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D5.4 Undergraduate/Master Curricula Implemented

Title of Course

Power Converters

Title of the presentation

Electric Vehicle Power Converters Topology - Overview

др Саша Штаткић

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Partnership for Promotion and Popularization of Electrical Mobility through Transformation and Modernization of WB HEIs Study Programs/PELMOB

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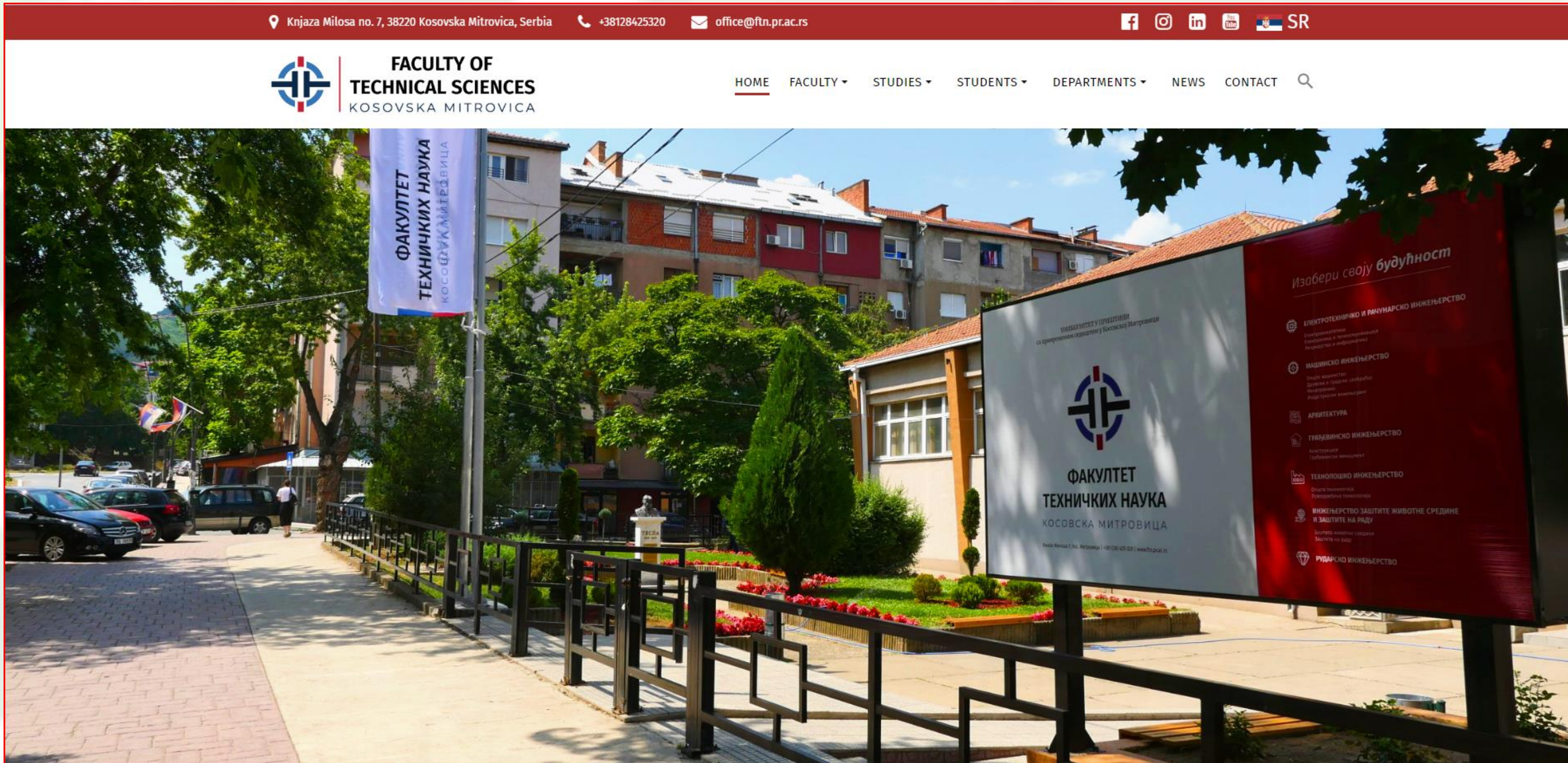

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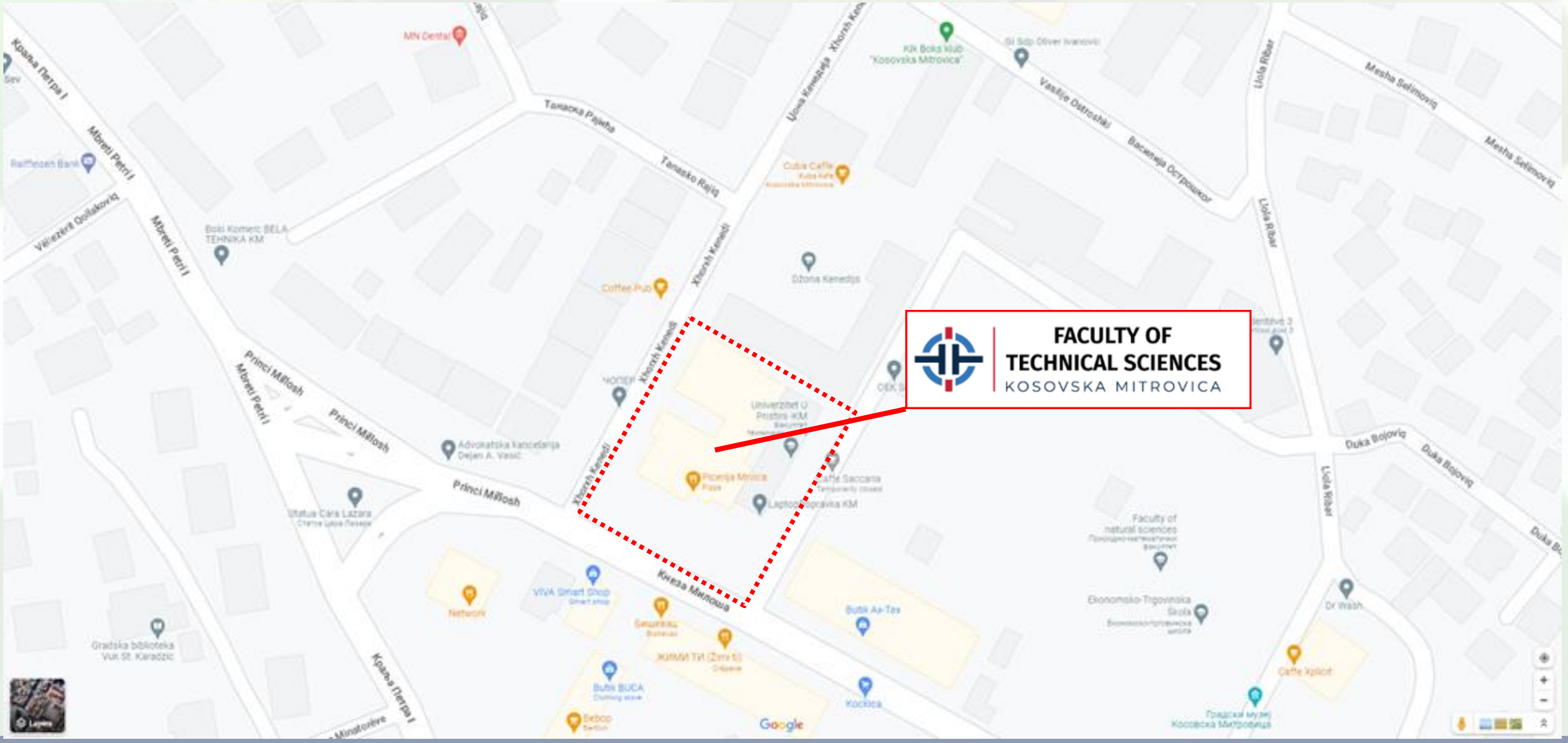

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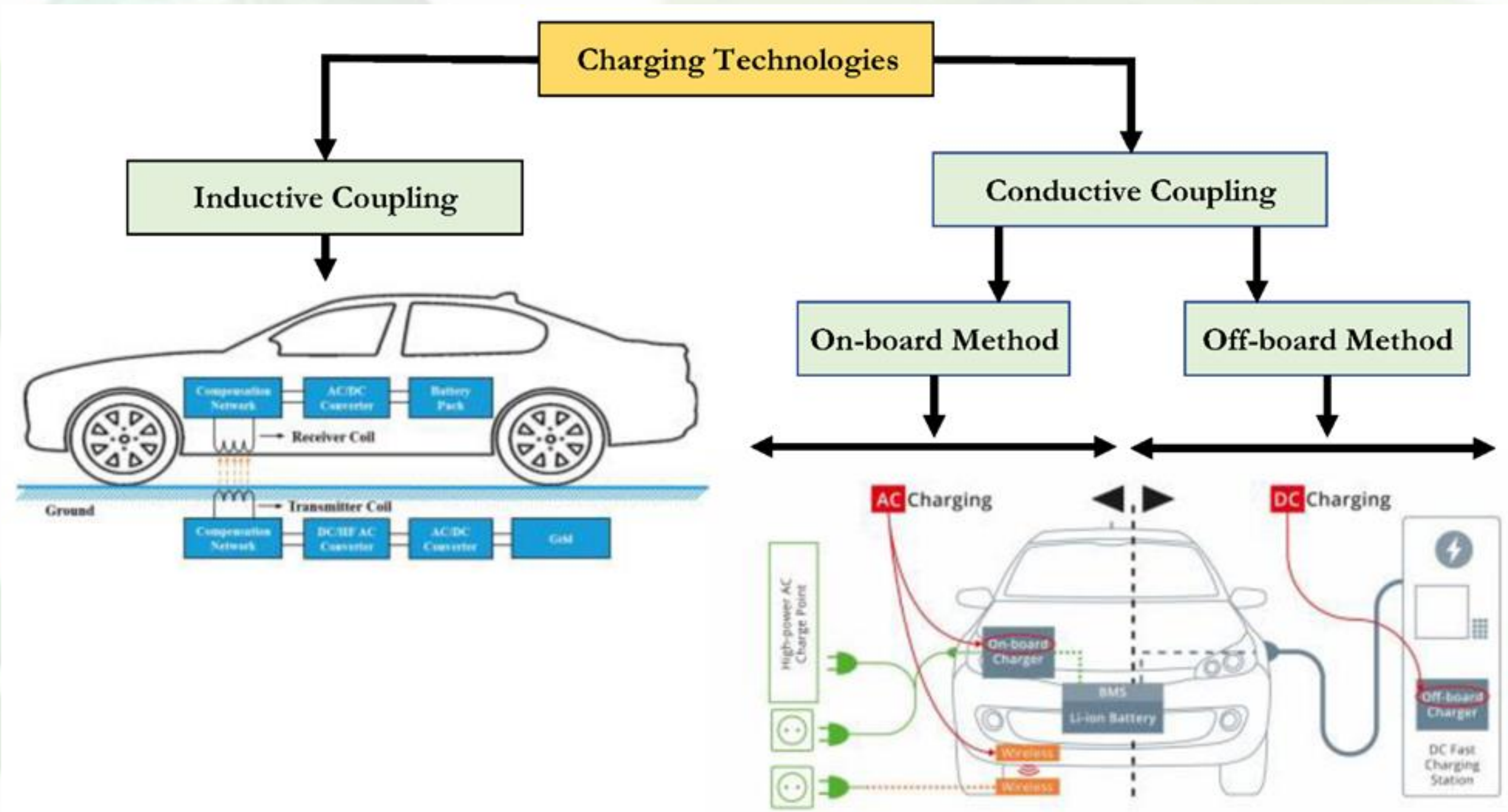
Electric Vehicle Power Converters Topology

The schematic layout of the wired and wireless charging methods



Electric Vehicle Power Converters Topology

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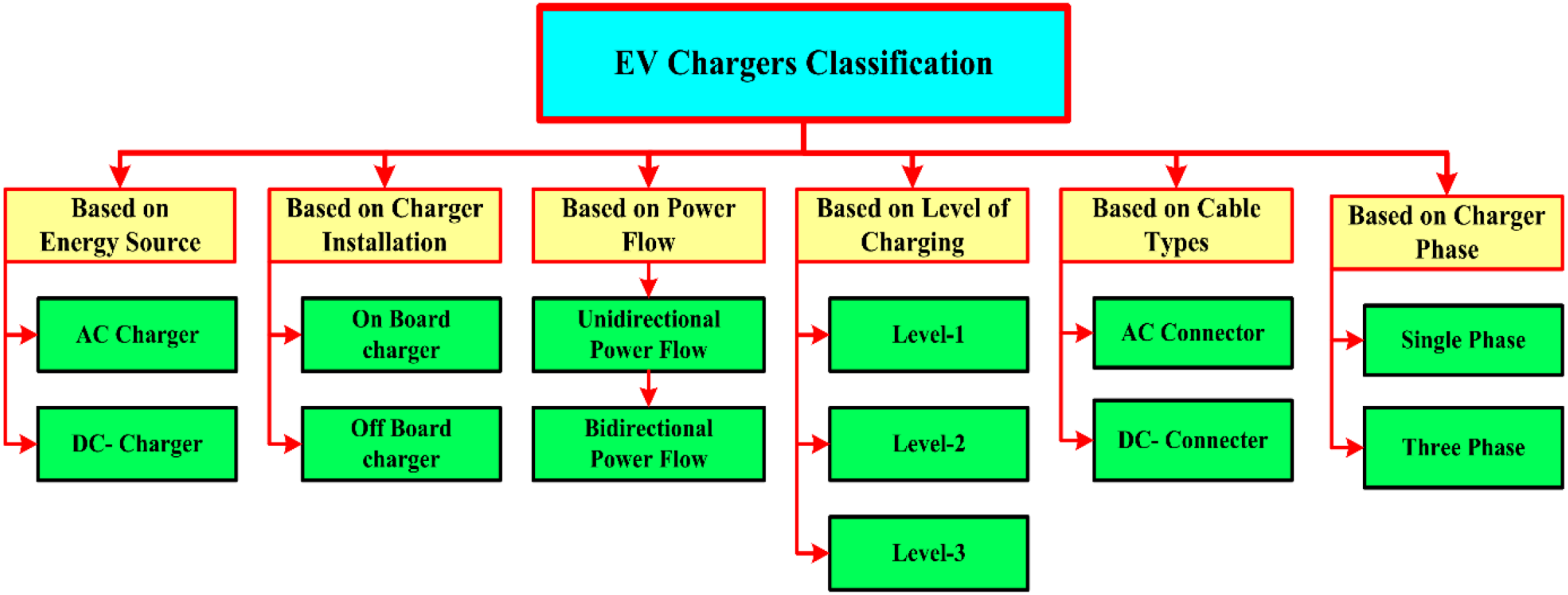
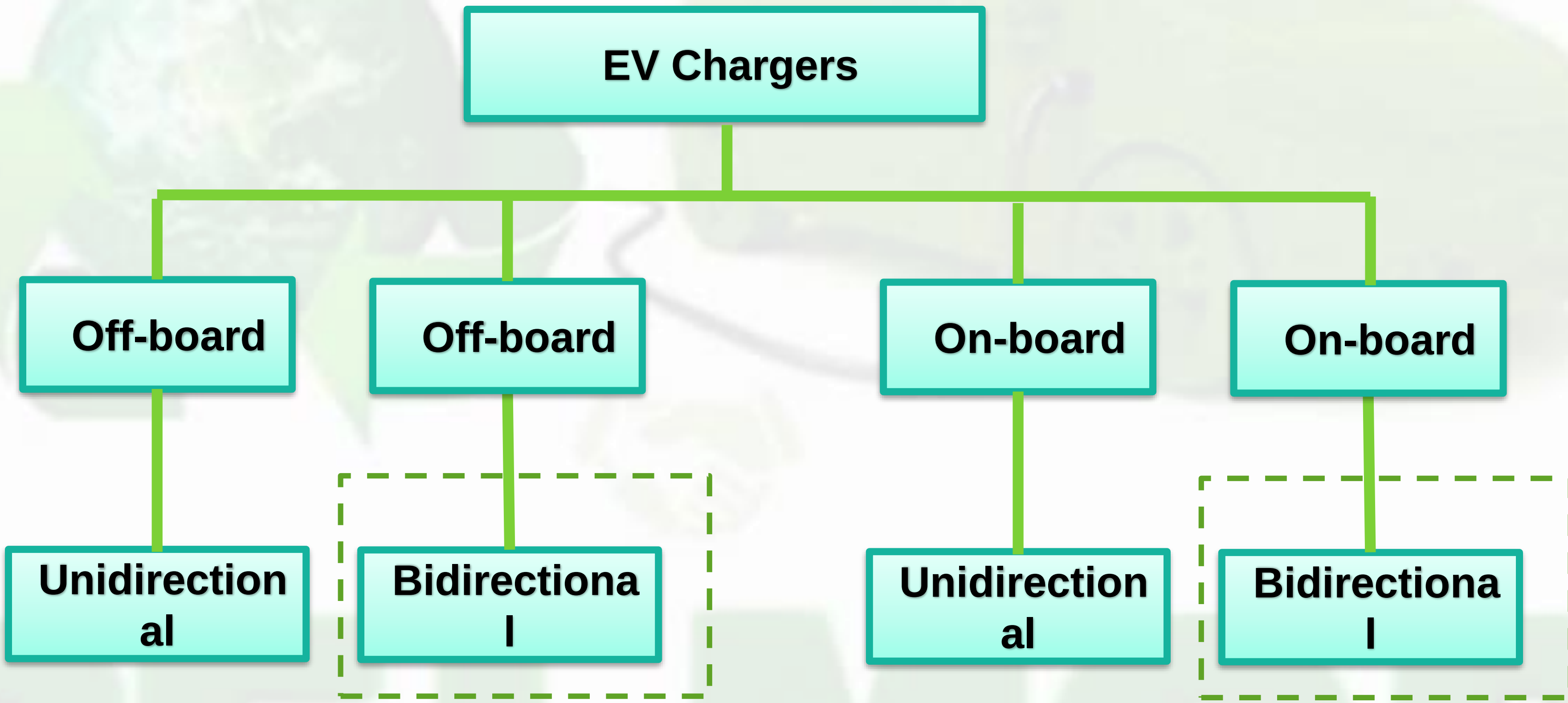
Understanding the Different Types of EV Chargers



