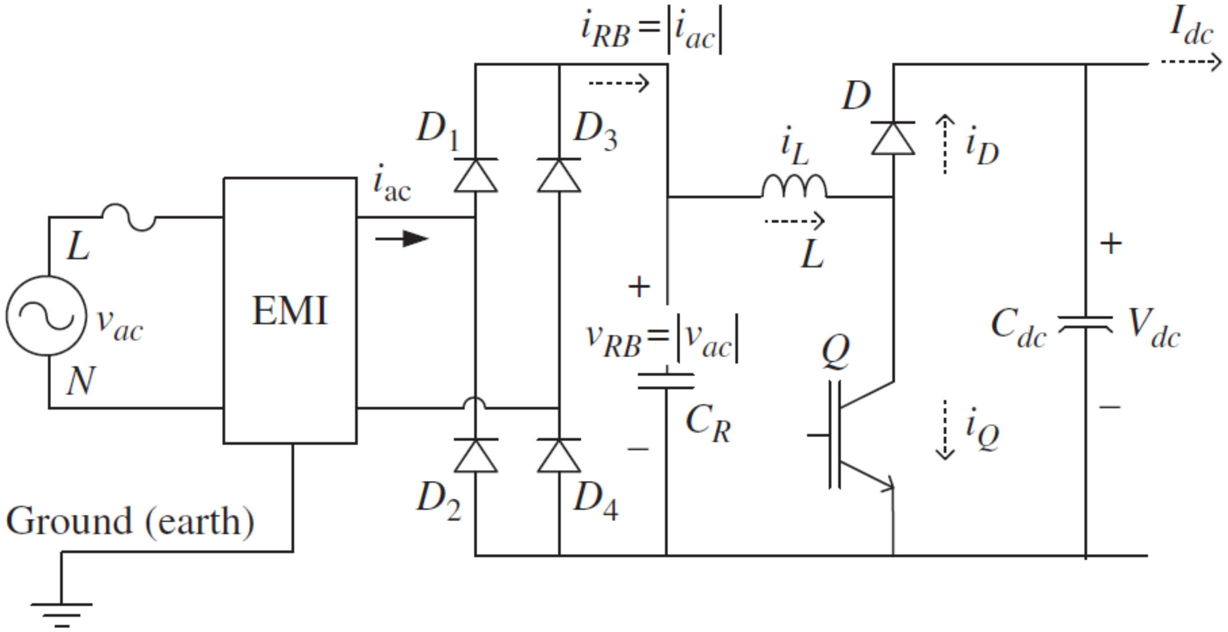
- DC current

$$i_D(\theta) = \frac{p_{ac}(\theta)}{V_{dc}} = \frac{2V_{ph}I_{ph}}{V_{dc}}\cos^2\theta$$

PFC boost inductor design

- Duty cycle for the switch

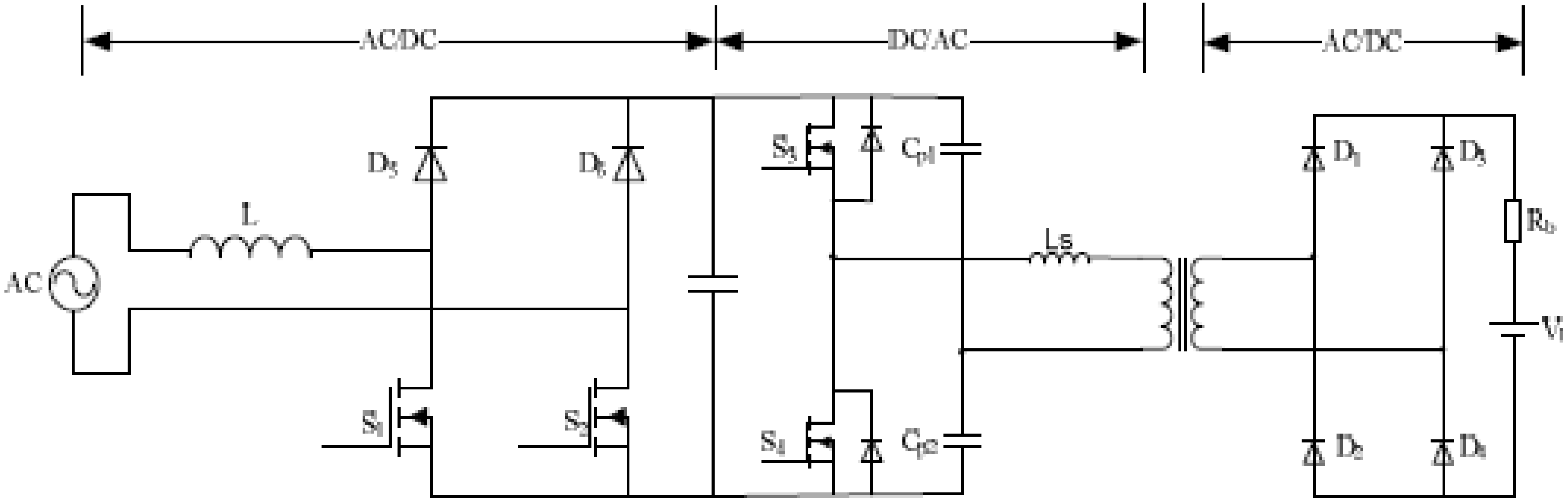
$$d(\theta) = 1 - \frac{v_{RB}(\theta)}{V_{dc}} = 1 - \frac{\sqrt{2}V_{ph}|\cos\theta|}{V_{dc}}$$



- Peak-peak current ripple

$$\Delta I_{L(p-p)}(\theta) = \frac{\sqrt{2}V_{ph}|\cos\theta|}{f_s L} d(\theta) = \frac{\sqrt{2}V_{ph}}{f_s L}\left(|\cos\theta| - \frac{\sqrt{2}V_{ph}\cos^2\theta}{V_{dc}}\right)$$