Electric Vehicle Power Converters Topology

Understanding the Different Types of EV Chargers



V2G technology

NO YES

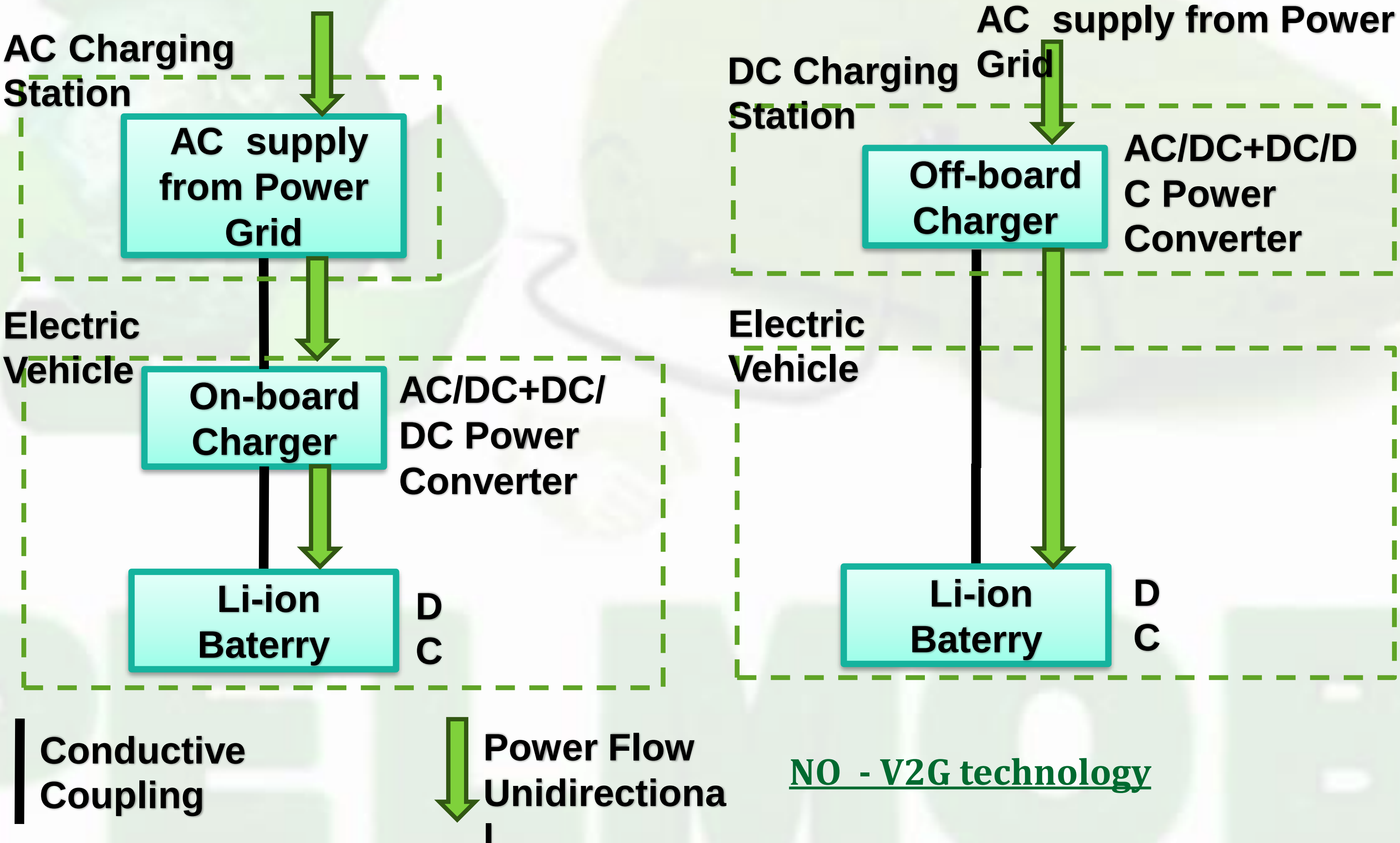
V2G technology

NO YES

Electric Vehicle Power Converters Topology

On-Board and Off-Board Charger

Power Flow Unidirectional



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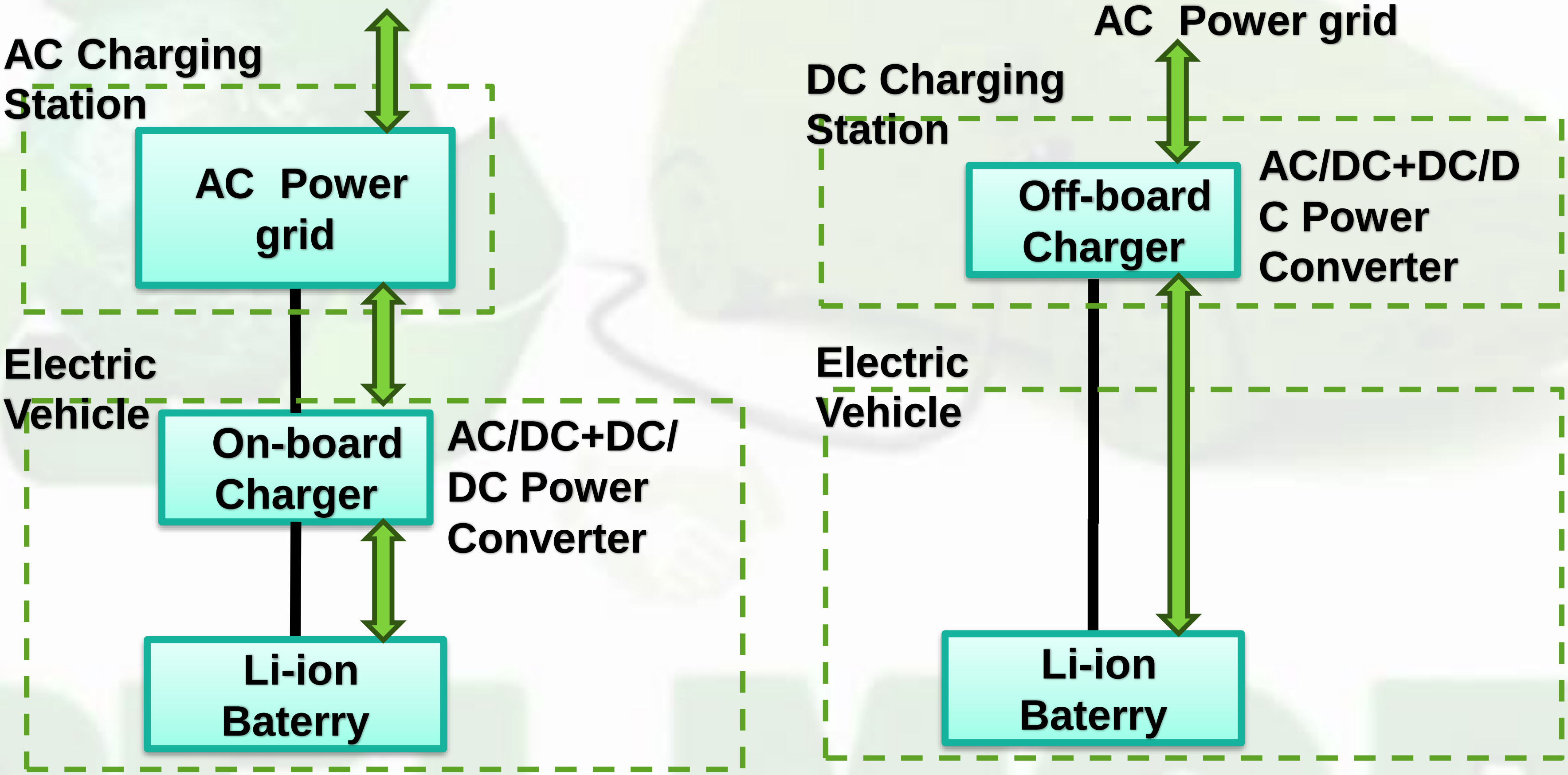
Electric Vehicle Power Converters Topology

On-Board and Off-Board Charger

Power Flow Bidirectional



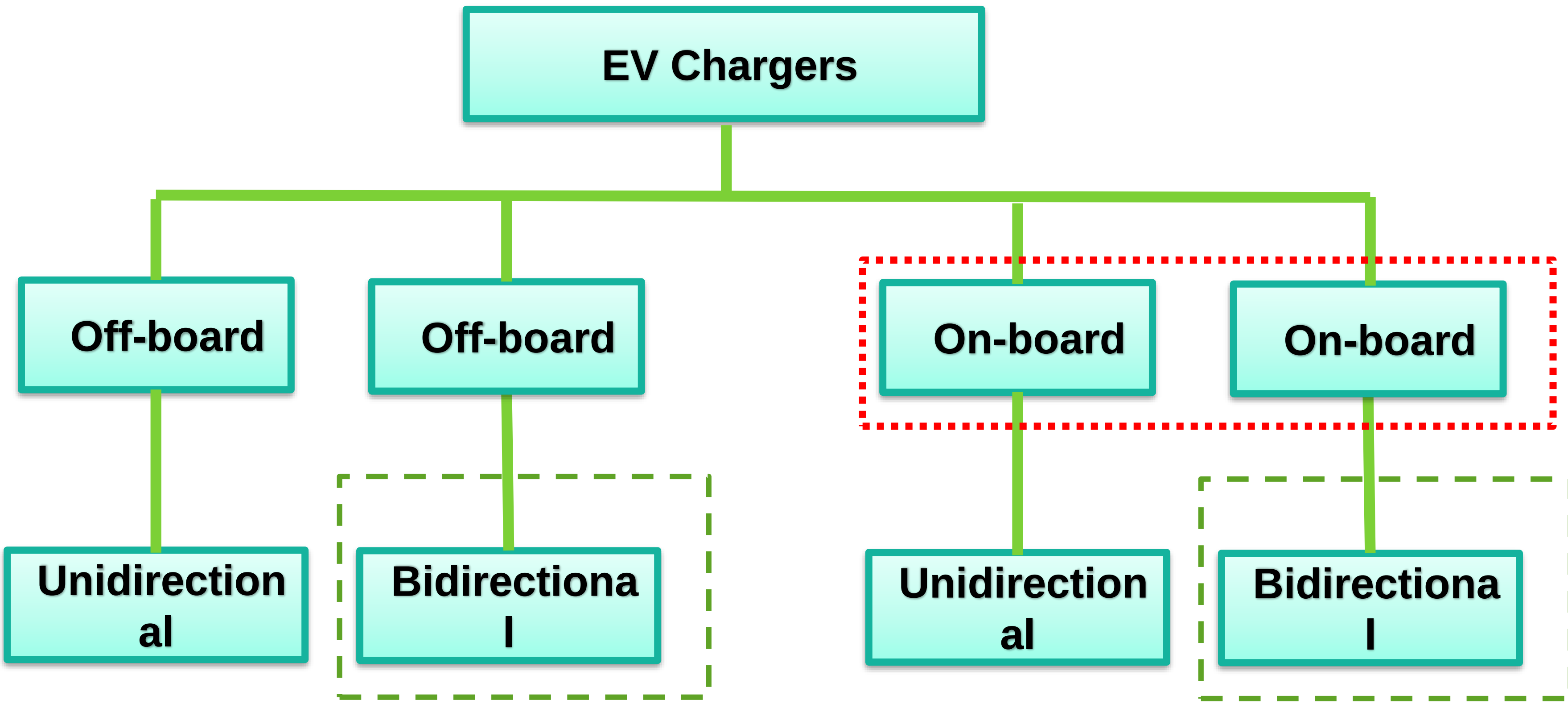
Conductive Coupling

Power Flow Bidirectional

YES - V2G technology

Electric Vehicle Power Converters Topology

Understanding the Different Types of EV Chargers



V2G technology

NO YES

V2G technology

NO YES

Electric Vehicle Power Converters Topology

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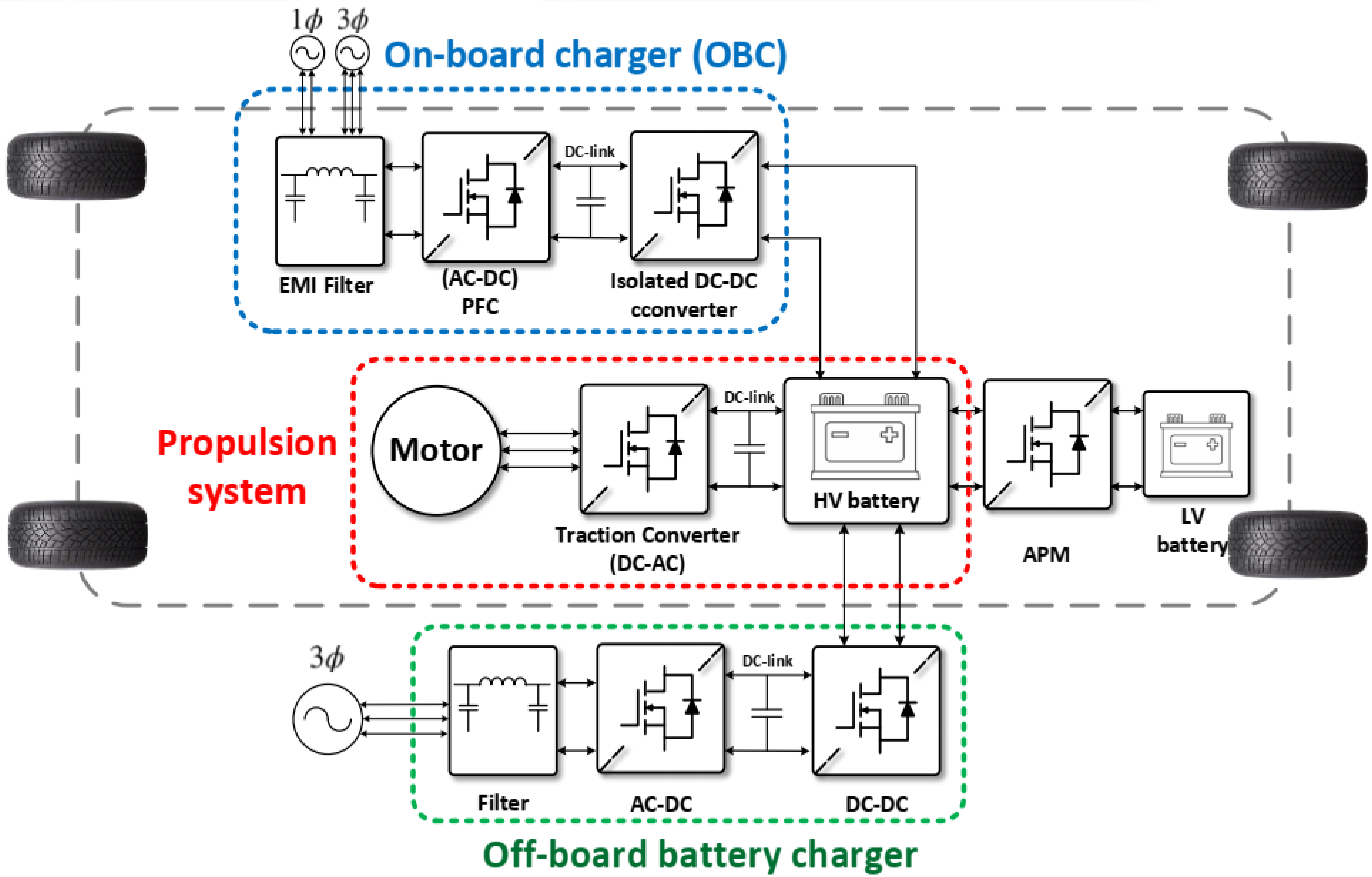
Electric vehicle charging configurations



Electric Vehicle Power Converters Topology

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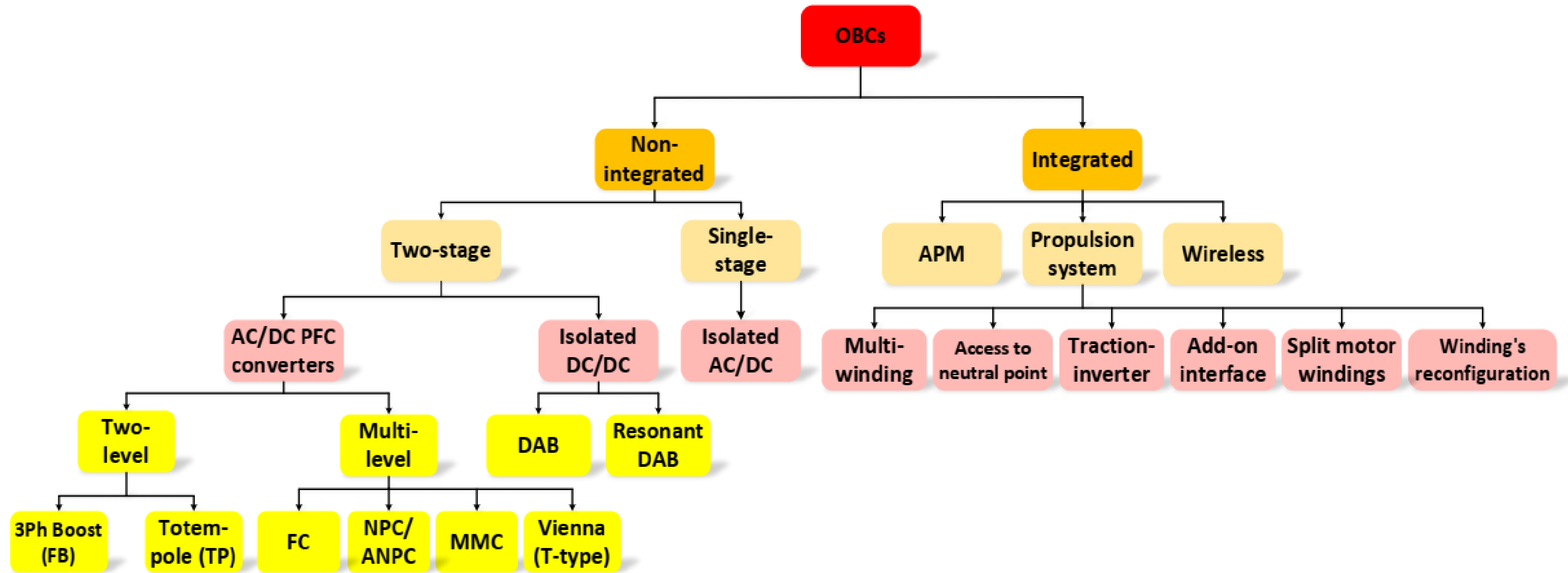
On-Board Battery Chargers (OBCs)



Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Non-integrated OBCs

- Two-stage
  - ✓ AC/DC PFC Converters
    - ❖ Two-level
      - 3PH Boost (FB)
      - Totempole (TP)
    - ❖ Multi-level
      - FC (Flying Capacitor)
      - NPC/ANPC (Neutral Point Clamped/Active NPC)
      - MMC (Modular Multilevel Converter)
      - Vienna (T-type)
  - ✓ Isolated DC/DC
- Single-stage
  - ✓ Isolated AC/DC

Integrated OBCs

- APM (Auxiliary Power Module)
- Propulsion system
  - ✓ Multi-winding
  - ✓ Access to neutral point
  - ✓ Traction-inverter
  - ✓ Add-on interface
  - ✓ Split motor windings
  - ✓ Winding's reconfiguration
- Wireless

Non-integrated OBCs

Non-integrated On-Board Chargers (OBCs) operate as standalone systems, separate from other vehicle components. They are typically classified into two-stage and single-stage configurations, each with distinct power conversion topologies.

1.1 Two-stage Non-integrated OBCs

A two-stage design separates the power conversion process into two main phases:

1. **AC/DC Power Factor Correction (PFC) Converters** – Converts AC grid voltage to regulated DC while improving power factor.
2. **Isolated DC/DC Converters** – Steps the DC voltage to the battery's required level while providing galvanic isolation.

AC/DC PFC Converters

Two-level Converters

- **3PH Boost (Full-Bridge, FB)**:
  - A three-phase boost converter with full-bridge rectification.
  - Suitable for medium-power applications with simple control.
- **Totempole (TP) PFC**:
  - A high-efficiency, bridgeless PFC topology.
  - Commonly used in bidirectional charging systems.

AC/DC PFC Converters

Comparison Table: 3PH Boost (FB) vs. Totempole (TP) PFC

Parameter	3PH Boost (Full-Bridge, FB)	Totempole (TP) PFC	Remarks
Topology Type	Two-level, diode-bridge + boost converter	Bridgeless, totem-pole (semi-bridgeless)	TP eliminates diode losses
Efficiency	~94-96% (due to diode losses)	~97-99% (lower conduction losses)	TP is more efficient
Switching Devices	6 diodes + 3/6 switches (boost stage)	4-6 MOSFETs/SiC/GaN (no diodes)	TP uses active rectification
Conduction Losses	Higher (diode bridge + switches)	Lower (only MOSFETs)	TP better for high power
Complexity	Moderate (needs separate PFC stage)	Higher (requires precise switching)	TP needs advanced control
Bidirectional Capability	No (unless modified)	Yes (with proper gate control)	TP supports V2G/V2L
EMI/Noise	Higher (due to diode commutation)	Lower (soft switching possible)	TP better for noise-sensitive apps
Cost	Lower (standard diodes)	Higher (SiC/GaN MOSFETs)	TP more expensive
Thermal Management	More heat (diode losses)	Less heat (efficient switching)	TP runs cooler
Common Applications	Industrial, mid-power EV chargers	High-efficiency EV chargers, data centers	TP for premium systems

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AC/DC PFC Converters

Multi-level Converters

- **FC (Flying Capacitor)**:
  - Uses capacitors to create intermediate voltage levels, reducing harmonic distortion.
- **NPC/ANPC (Neutral Point Clamped / Active NPC)**:
  - NPC: Clamps voltage to a neutral point, reducing switching stress.
  - ANPC: Adds active switches for better efficiency and thermal management.
- **MMC (Modular Multilevel Converter)**:
  - Highly scalable for high-voltage applications with distributed submodules.
- **Vienna (T-type)**:
  - A three-level rectifier with reduced switching losses, ideal for high-power charging.

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

AC/DC PFC Converters

Comparison Table: NPC vs. ANPC Converters

Parameter	NPC (Neutral Point Clamped)	ANPC (Active NPC)	Key Difference
Topology	**Uses clamping diodes to limit voltage stress.**	**Replaces diodes with active switches (MOSFETs/IGBTs).**	**ANPC eliminates diode recovery losses.**
Switching Devices	**4 switches + 2 diodes per phase.**	**6 switches per phase (no diodes).**	**ANPC has higher component count.**
Voltage Stress	**Switches clamped to half DC-link voltage (Vdc/2).**	**Same as NPC, but with better balance control.**	**ANPC reduces voltage imbalance risk.**
Switching Losses	**Higher (due to diode reverse recovery).**	**Lower (active switches enable soft switching).**	**ANPC improves efficiency at high frequency.**
Conduction Losses	**Moderate (diode forward drop).**	**Lower (MOSFETs have lower R_{ds(on)}).**	**ANPC better for high current.**
Control Complexity	**Simpler (fixed diode clamping).**	**More complex (requires active switch timing).**	**NPC easier to implement.**
Efficiency	**~95-97% (at low/mid frequencies).**	**~97-99% (with SiC/GaN).**	**ANPC wins at high power/frequency.**
Thermal Management	**Diodes generate heat.**	**More even heat distribution (active clamping).**	**ANPC handles higher power density.**
Cost	**Lower (fewer switches).**	**Higher (extra switches + gate drivers).**	**NPC more cost-effective.**
Applications	**Industrial drives, solar inverters (low-mid frequency).**	**EV traction, high-power UPS (high frequency).**	**ANPC for premium/high-performance systems.**

AC/DC PFC Converters

Waveform Comparison: NPC vs. ANPC Converters

Waveform	NPC	ANPC	Insight
Output Voltage	**3-level staircase, neutral-point ripple.**	**Cleaner 3-level, better neutral balance.**	**ANPC reduces low-frequency harmonics.**
Switch Voltage	**Clamped at Vdc/2, but with diode recovery spikes.**	**Smoothed clamping (no spikes with ZVS).**	**ANPC minimizes voltage overshoot.**
Neutral Current	**Unbalanced under heavy loads.**	**Actively balanced via switch control.**	**ANPC prevents DC-link capacitor imbalance.**

AC/DC PFC Converters

Comparison Table: FC vs. Vienna (T-Type) vs. MMC Converters

Parameter	Flying Capacitor (FC)	Vienna (T-Type)	Modular Multilevel (MMC)	Remarks
Topology	Capacitors create intermediate voltage levels.	3-level hybrid rectifier (diodes + switches).	Series-connected submodules (SMs) with capacitors.	MMC is highly modular.
Switching Devices	4-12 switches + flying capacitors per phase.	3 switches + 6 diodes (3-phase).	2N switches per phase (N = submodules).	MMC scales with voltage levels.
Voltage Stress	Switches clamped to capacitor voltage (Vdc/n).	Switches block Vdc/2.	Switches block Vdc/N (per submodule).	MMC reduces per-device voltage stress.
Capacitor Requirements	High (multiple flying capacitors).	Low (only DC-link capacitors).	Very high (capacitors per submodule).	MMC needs capacitor balancing.
Efficiency	~96-98% (Si/SiC).	~97-98.5% (SiC diodes improve performance).	~98-99% (low switching losses).	MMC best for ultra-high voltage.
Control Complexity	Moderate (capacitor voltage balancing needed).	Simple (natural voltage clamping).	High (submodule synchronization essential).	Vienna is easiest to control.
THD (Output Voltage)	Low (multi-level smoothing).	Moderate (3-level).	Very low (near-sinusoidal with many levels).	MMC excels in waveform quality.
Fault Tolerance	Poor (capacitor failures disrupt operation).	Fair (diode redundancy helps).	Excellent (bypass faulty submodules).	MMC is most reliable.
Cost	Medium (extra capacitors increase cost).	Low (fewer switches than FC).	Very high (many submodules + capacitors).	Vienna is cost-optimal for mid-power.
Applications	Motor drives, medium-voltage UPS.	PFC rectifiers, EV chargers (3-phase).	HVDC, grid-tied inverters, rail traction.	MMC dominates high-voltage scenarios.