Other types of PFC

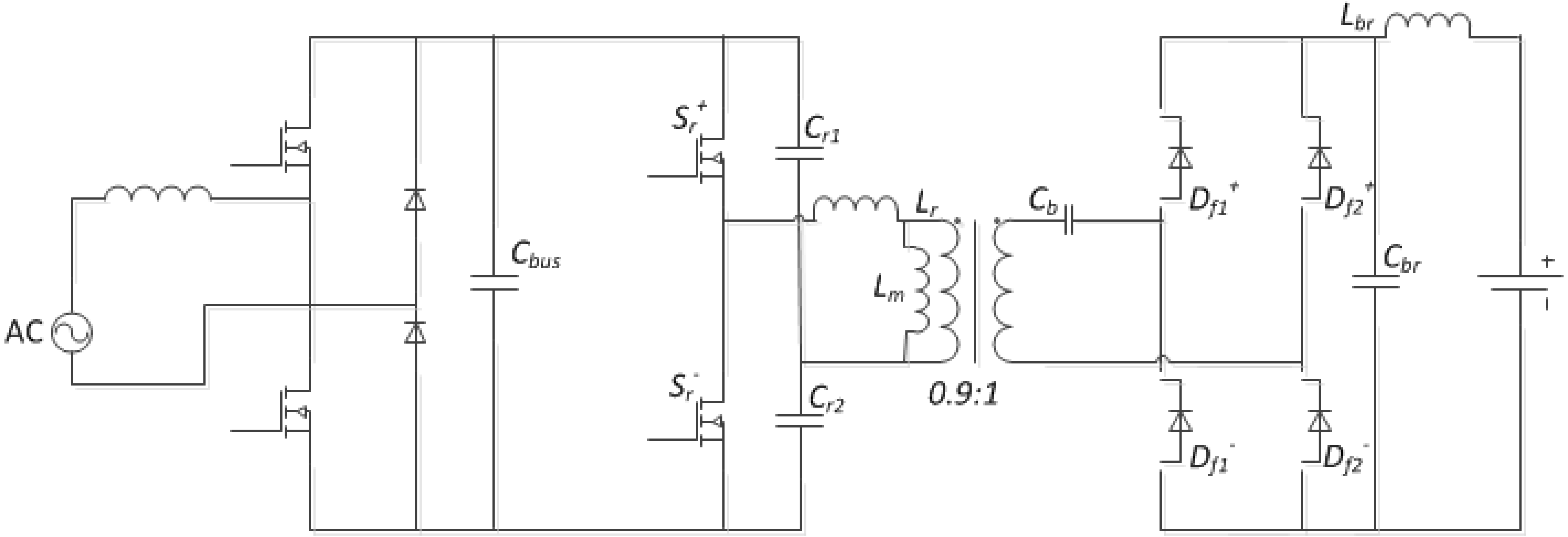


Conventional Single-phase OBC (H-bridge PFC+Half-bridge Resonant)

Boost-type PFC

Grid-side diodes are hard turned off.

Other types of PFC



Totem Pole PFC+Half-bridge Resonant DCDC

Boost-type PFC

Grid-side diodes are soft switched.