AC/DC PFC Converters

1.1.2 Isolated DC/DC Converters

- Provides galvanic isolation between the grid and battery.
- Common topologies include **Dual Active Bridge (DAB)** and resonant variants for high efficiency.

Single-stage Non-integrated OBCs

A simplified design where **AC/DC conversion and isolation happen in a single stage**, reducing component count but often at the cost of flexibility.

Isolated AC/DC Converters

- Combines PFC and DC/DC conversion into one unit.
- Typically uses high-frequency transformers for isolation.
- Less common due to complexity in control but offers compactness.

Summary

- **Two-stage** OBCs offer better efficiency and flexibility but require more components.
- **Single-stage** OBCs are simpler but may have limitations in power handling and efficiency.
- **PFC topologies** (Two-level, Multi-level) determine efficiency and harmonic performance.
- **Isolated DC/DC** ensures safety and voltage adaptation for the battery.

This structure allows engineers to select the optimal OBC configuration based on power requirements, efficiency targets, and cost constraints.

Integrated OBCs (On-Board Chargers)

Integrated OBCs combine charging functionality with other vehicle systems, improving efficiency, space utilization, and cost-effectiveness.

1. APM (Auxiliary Power Module)

•Integrates the OBC with the **Auxiliary Power Module**, which powers low-voltage systems (e.g., infotainment, lighting, HVAC).

•**Advantages:**

- Reduces redundant components.
- Enables shared cooling and control systems.

•**Applications:** Used in EVs with high auxiliary power demands.

Integrated OBCs (On-Board Chargers)

2. Propulsion System Integration

Integrates the OBC with the **electric motor and inverter**, allowing shared components for charging and driving.

2.1 Multi-winding

•Uses **multiple transformer or motor windings** to enable simultaneous charging and propulsion.

•**Example:** A motor's windings act as inductors during charging.

2.2 Access to Neutral Point

•Allows connection to the **neutral point of the motor windings** for balanced charging.

•**Benefit:** Enables flexible voltage utilization.

2.3 Traction-Inverter Integration

•The **traction inverter (used for driving the motor) doubles as a charger**.

•**Advantages:**

•Eliminates the need for a separate OBC. Supports **bidirectional charging (V2G, V2L)**.

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Integrated OBCs (On-Board Chargers)

2. Propulsion System Integration

2.4 Add-on Interface

•Provides **modular connectivity** for future upgrades (e.g., fast-charging modules).

2.5 Split Motor Windings

•Motor windings are **split into separate circuits**—some for driving, others for charging.
•**Example:** During charging, half the windings act as a transformer.

2.6 Winding's Reconfiguration

•Dynamically **switches motor windings between driving and charging modes**.
•**Benefit:** Optimizes efficiency for different operating conditions.

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Integrated OBCs (On-Board Chargers)

Wireless Integrated OBCs

- Uses **inductive or resonant wireless charging** instead of cables.
- **Advantages:**
  - No physical connectors (improves durability).
  - Enables **automatic charging (park-and-charge)**.
- **Challenges:** Lower efficiency compared to wired charging.

Summary of Benefits

Integration Type	Key Advantage	Use Case
APM	Shared power delivery	High auxiliary load EVs
Propulsion System	Eliminates separate OBC	Cost-sensitive EVs
Wireless	No cables, automated charging	Luxury/premium EVs

Integrated OBCs are the future of EV charging, reducing weight, cost, and complexity while enabling smart energy management.

Electric Vehicle Power Converters Topology

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On-Board Battery Chargers (OBCs)

Role of each power converter topology in EV technology

Category	Topology	Role in EVs	Advantages	Disadvantages	Example Applications
Non-Integrated OBCs					
Two-Stage	3PH Boost (FB)	AC/DC conversion with diode bridge.	Low cost, simple control.	Lower efficiency (~95%).	Mid-power chargers (3.3–6.6 kW).
	Totempole (TP) PFC	Bridgeless AC/DC conversion for bidirectional charging.	High efficiency (>98%), V2G support.	Requires SiC/GaN (expensive).	Tesla Model 3, Lucid Air.
	FC (Flying Capacitor)	Multi-level AC/DC conversion for reduced EMI.	Better waveform quality.	Complex capacitor balancing.	800V high-performance EVs.
	NPC/ANPC	Neutral-point clamped AC/DC conversion.	Lower switch stress (Vdc/2).	ANPC needs complex control.	Porsche Taycan (800V).
	MMC	Modular AC/DC for ultra-high-power charging.	Scalable to MW levels, low THD.	Very high cost/complexity.	Megawatt charging (trucks, buses).
	Vienna (T-type)	3-level PFC for compact designs.	Cost-effective, efficient (~97%).	Limited to 3-level output.	Tesla Gen 2 charger.
Isolated DC/DC	DAB/LLC	Steps up/down DC voltage with isolation.	Bidirectional (DAB), high frequency.	Large magnetics (LLC).	11–22 kW OBCs.
Single-Stage	Isolated AC/DC	Combines PFC and DC/DC in one stage.	Compact design.	Challenging control.	Low-power portable chargers.
Integrated OBCs					
APM-Integration		Combines OBC with auxiliary power module.	Shared cooling/control.	Limited power scalability	Tesla "charger + DC/DC" combo.
Propulsion System	Multi-winding	Uses motor windings as inductors during charging.	Saves weight/cost.	Reduced motor performance while charging.	BMW i3.
	Traction-Inverter	Reuses inverter as a charger.	No separate OBC needed.	Complex thermal management.	Hyundai E-GMP platform.
	Wireless	Inductive charging without cables.	Convenience, automation.	Low efficiency (~90%), high cost.	Luxury EVs (e.g., Mercedes EQ).

Electric Vehicle Power Converters Topology

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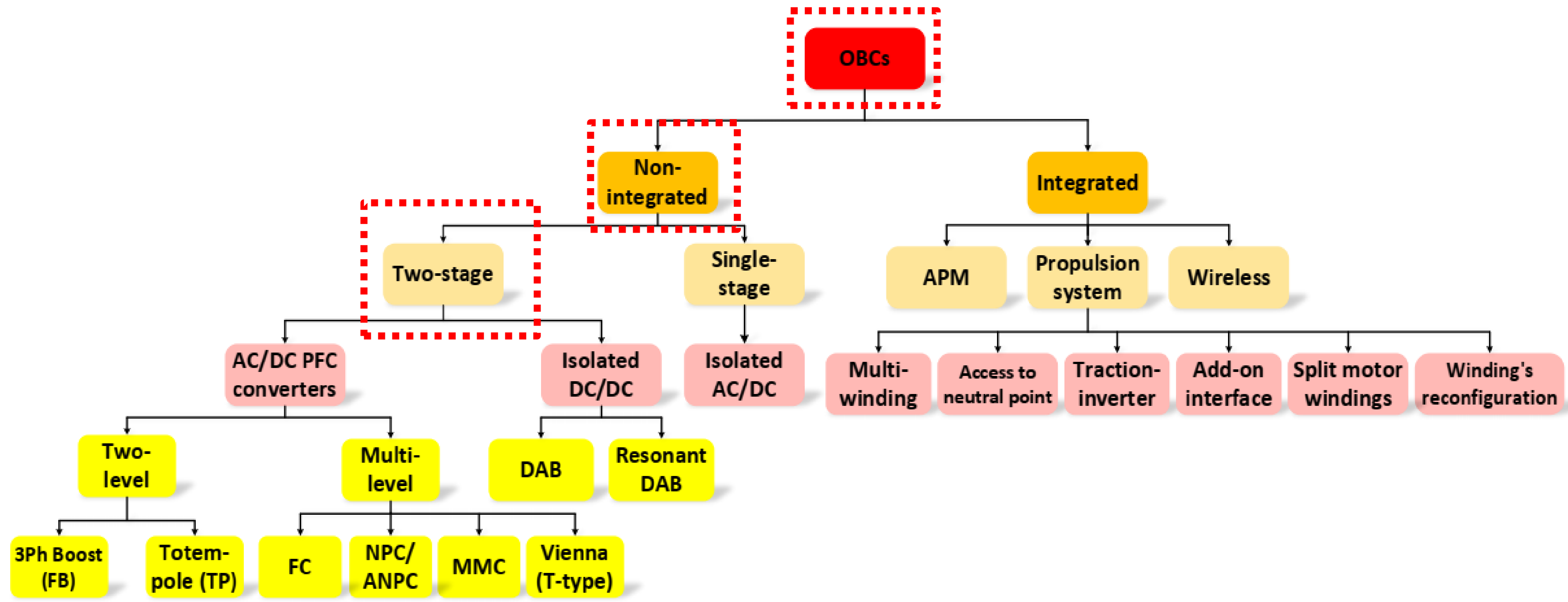
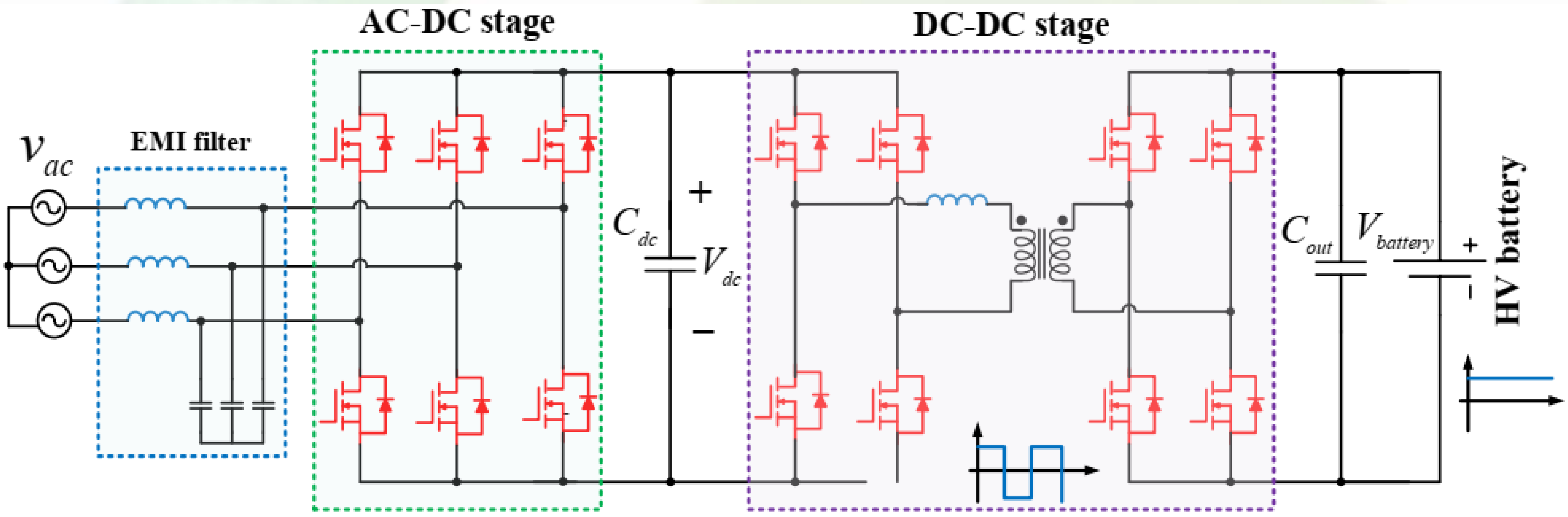
On-Board Battery Chargers (OBCs)



Electric Vehicle Power Converters Topology

Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)



Electromagnetic interference (EMI) filter

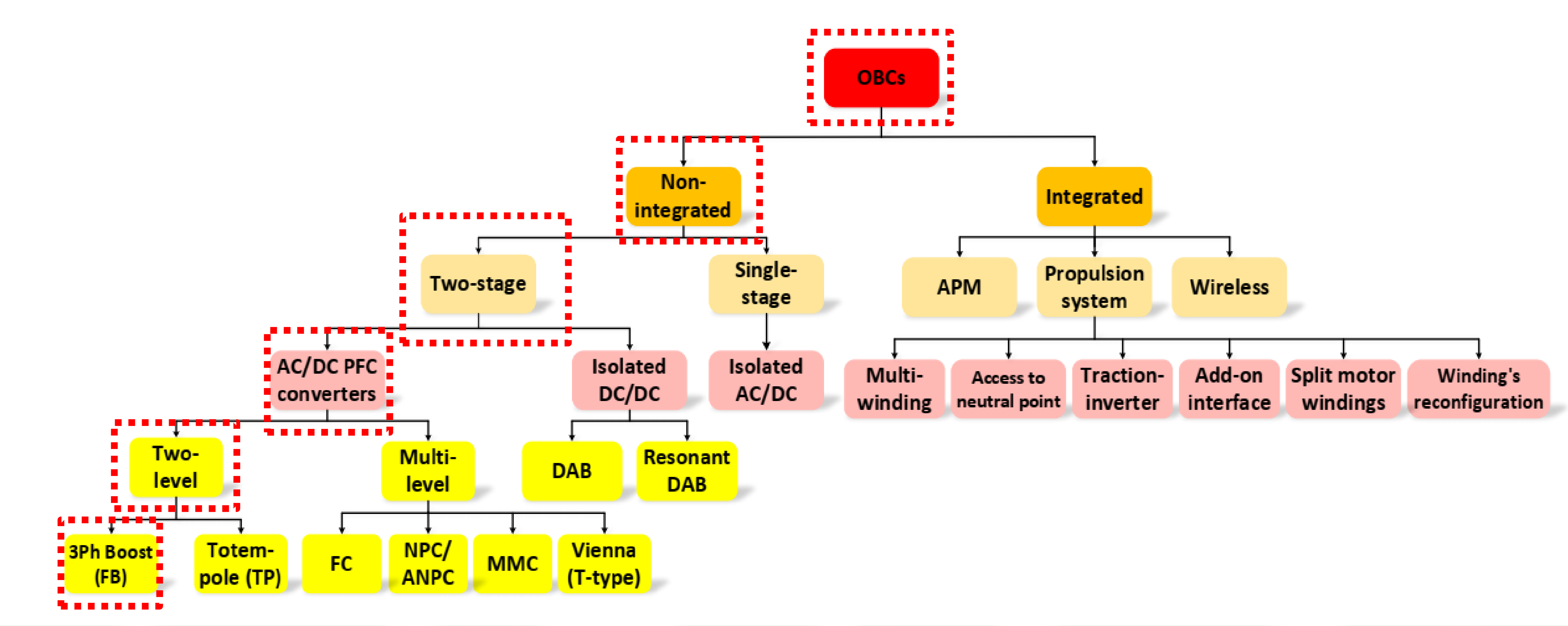
AC-DC power factor correction (PFC) unit

DC link

Galvanically isolated DC-DC converter

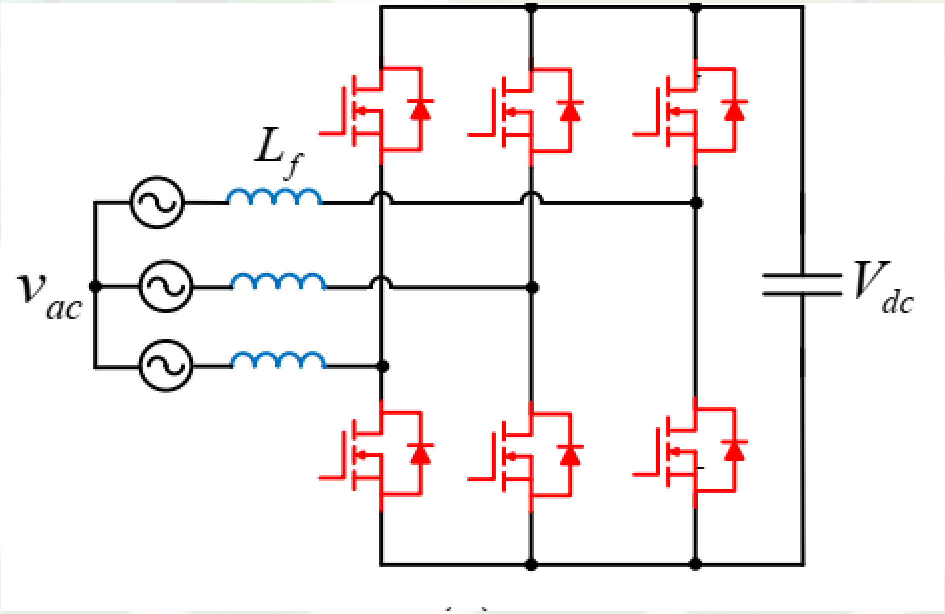
Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)



AC-DC PFC Converter Topologies for Two-Stage Non-Integrated OBCs

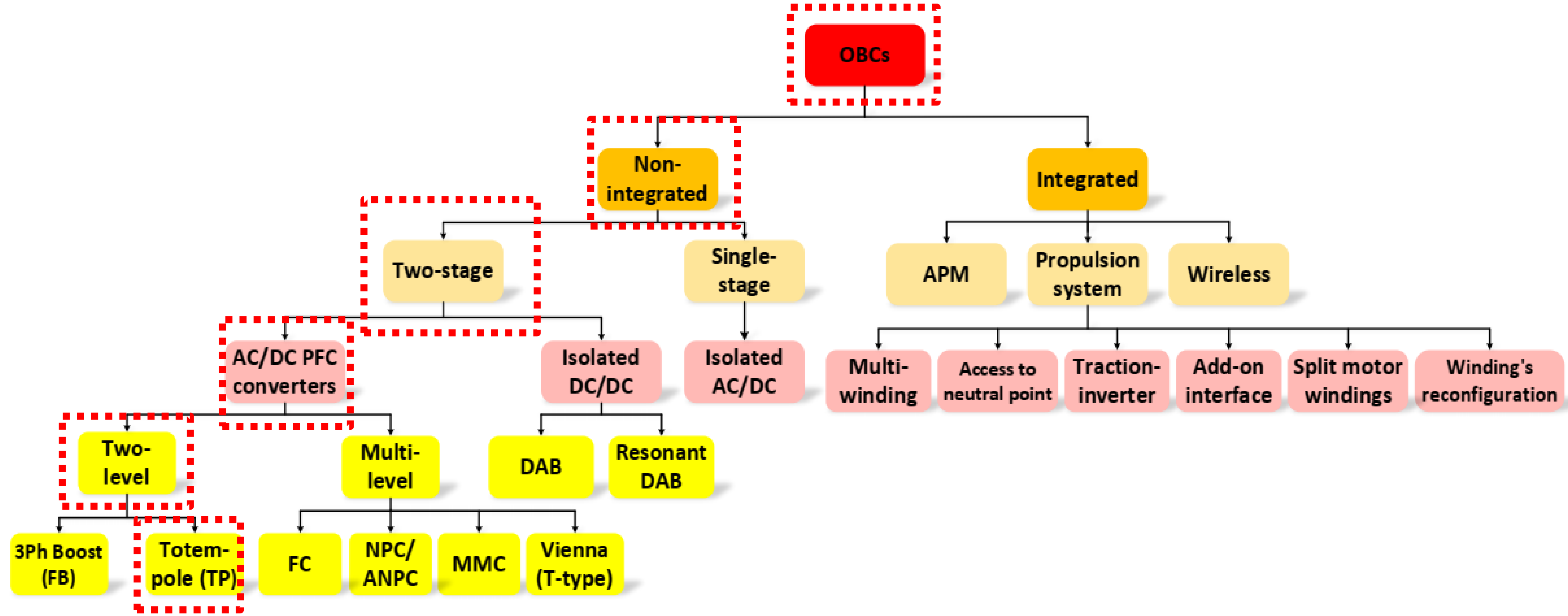
Examples of two-level AC-DC PFCs for two-stage OBCs



Three-phase boost PFC - full bridge PFC

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)



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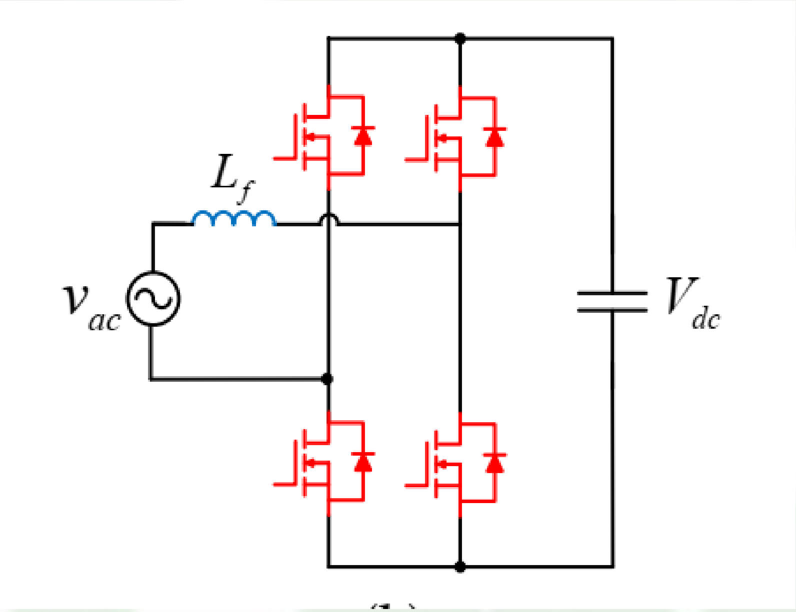