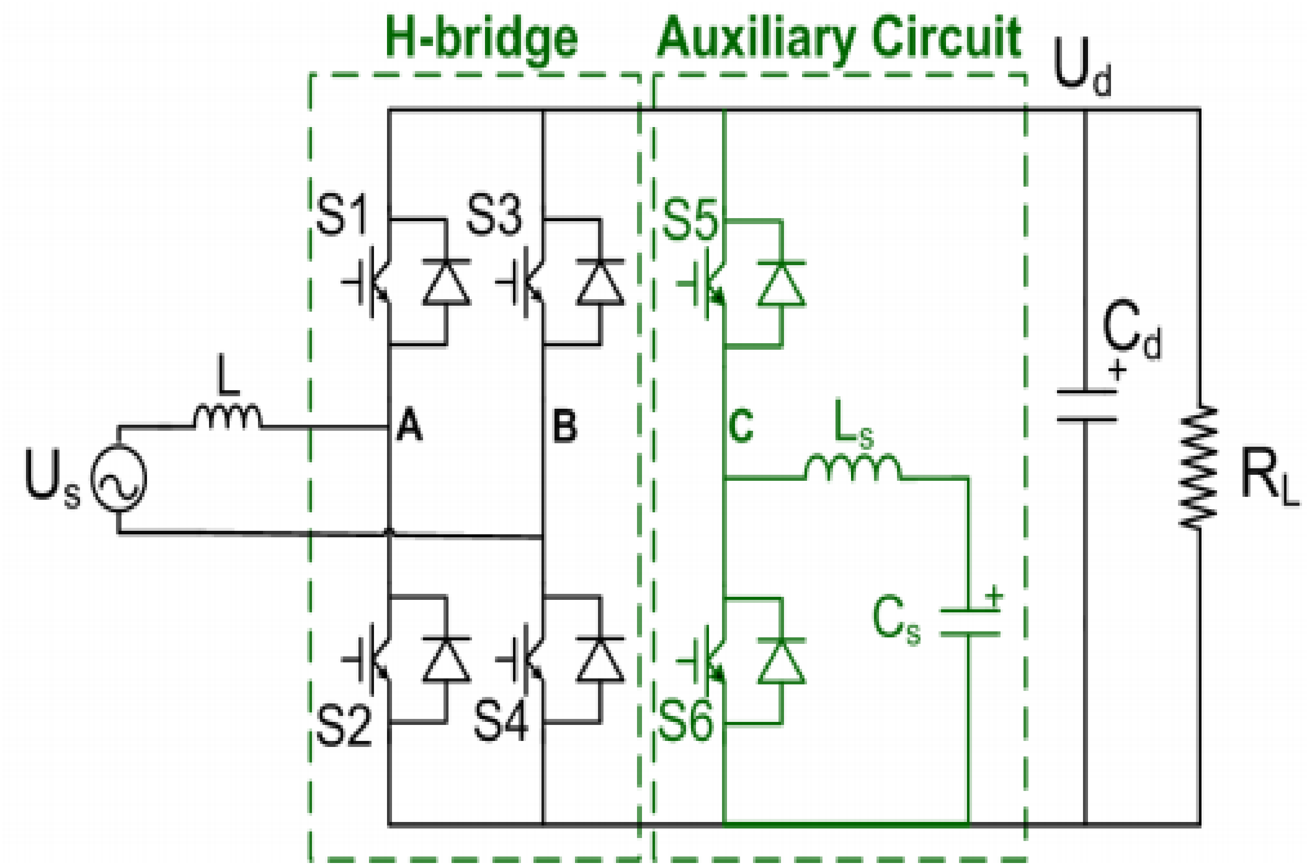
DC capacitor design

- Challenges: presence of second harmonic current
- Option 1: allow this current into battery
- Option 2: Filter out this current with the DC capacitor