Totem-pole PFC

AC-DC PFC Converter Topologies for Two-Stage Non-Integrated OBCs

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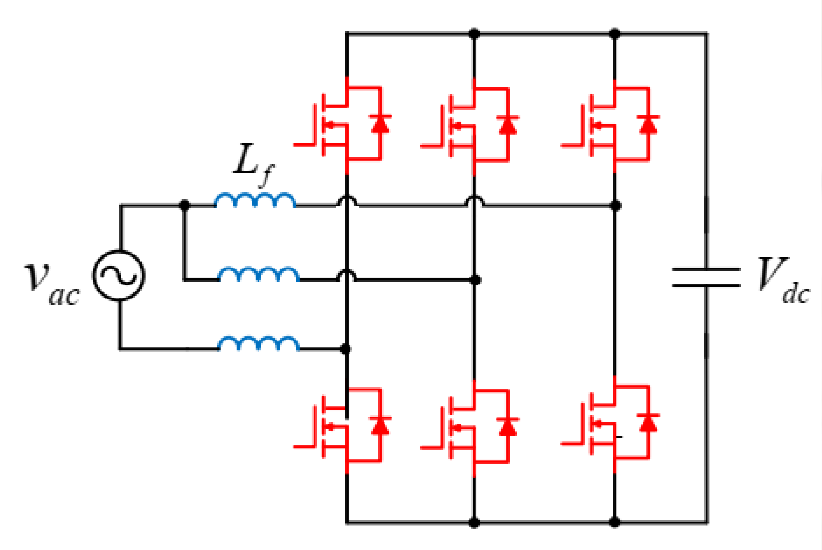
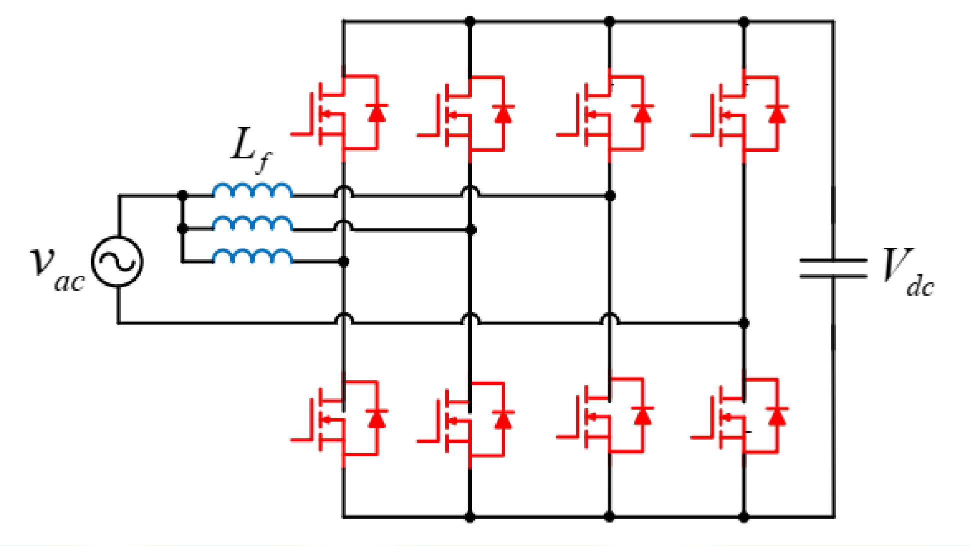


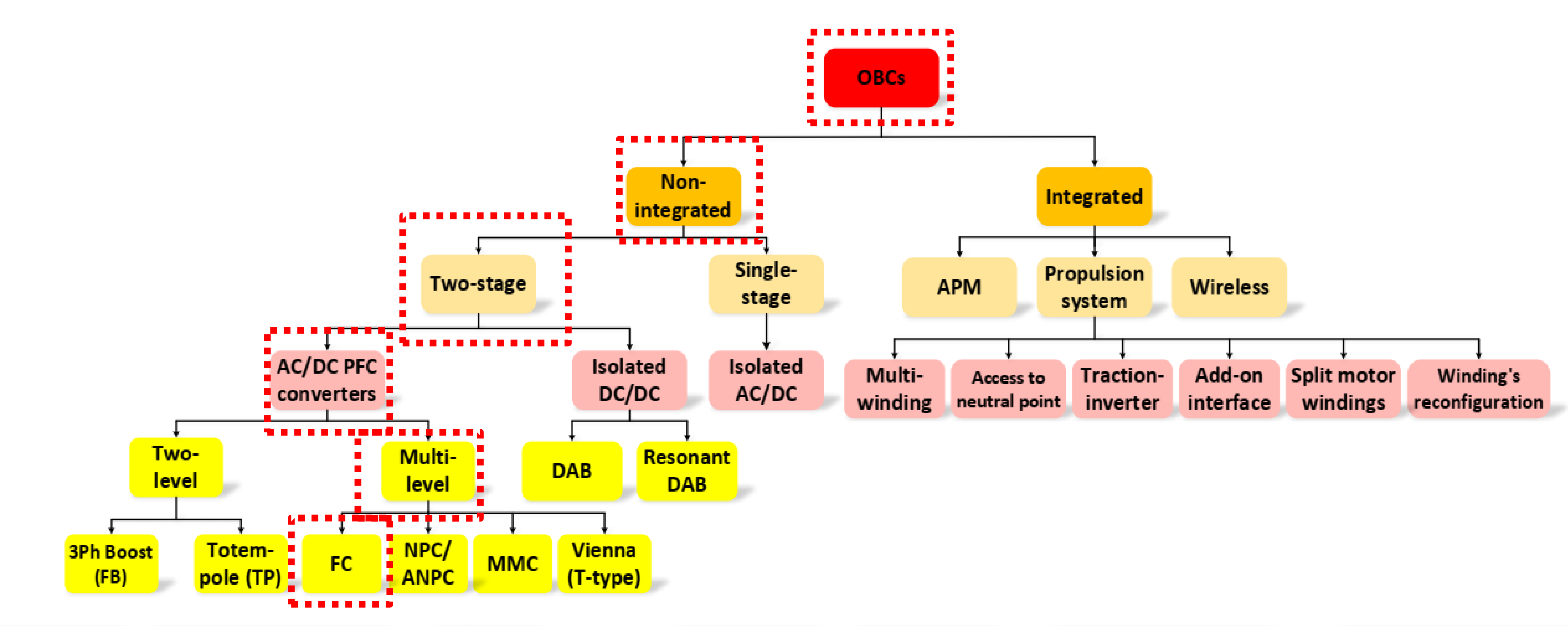
Two-channel interleaved totem-pole PFC



Three-channel interleaved totem-pole PFC

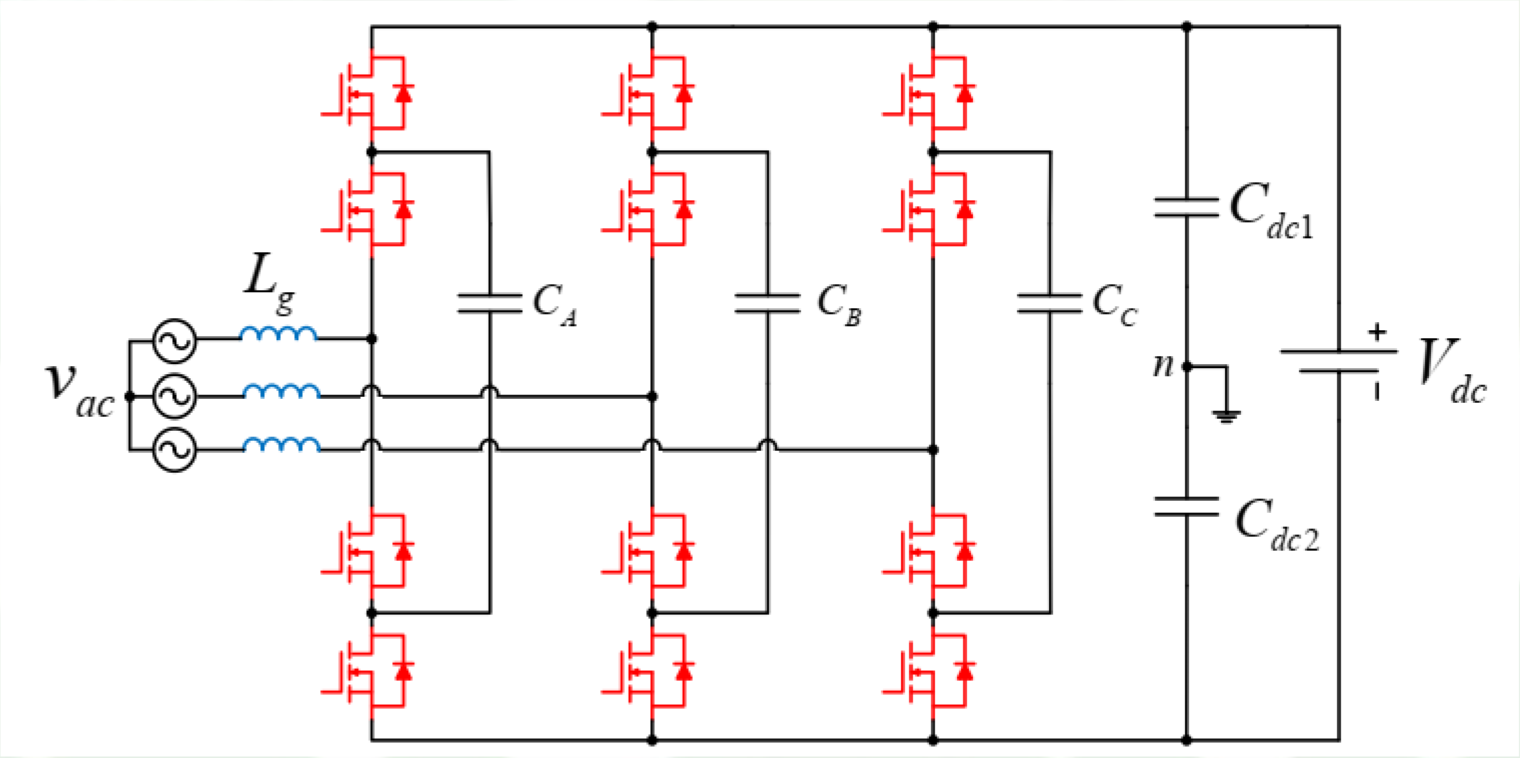
Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)



AC-DC PFC Converter Topologies for Two-Stage Non-Integrated OBCs

Examples of multi-level AC-DC PFCs for two-stage non-integrated OBCs



Flying capacitor (FC) topology

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

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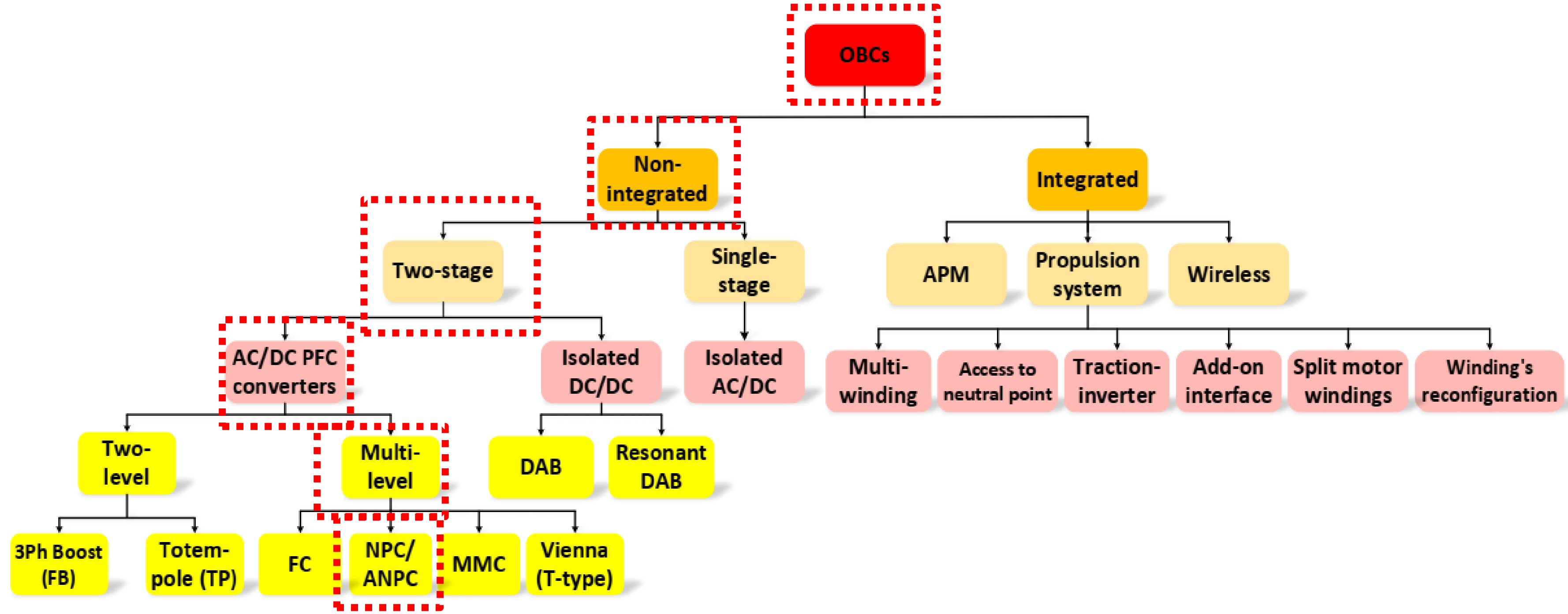
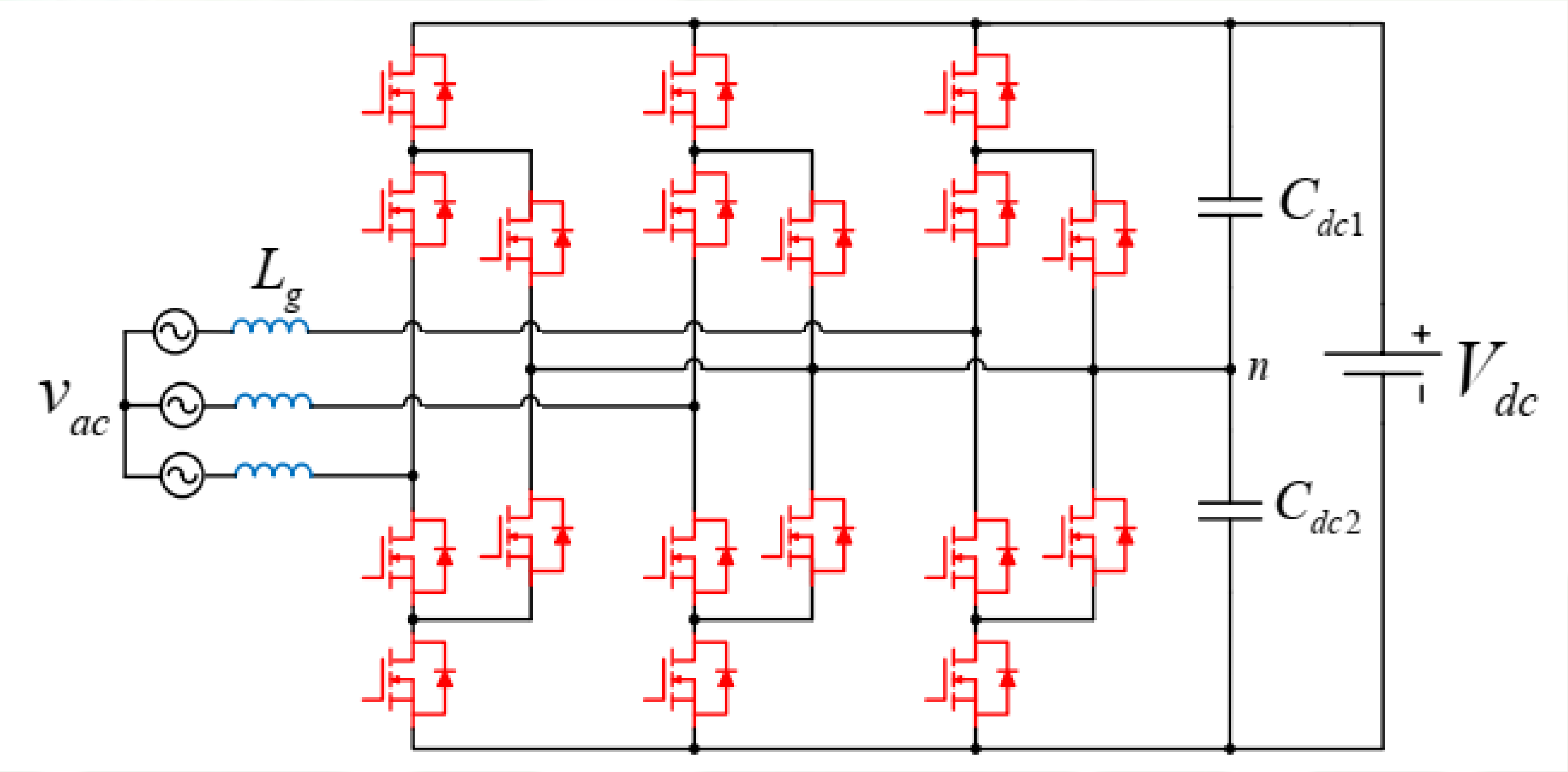


AC-DC PFC Converter Topologies for Two-Stage Non-Integrated OBCs

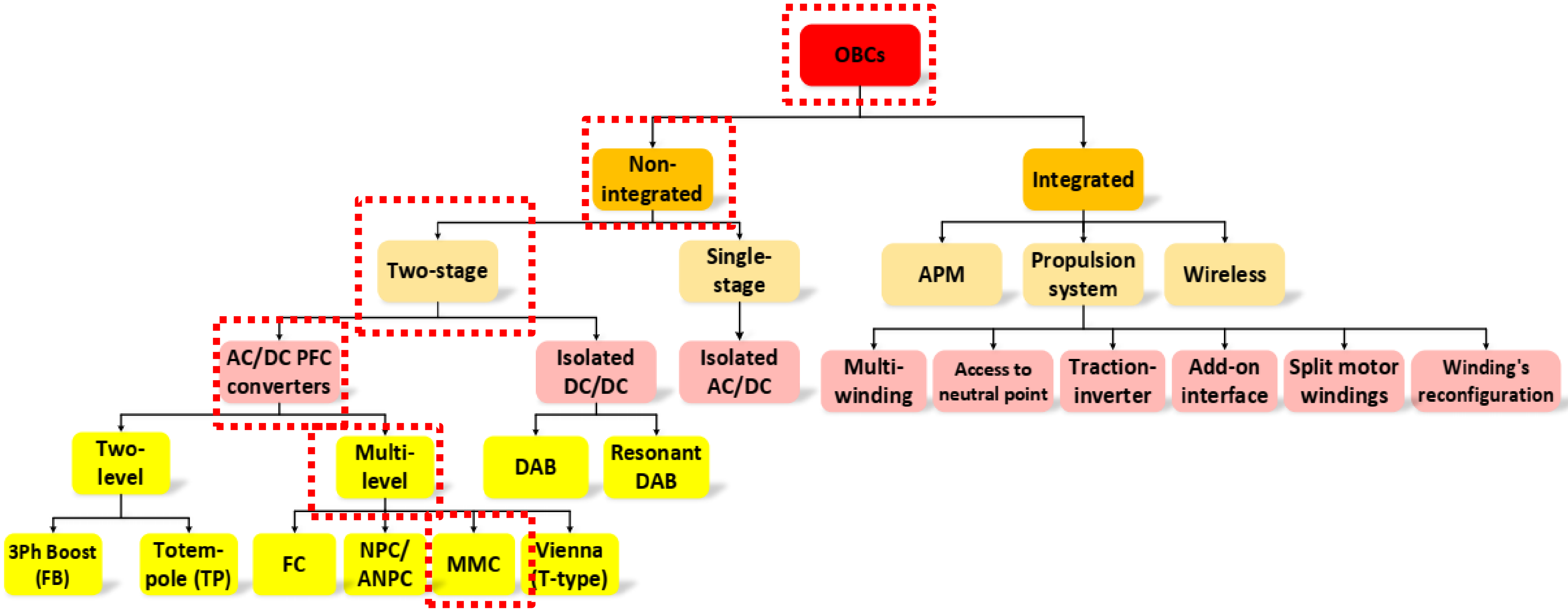
Examples of multi-level AC-DC PFCs for two-stage non-integrated OBCs



Active-neutral-point-clamped (ANPC) converter

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)



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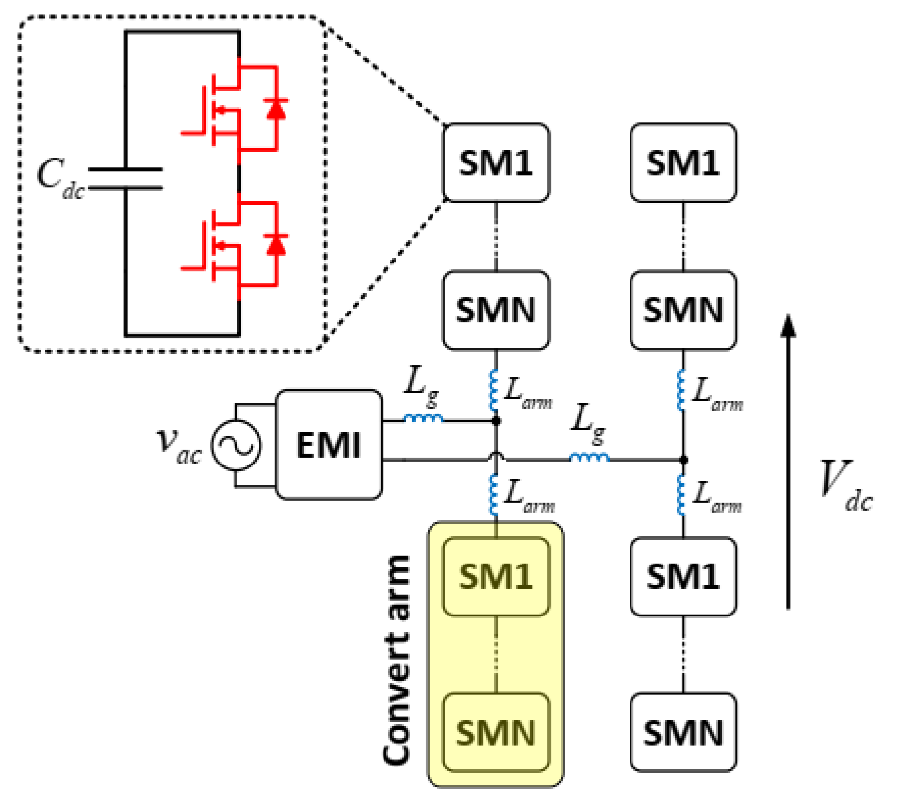
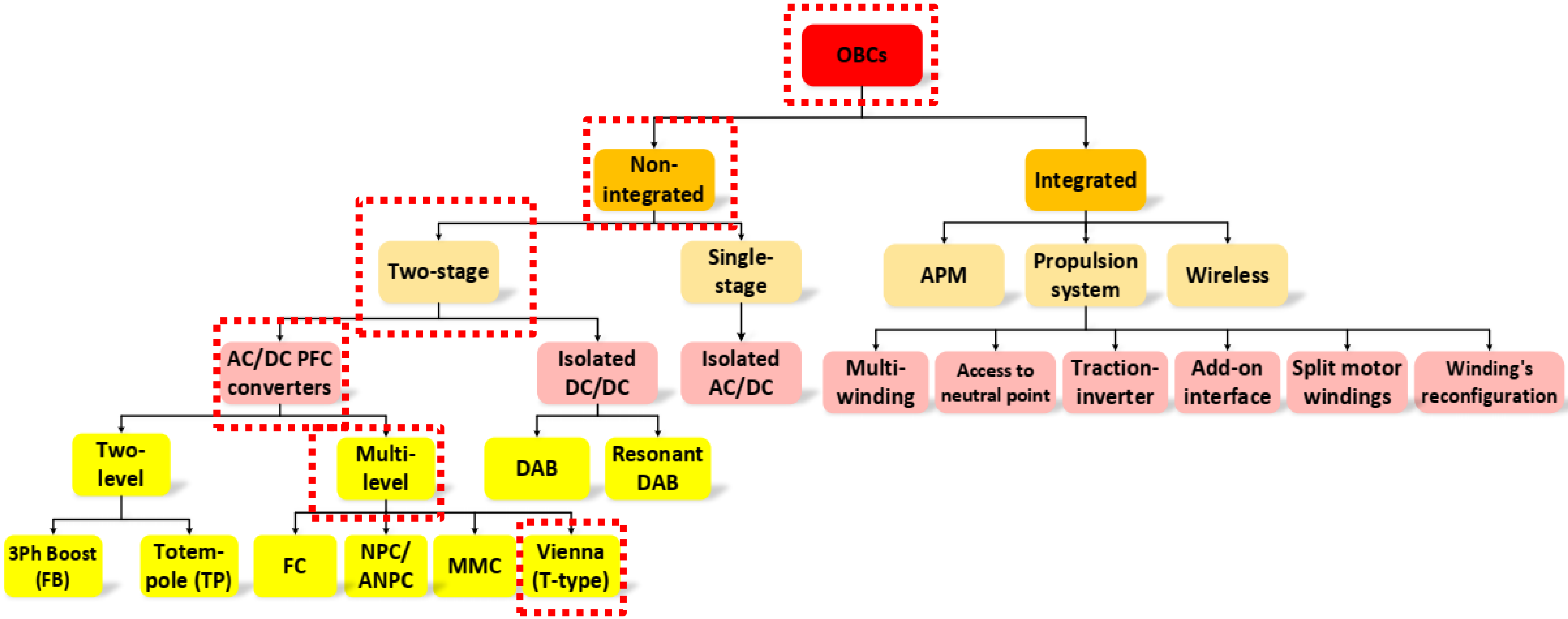


Modular multi-level converter

Electric Vehicle Power Converters Topology

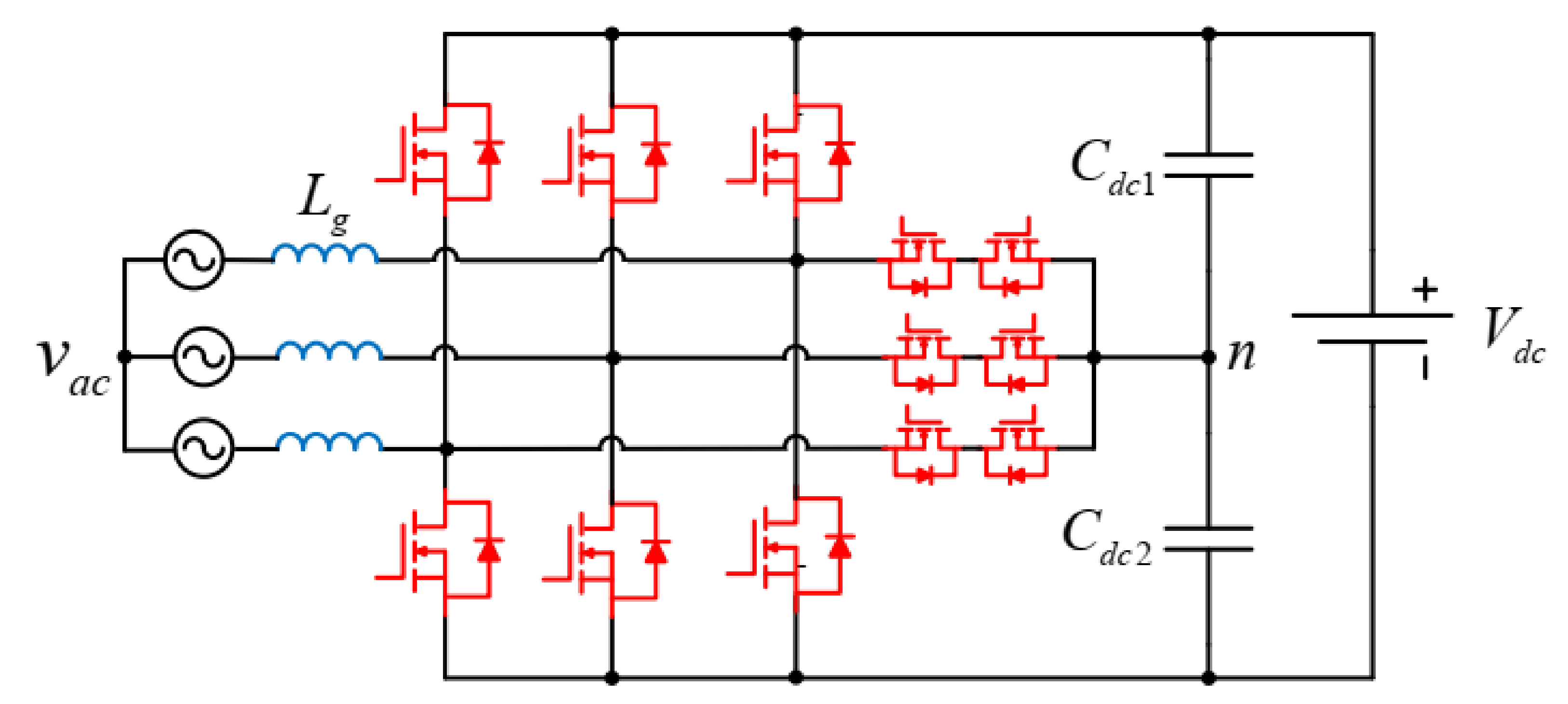
On-Board Battery Chargers (OBCs)



Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

AC-DC PFC Converter Topologies for Two-Stage Non-Integrated OBCs

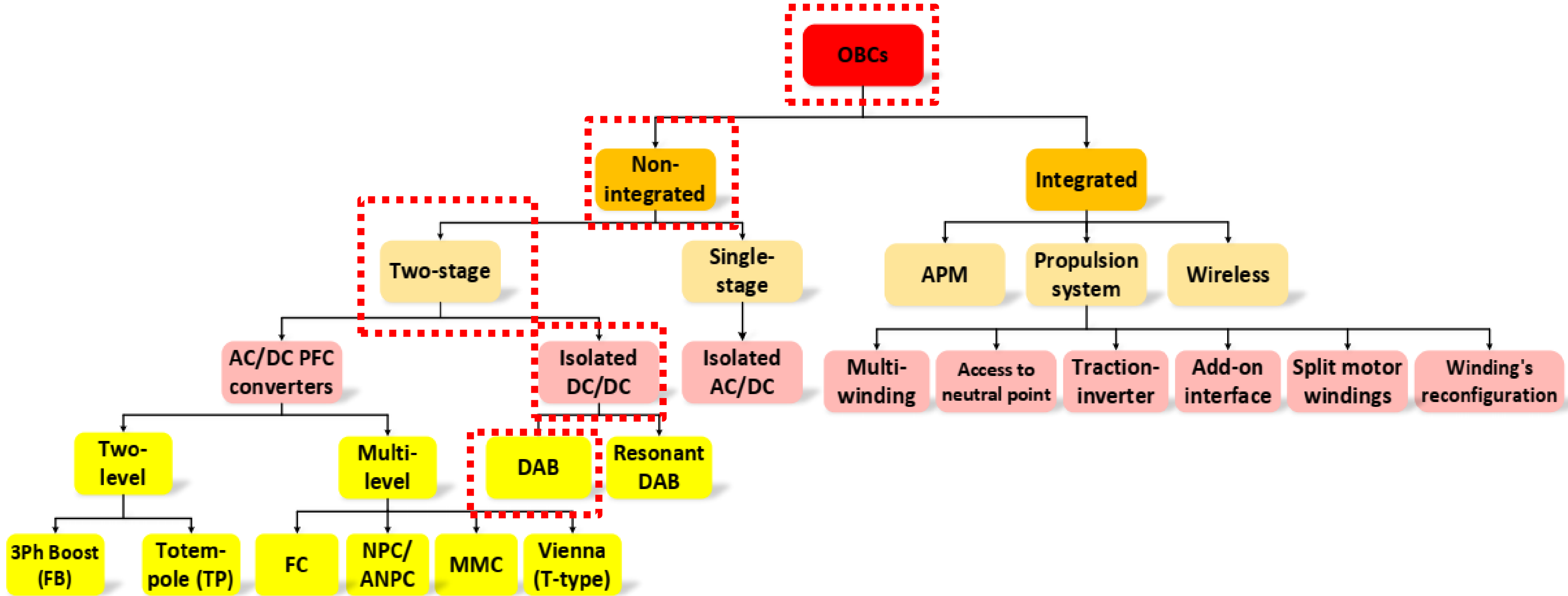
Examples of multi-level AC-DC PFCs for two-stage non-integrated OBCs



Three-level T-type boost PFC (Vienna rectifier)

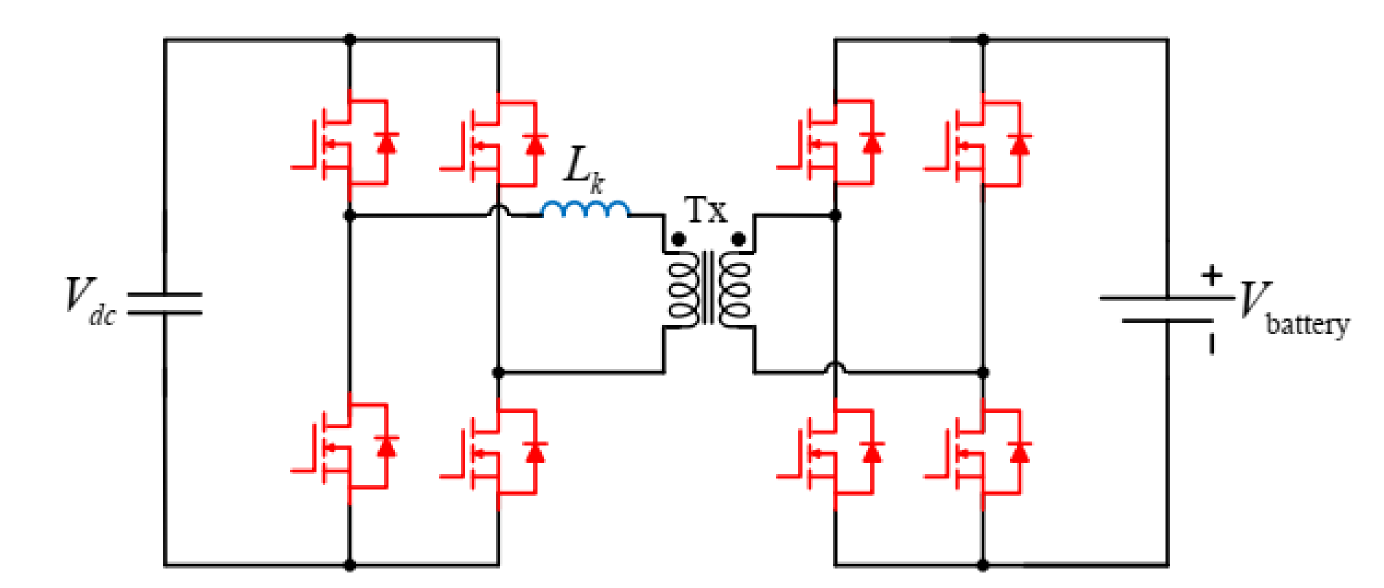
Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)



DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

Isolated DC-DC converter topologies for two-stage non-integrated OBCs:

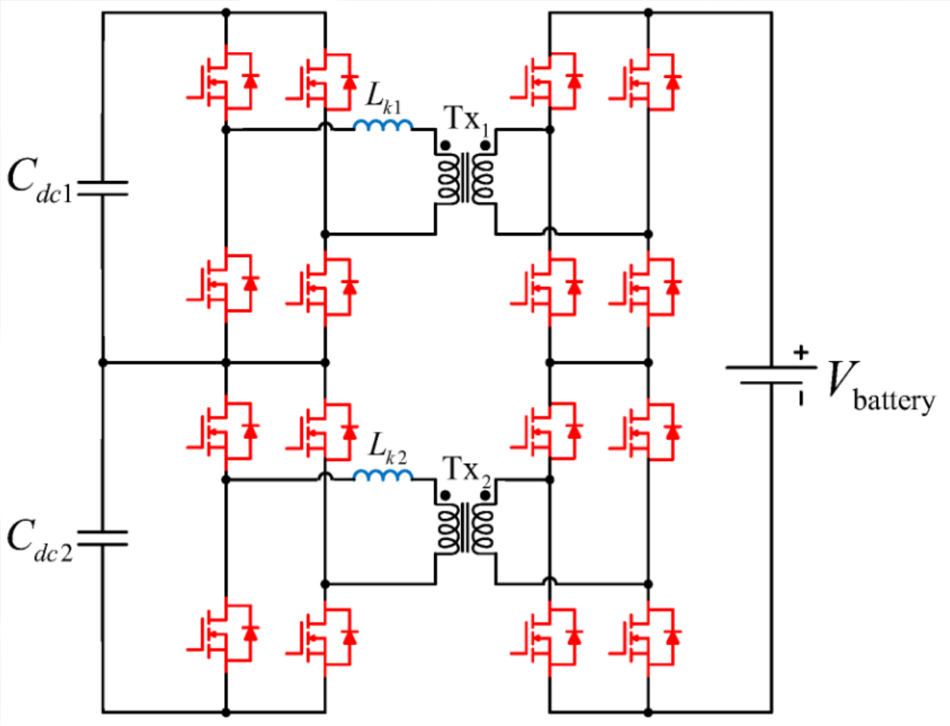


Dual active bridge (DAB) converter

High-frequency transformer (HFT)

DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

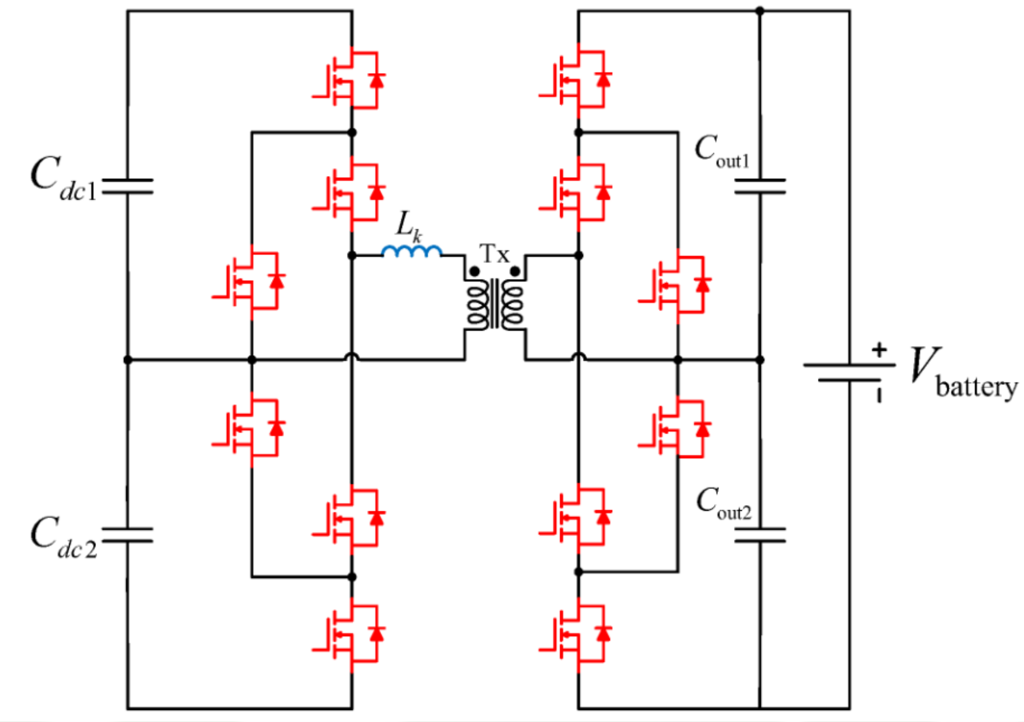
Examples of two-level and multi-level variants of DAB and resonant DAB converter topologies for two-stage non-integrated OBC



Two-level series-input–series-output DAB converter

DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

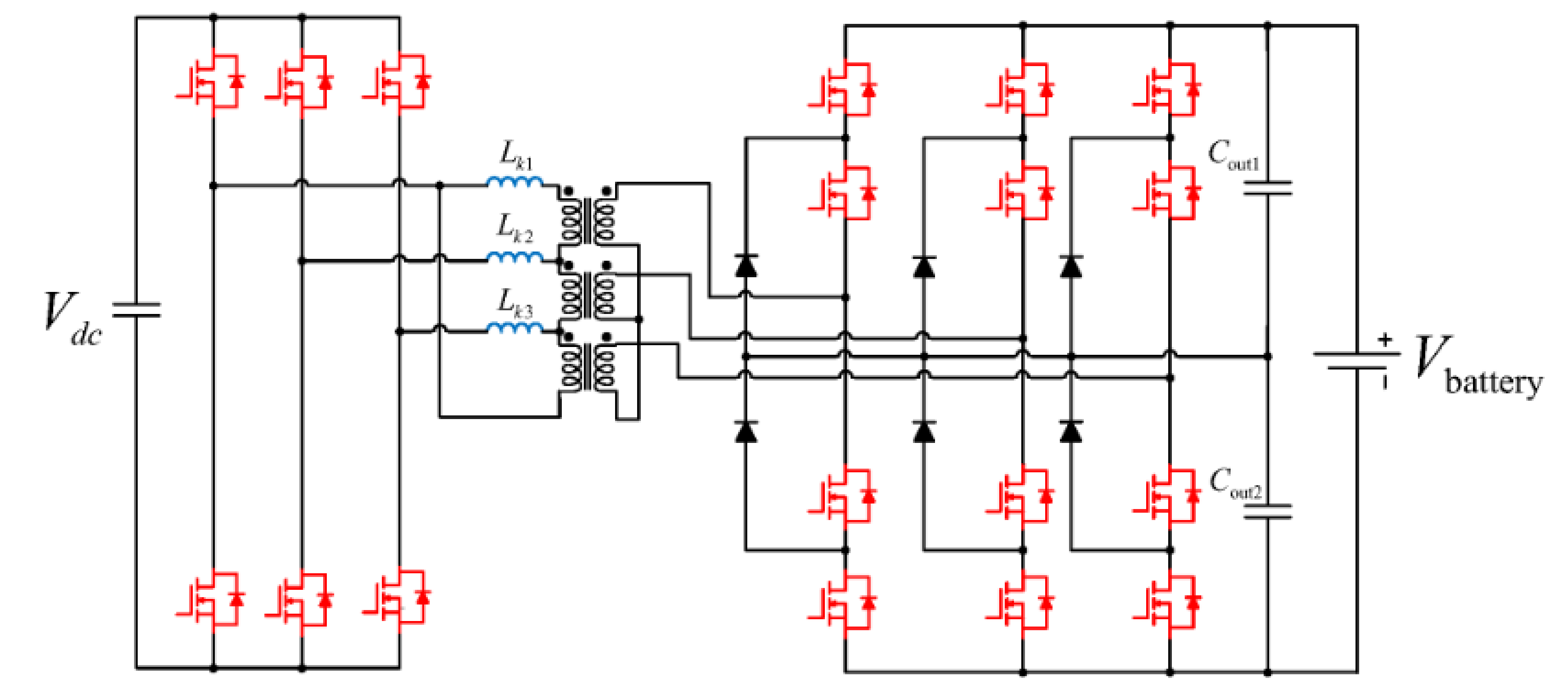
Examples of two-level and multi-level variants of DAB and resonant DAB converter topologies for two-stage non-integrated OBC



Three-level ANPC dual active half-bridge topology

DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

Examples of two-level and multi-level variants of DAB and resonant DAB converter topologies for two-stage non-integrated OBC