- Option 3: active dc bus

Active filtering

Drawbacks of passive filtering:

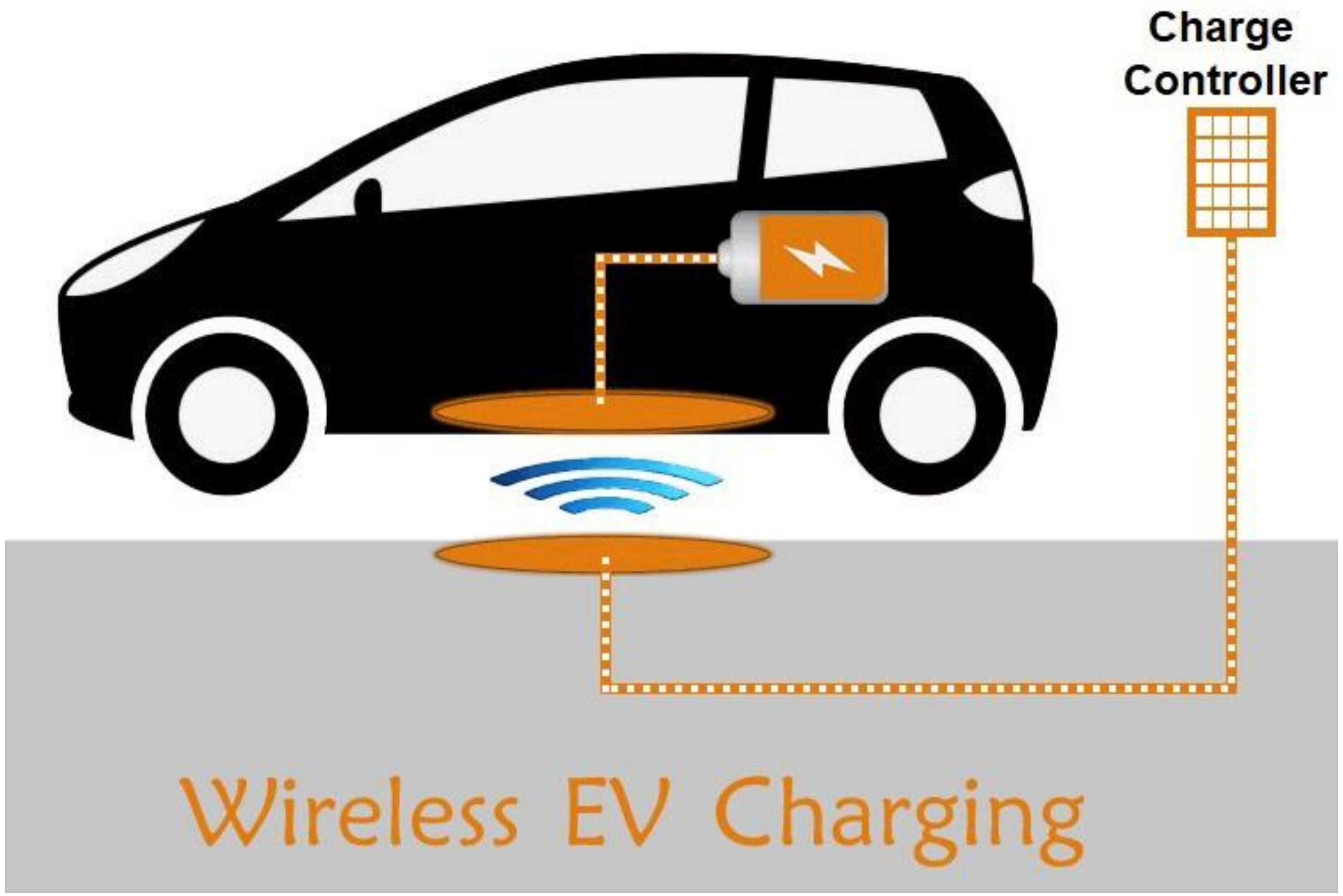
- Very costly (especially if High-Voltage / High-Power)
- Large weight