Three-level three-phase DAB converter

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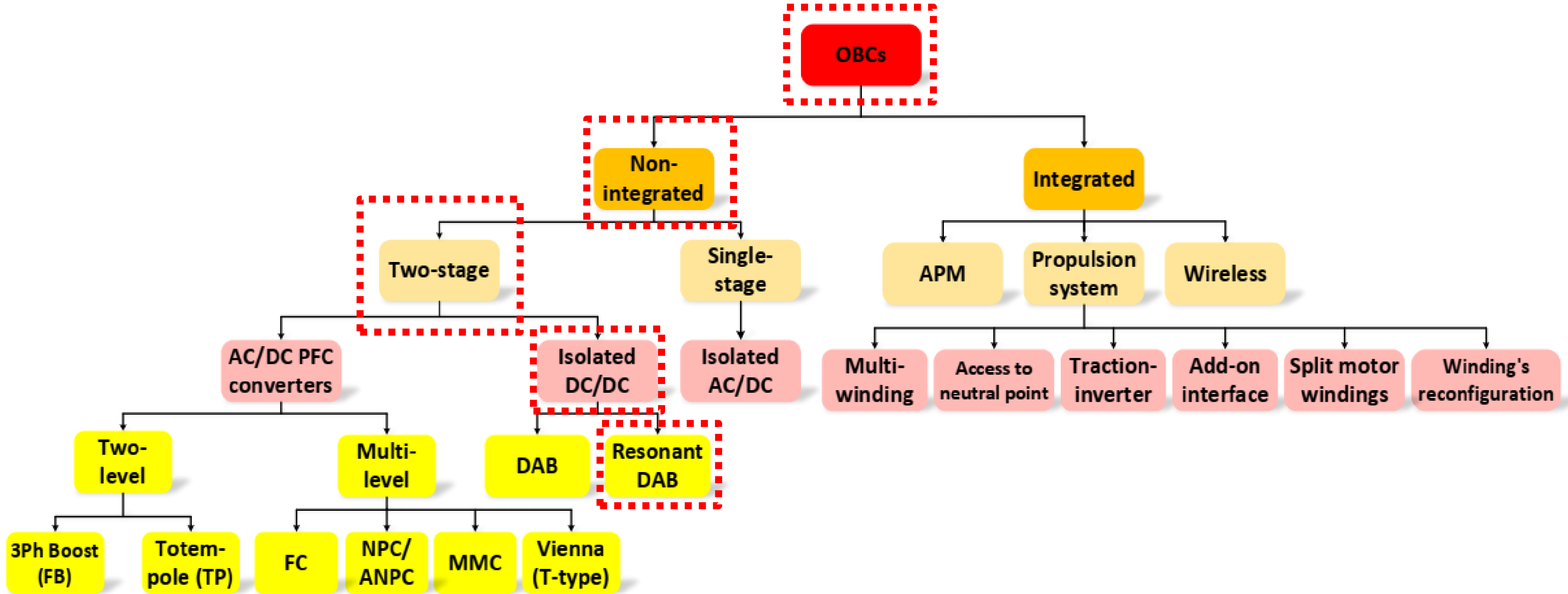
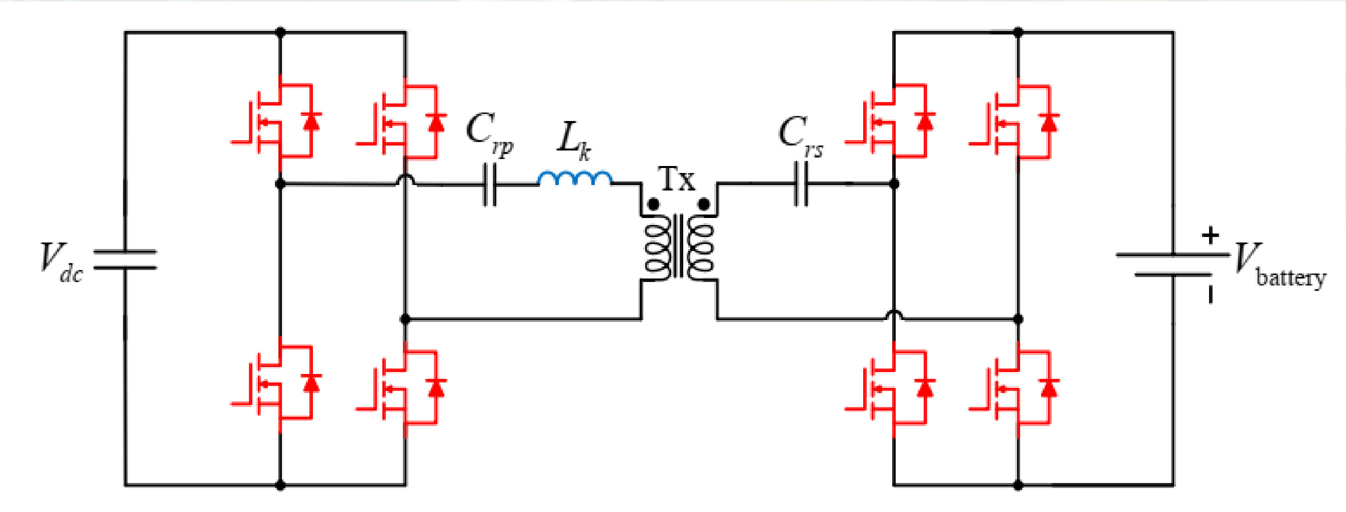
On-Board Battery Chargers (OBCs)



DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

Isolated DC-DC converter topologies for two-stage non-integrated OBCs:



Dual active bridge (DAB) converter

Resonant DAB converter (CLLC)

Electric Vehicle Power Converters Topology

Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

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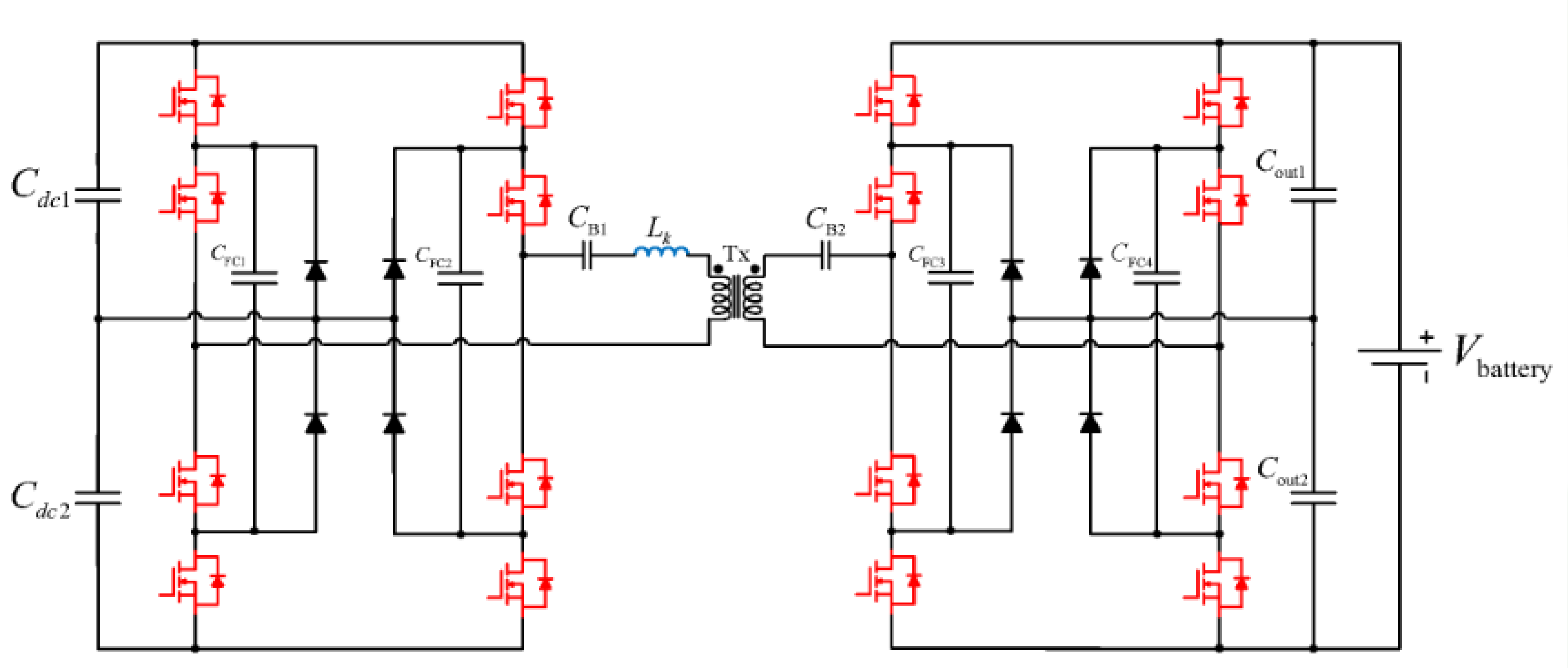
DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

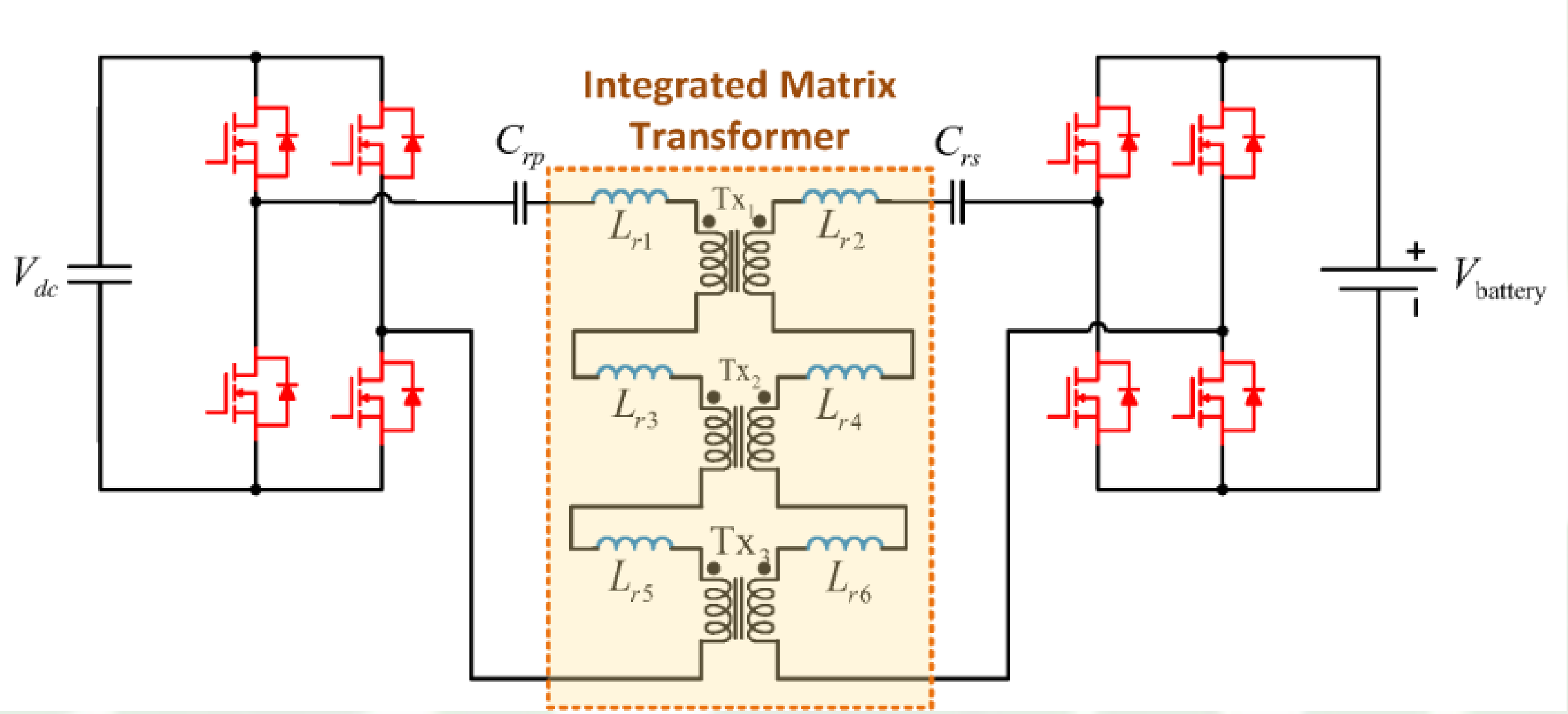
Examples of two-level and multi-level variants of DAB and resonant DAB converter topologies for two-stage non-integrated OBC



Three-level DAB converter with blocking capacitors

DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

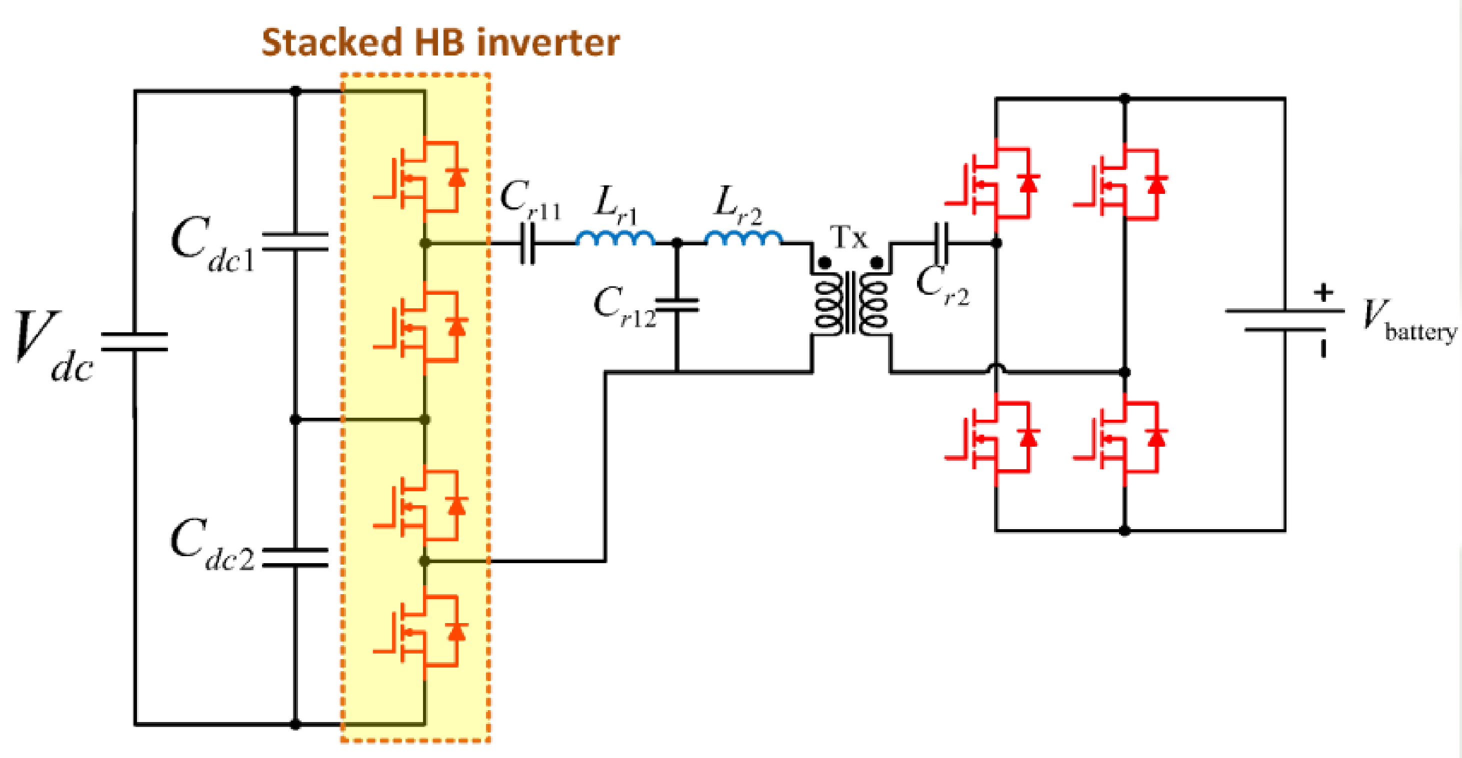
Examples of two-level and multi-level variants of DAB and resonant DAB converter topologies for two-stage non-integrated OBC



Two-level CLLC resonant converter with three modular transformers

DC-DC Converter Topologies for Two-Stage Non-Integrated OBCs

Examples of two-level and multi-level variants of DAB and resonant DAB converter topologies for two-stage non-integrated OBC



Multi-level stacked-half-bridge with LCL-T network with DC blocking capacitors

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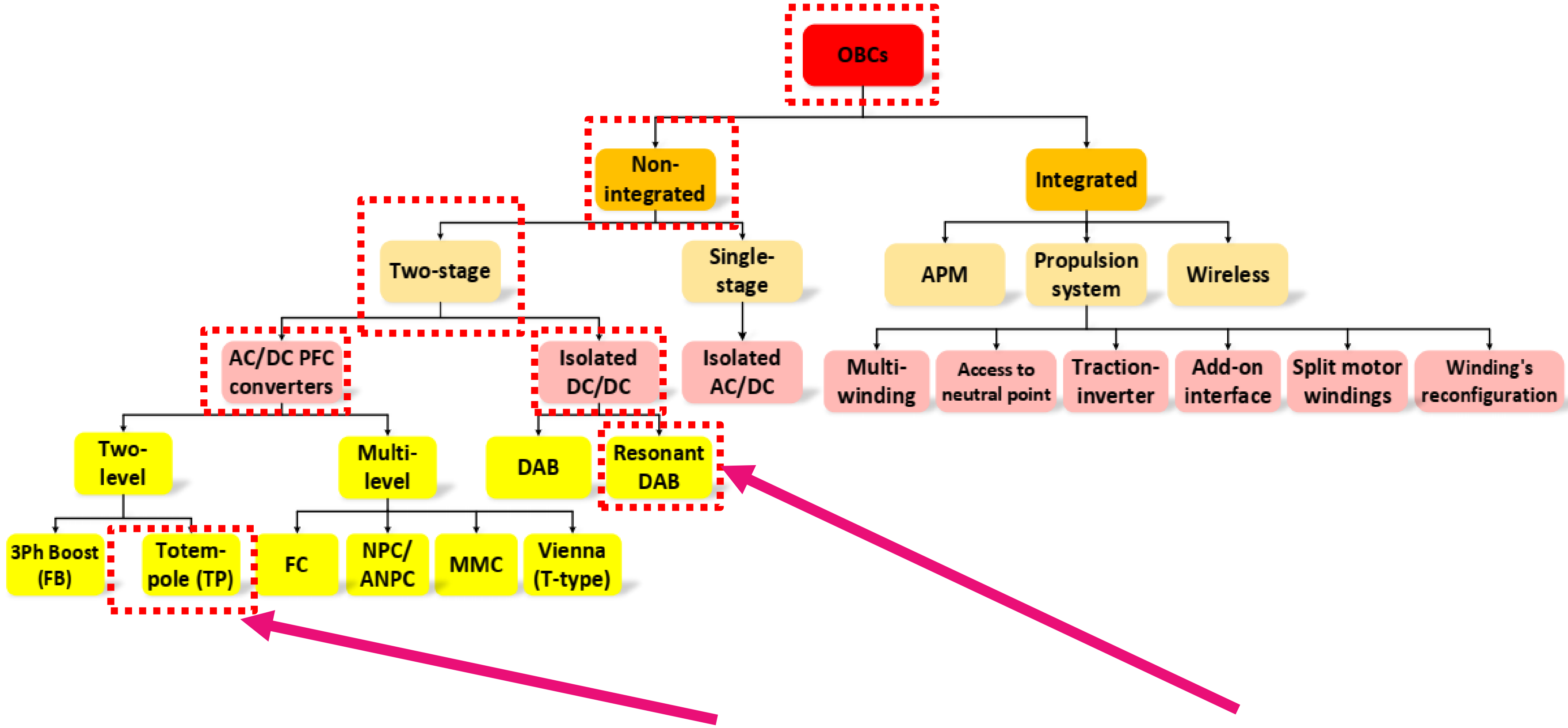
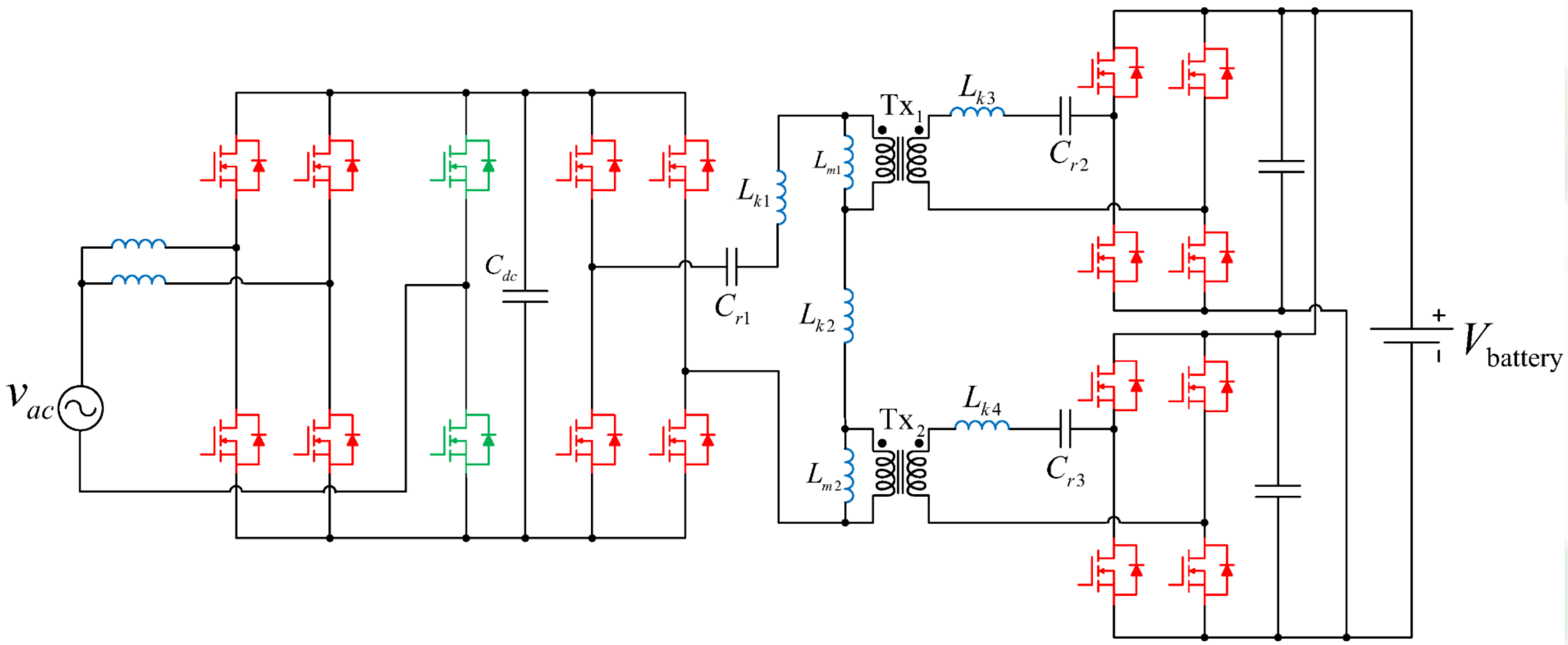
On-Board Battery Chargers (OBCs)



Two-Stage Non-Integrated OBCs with totem-pole PFC and resonant DC-DC converters

Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

Two-Stage Non-Integrated OBCs with totem-pole PFC and resonant DC-DC converters



Two-channel interleaved totem-pole PFC and single-phase CLLC resonant DAB converter

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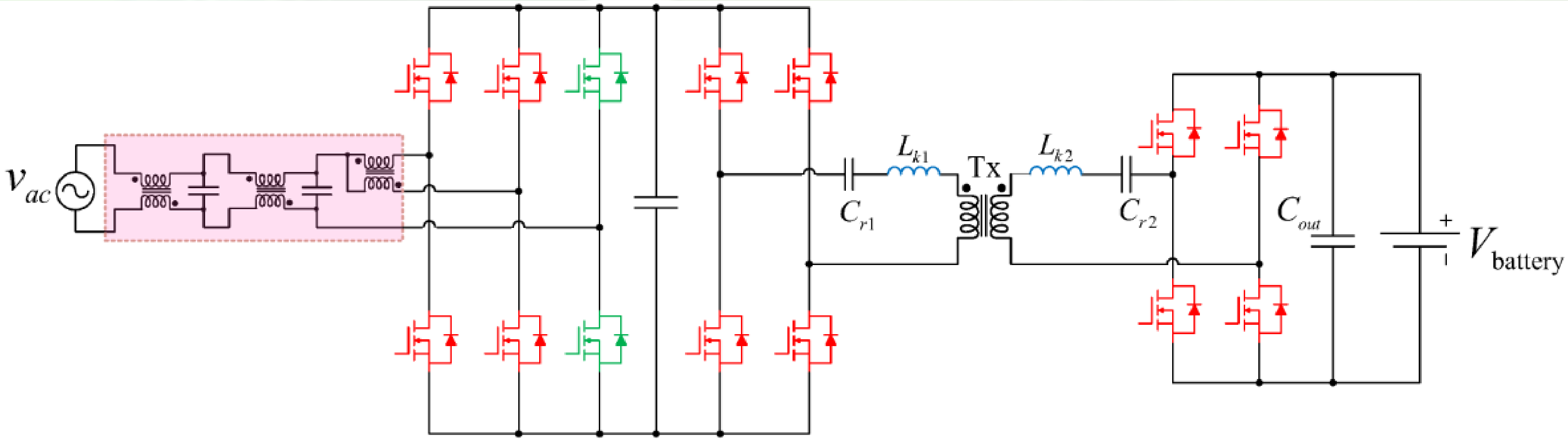
Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

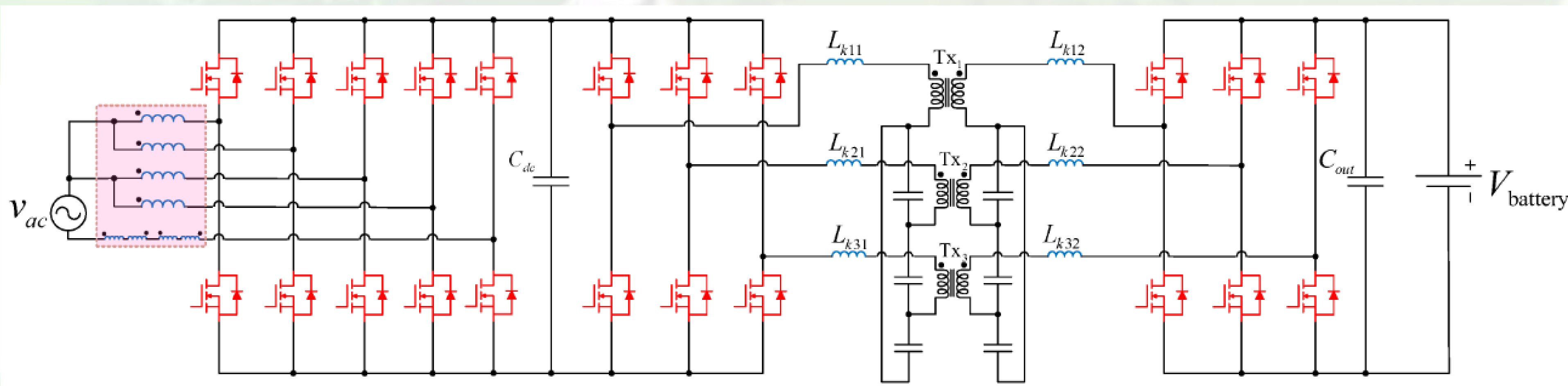
Two-Stage Non-Integrated OBCs with totem-pole PFC and resonant DC-DC converters



Two-channel interleaved totem-pole PFC and CLLC resonant converter

Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

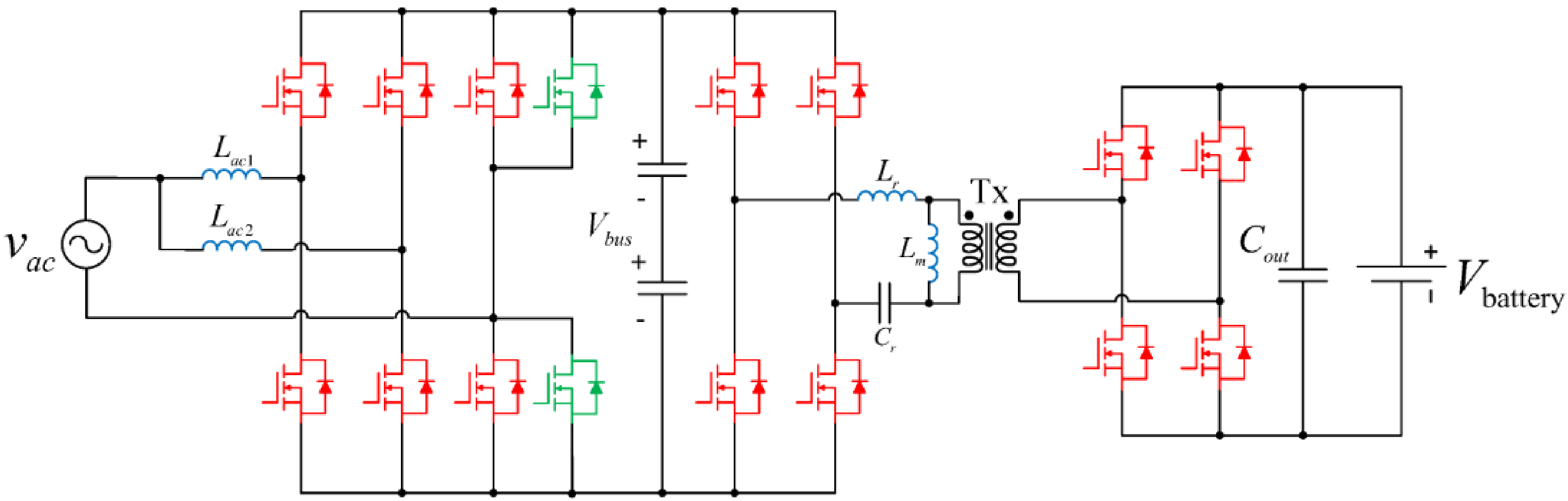
Two-Stage Non-Integrated OBCs with totem-pole PFC and resonant DC-DC converters



Four-channel interleaved totem-pole PFC with Return Path Windings and three-phase CLLC resonant converter

Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

Two-Stage Non-Integrated OBCs with totem-pole PFC and resonant DC-DC converters



Two-channel interleaved totem-pole PFC and LLC resonant converter

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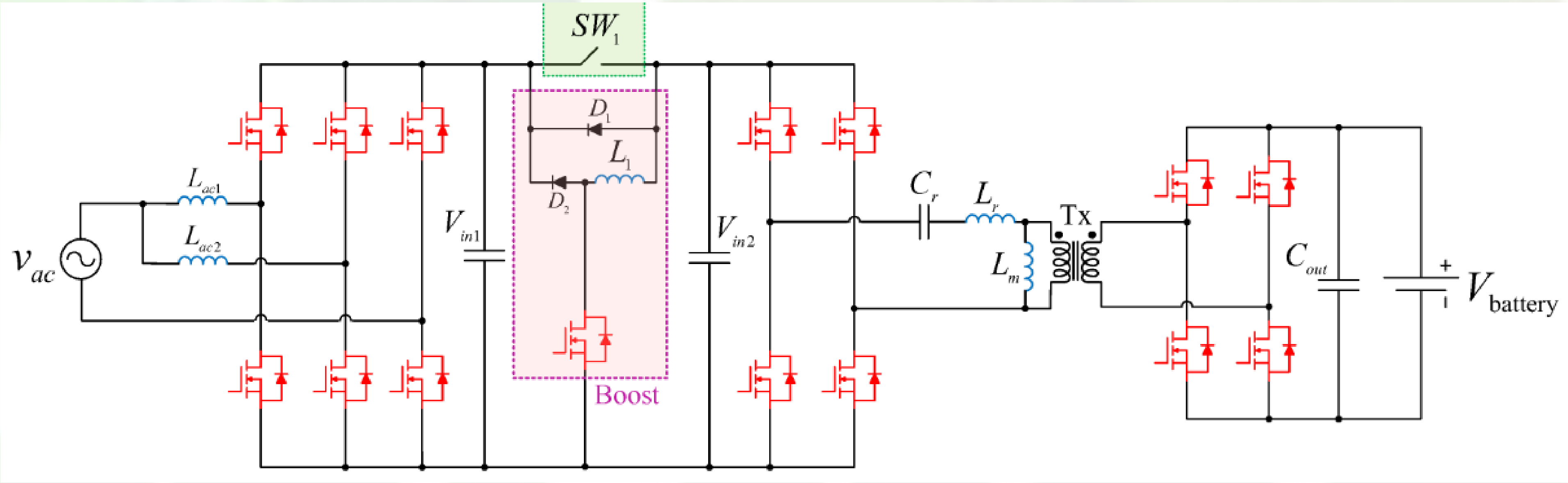
Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

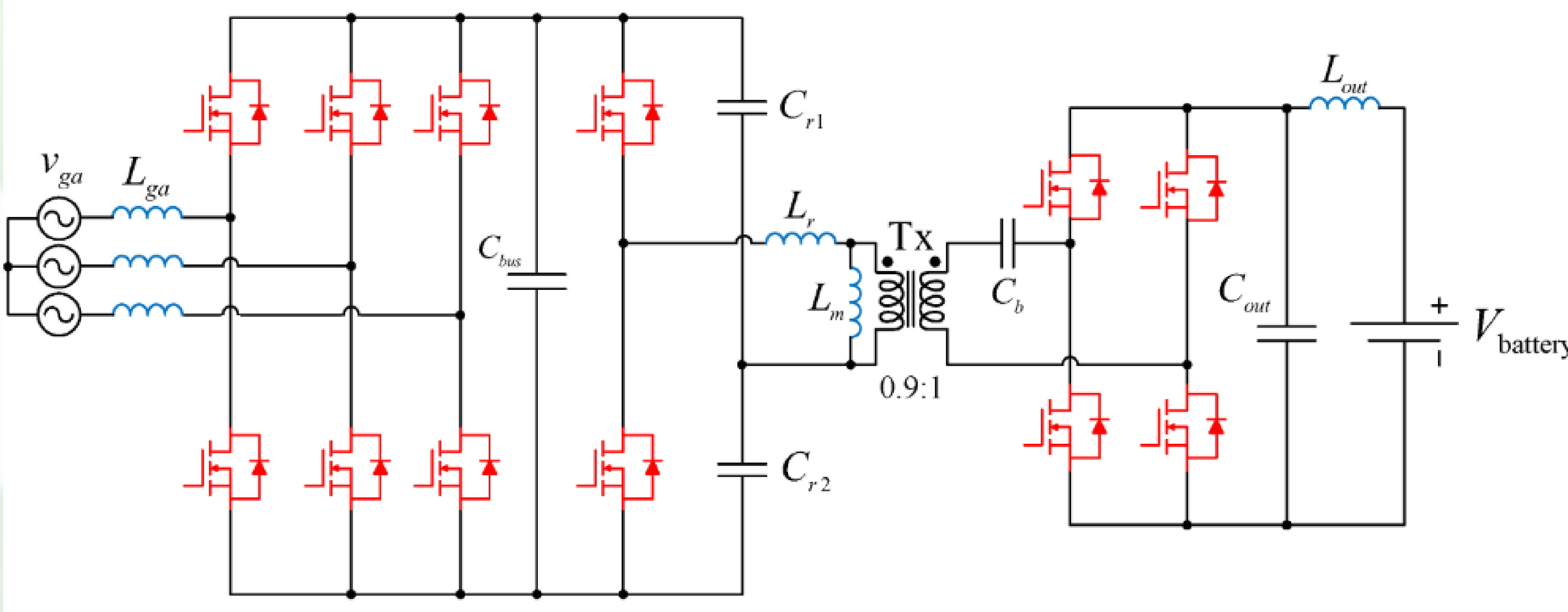
Two-Stage Non-Integrated OBCs with totem-pole PFC and resonant DC-DC converters



Two-channel interleaved totem-pole PFC with Mode Switch Boost converter and LLC resonant converter

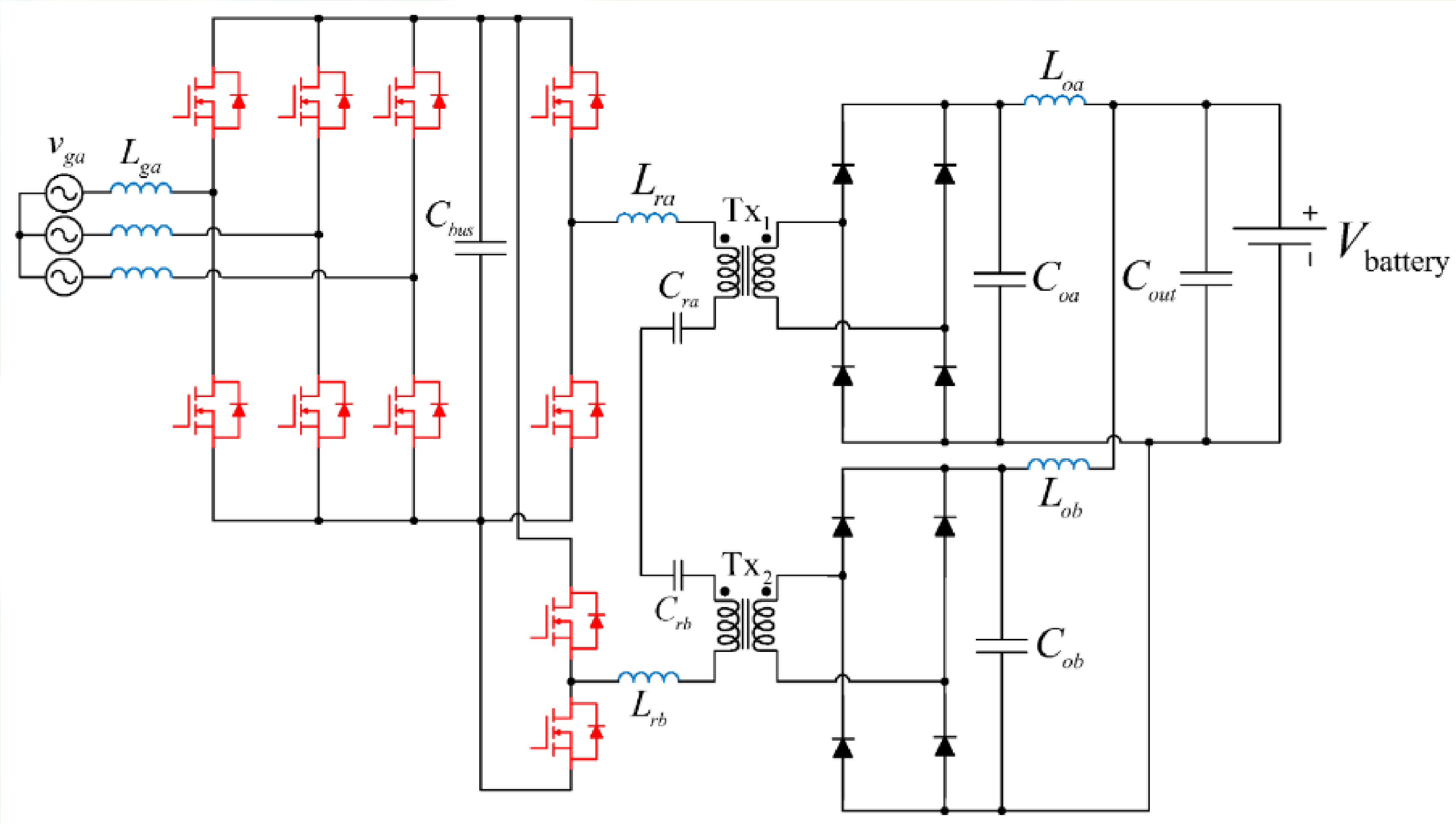
Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

Two-stage non-integrated isolated OBCs with three-phase boost PFC and resonant DC-DC converters



Three-phase boost PFC and LLC resonant converter

Two-stage non-integrated isolated OBCs with three-phase boost PFC and resonant DC-DC converters



Three-phase boost PFC and two parallel-connected resonant LLC converters

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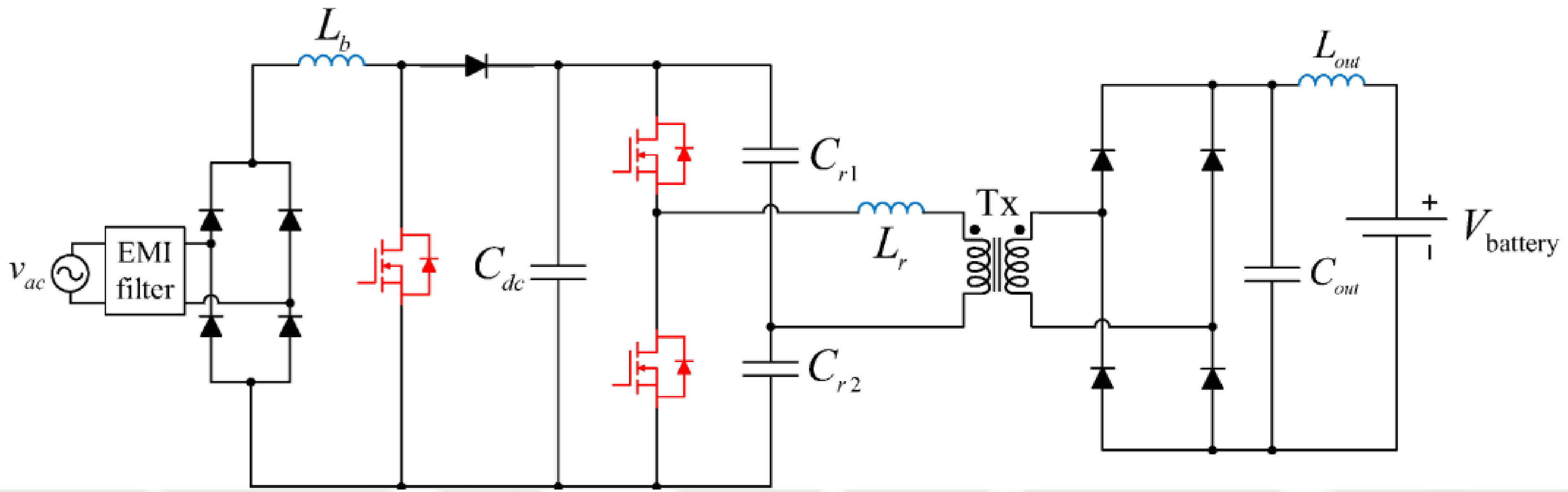
Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

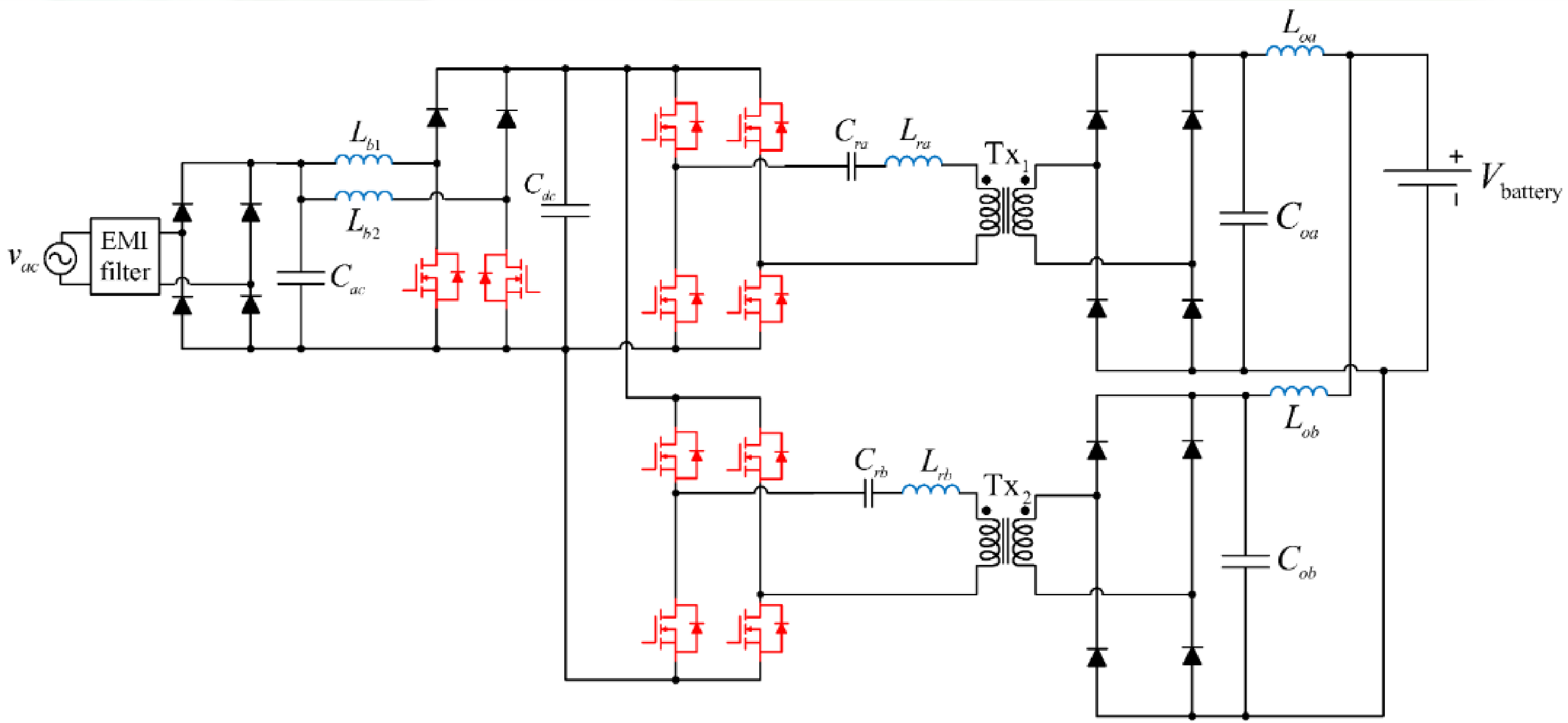
Two-stage non-integrated isolated OBCs with diode bridge PFC and resonant DC-DC converters