Active filtering:

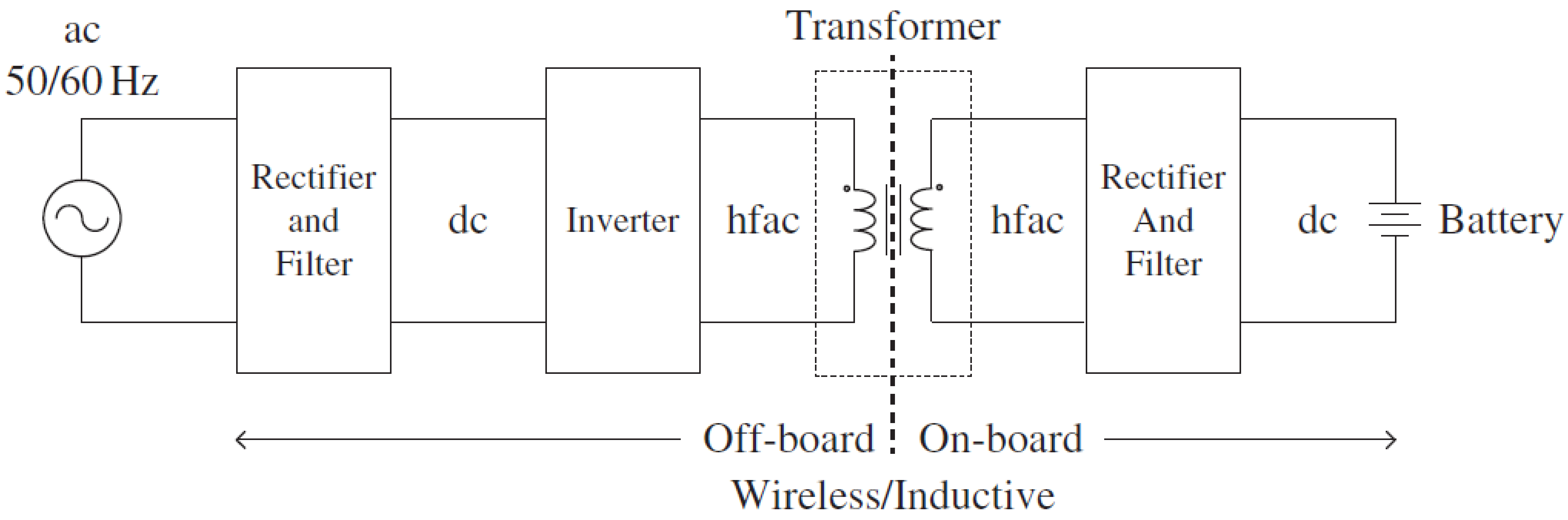
- Use additional circuitry to source/sink current into a "energy reservoir"
- Capacitor Cs can be small as it does not have any ripple specification

Wireless charging

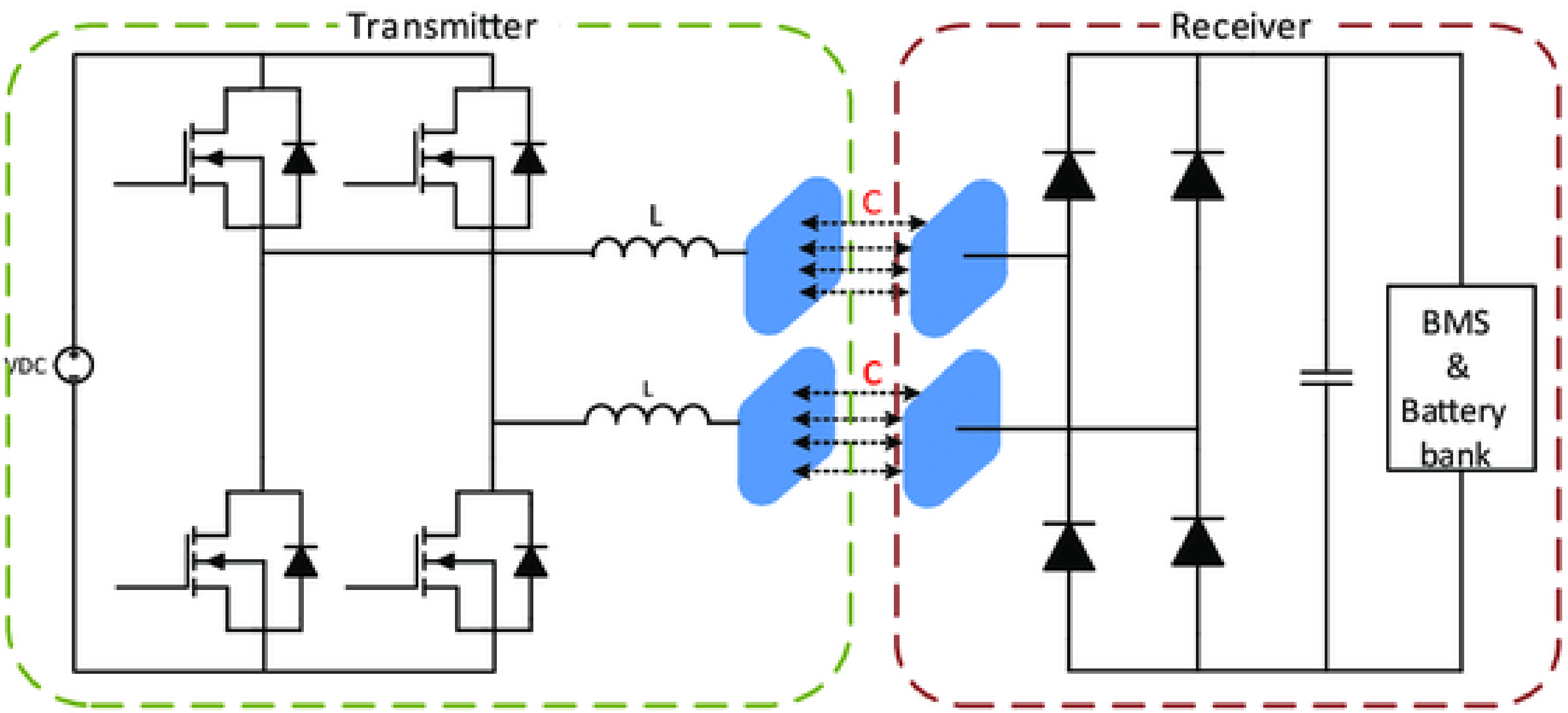


- enhanced safety
- More user friendly
- Higher technical challenges and cost

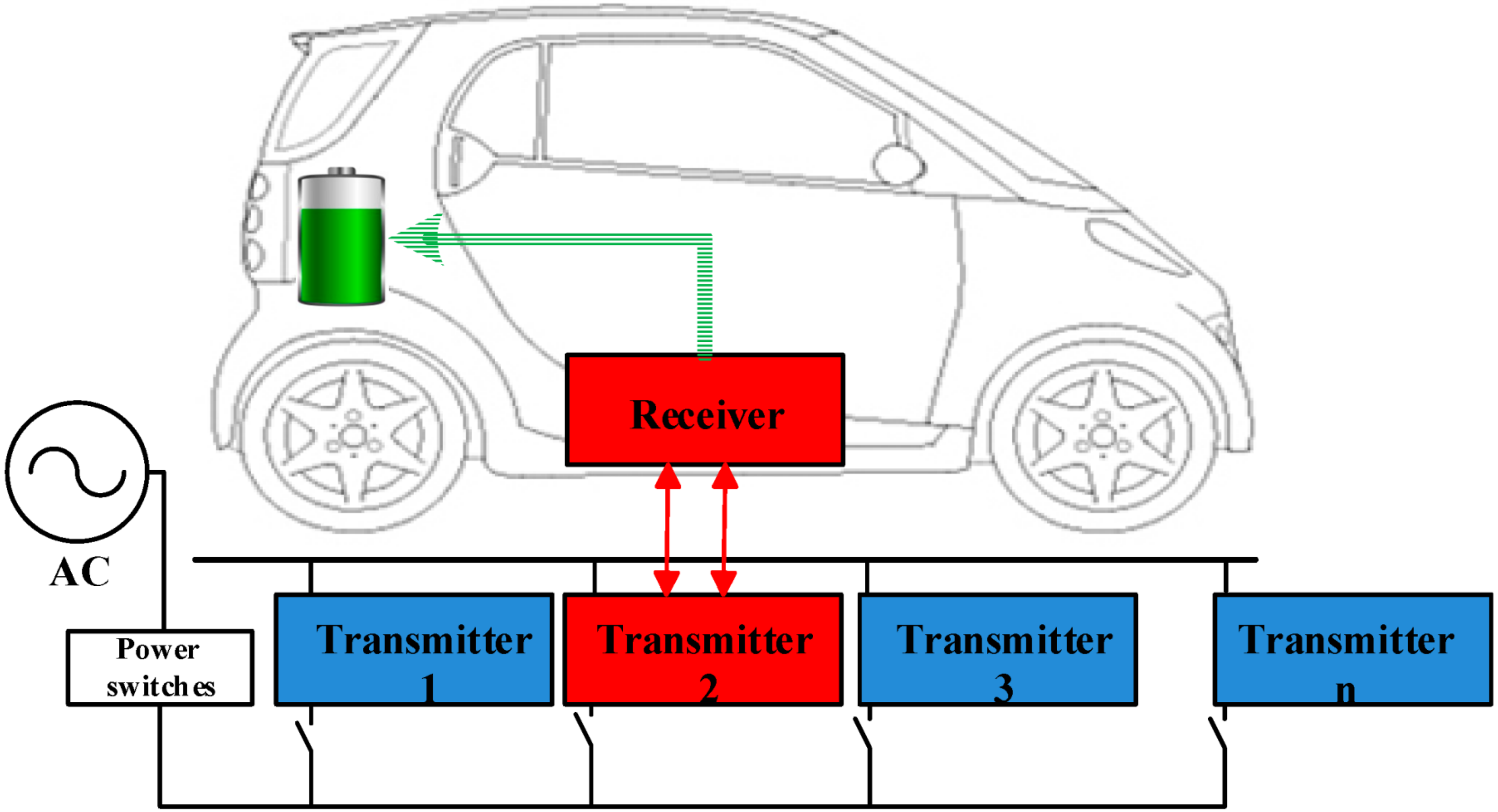
Wireless charger (inductive)



Wireless charger (capacitive)



Dynamic wireless charger



Thank you!