Diode bridge and boost converter in the PFC stage and a resonant LLC DC-DC converter at the HV battery side

Two-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

Two-stage non-integrated isolated OBCs with diode bridge PFC and resonant DC-DC converters



A diode bridge with an inrush current limiter and an interleaved boost converter at the grid side and two parallel-input–parallel-output (PIPO) LLC resonant converters at the HV battery side

Electric Vehicle Power Converters Topology

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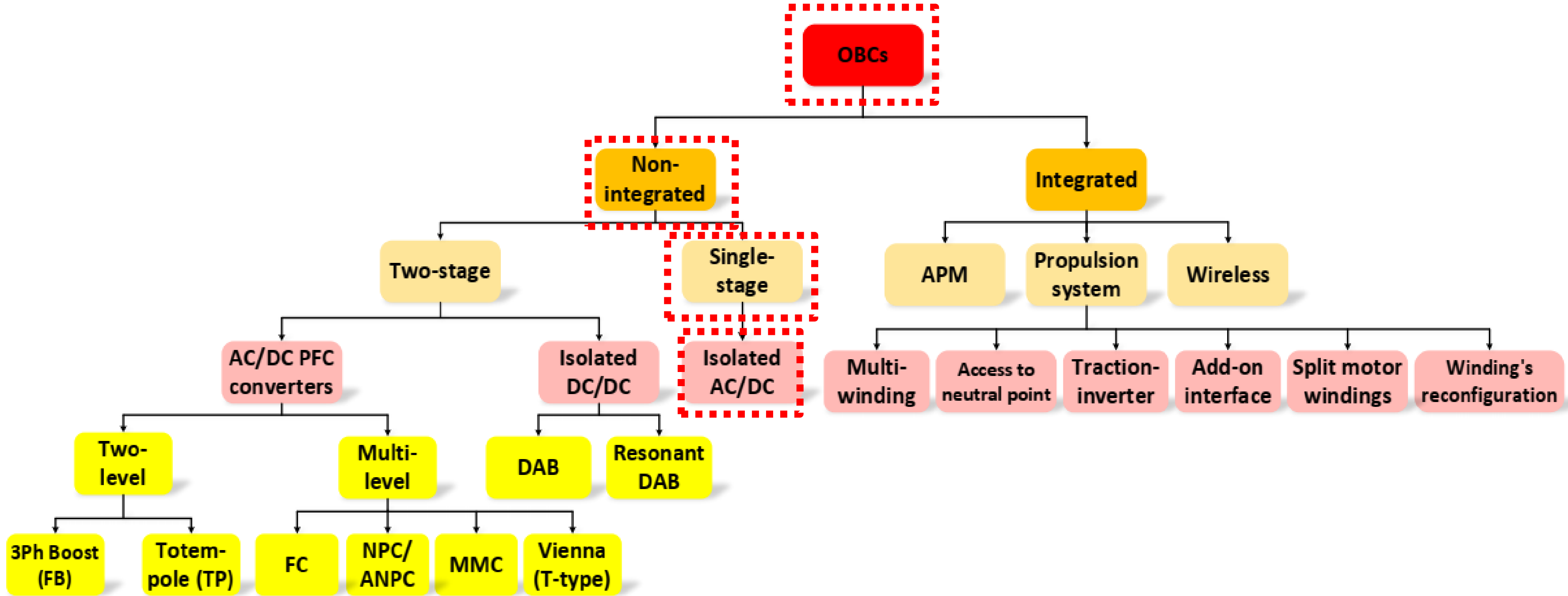
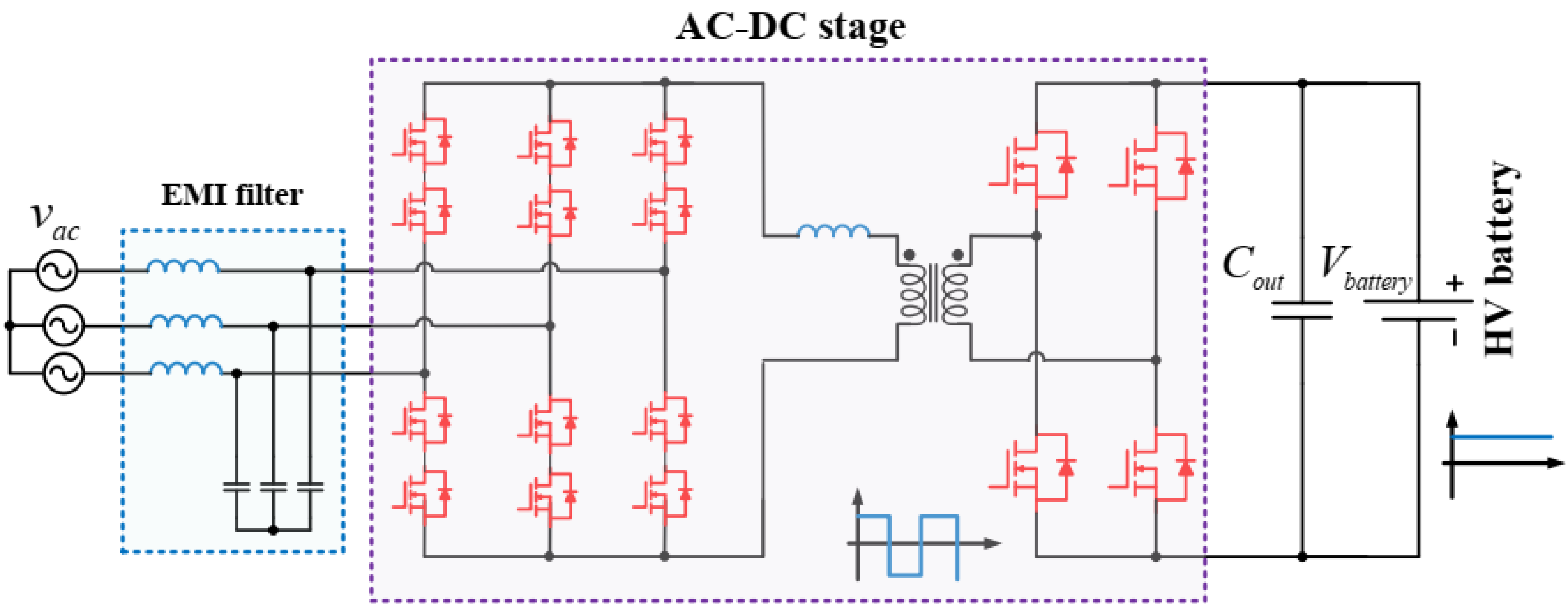
On-Board Battery Chargers (OBCs)



Single-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)



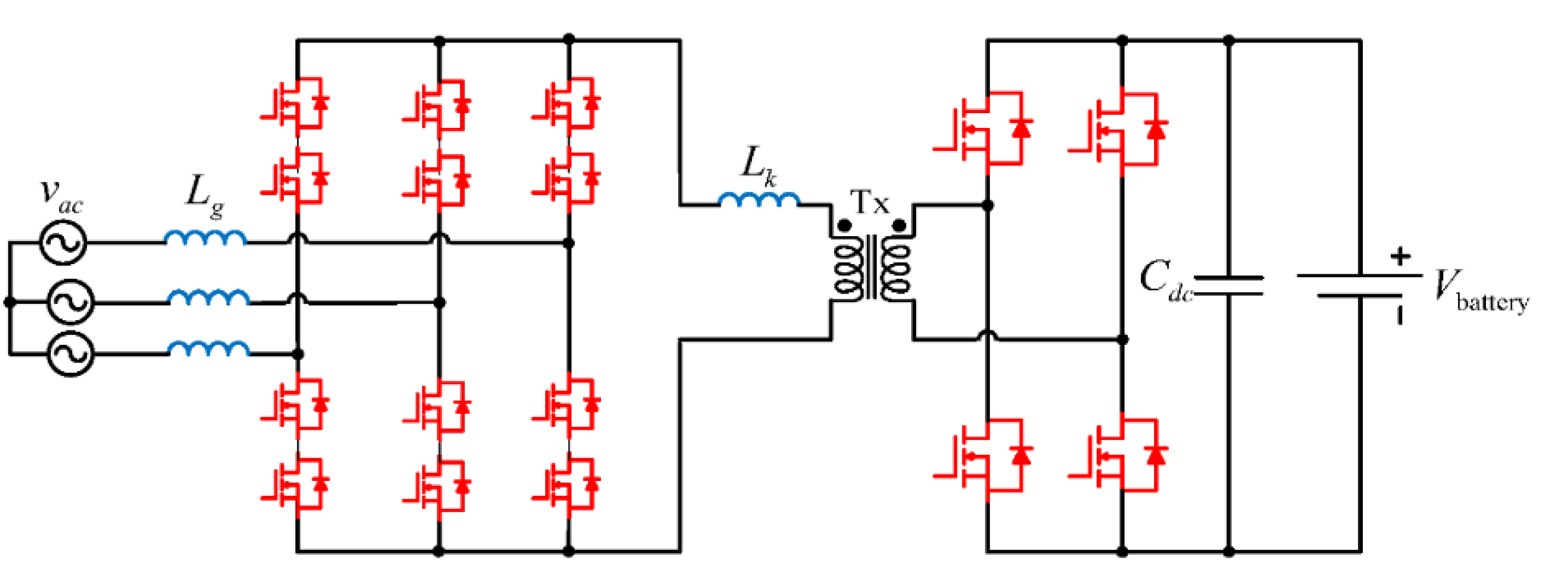
Electromagnetic interference (EMI) filter

AC-DC power factor correction (PFC) unit

DC link capacitors avoided

Galvanically isolated DC-DC converter

Single-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)



Three-phase matrix-type DAB three-phase rectifier

Electric Vehicle Power Converters Topology

Single-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

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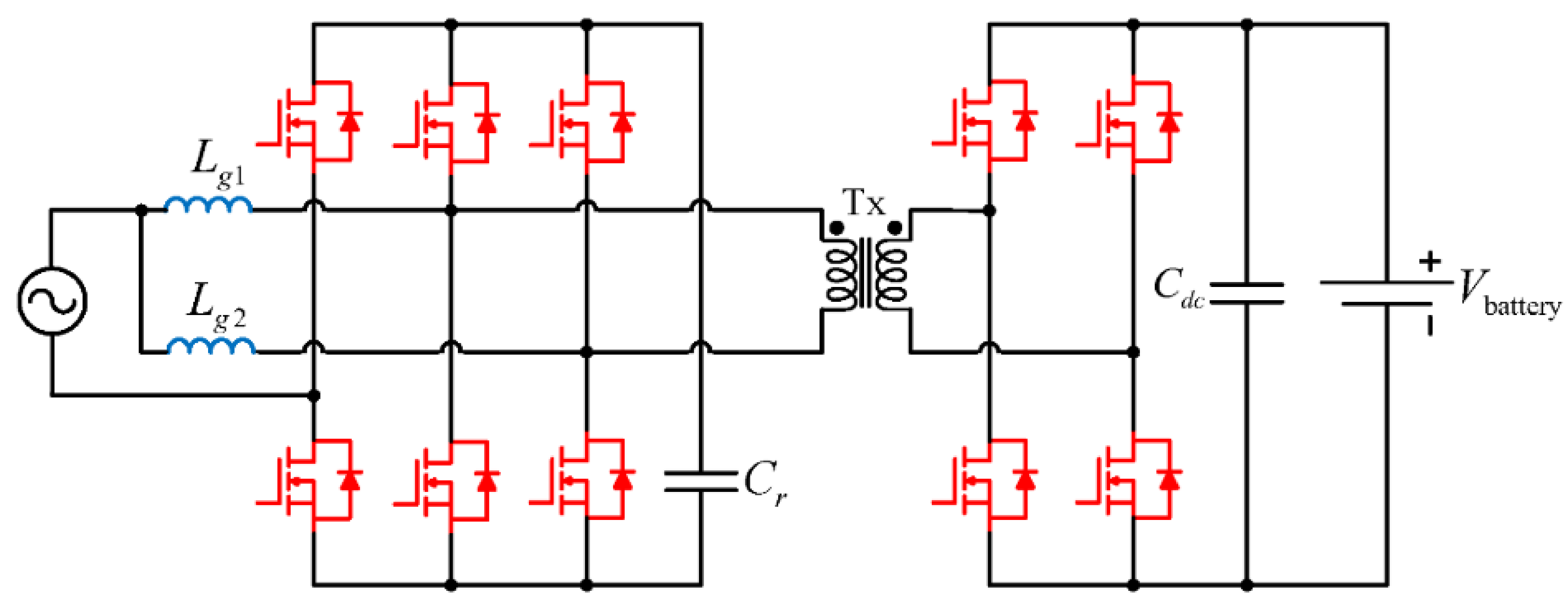

Single-phase interleaved boost DAB converter

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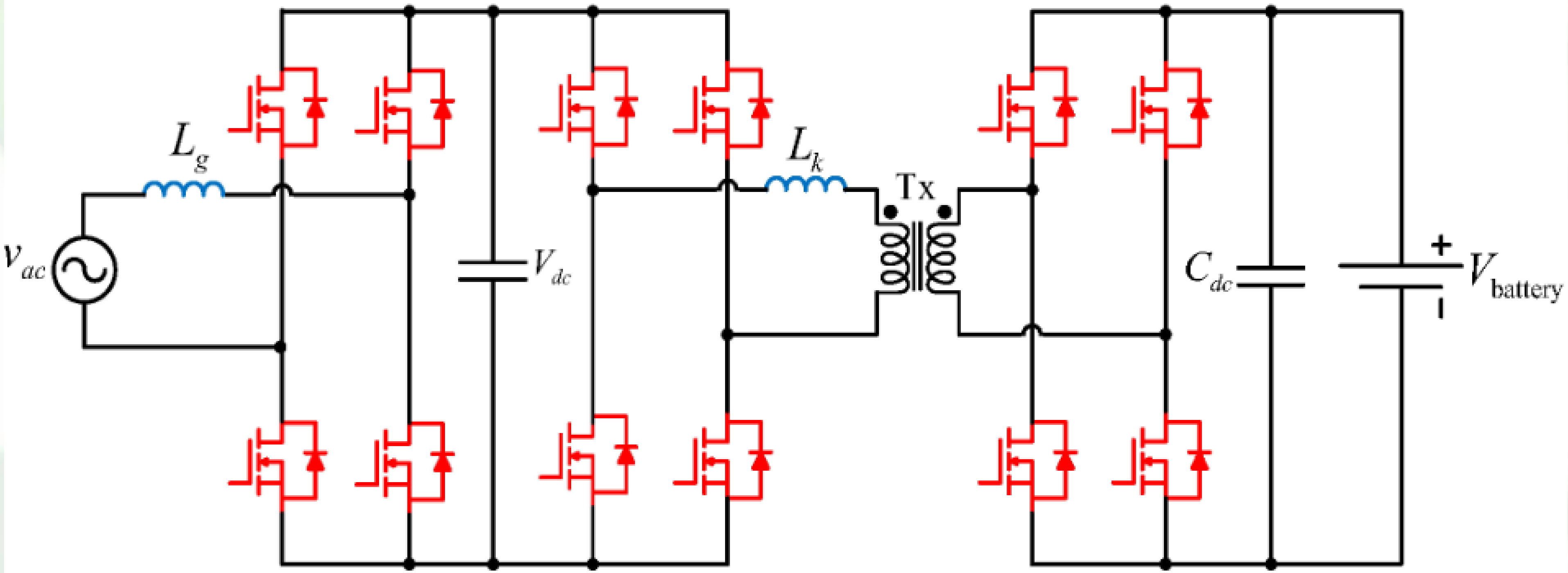
Single-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)



Single-phase modularized FB rectifier and DAB PFC

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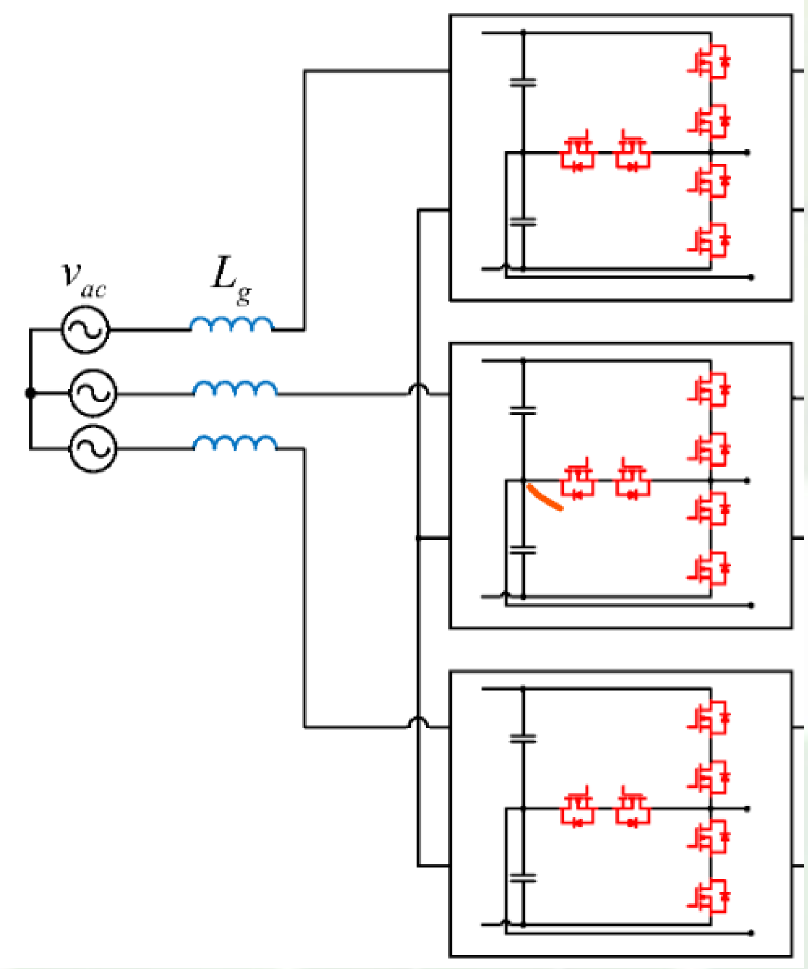
Single-stage Non-Integrated OBCs
On-Board Battery Chargers (OBCs)

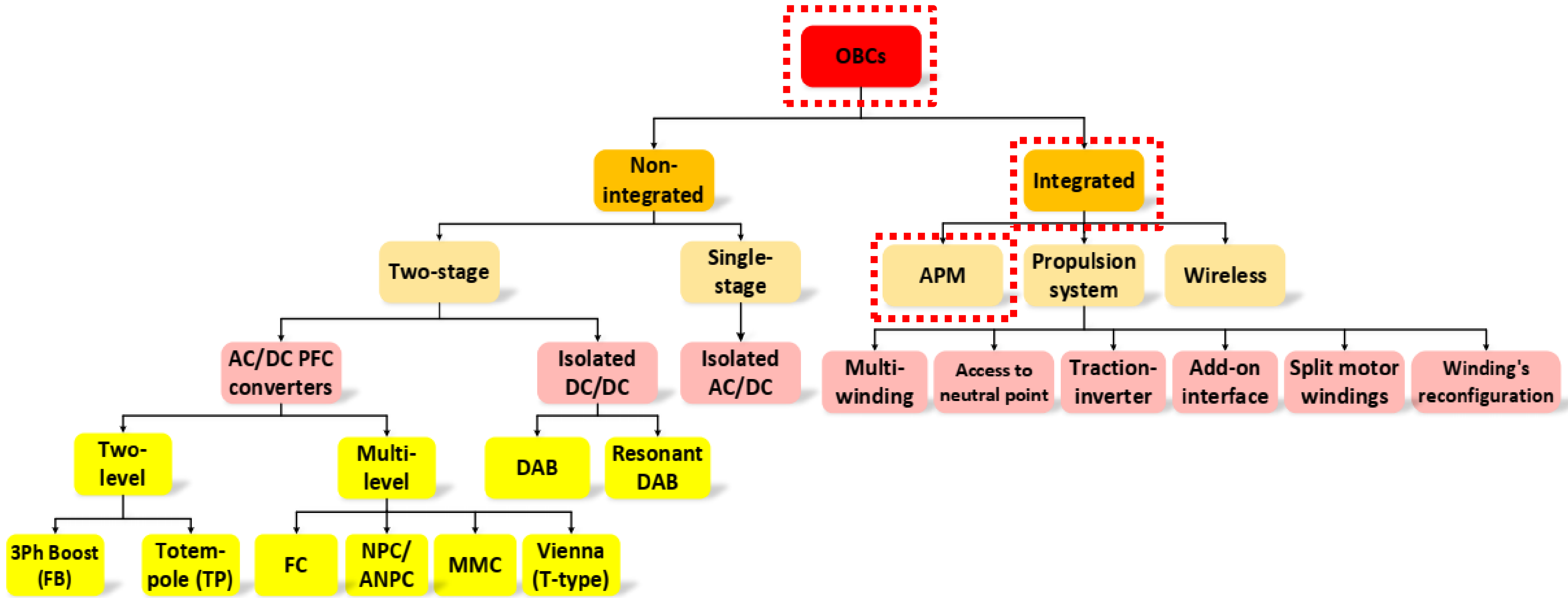


Three-phase T-type circuits and isolated FB converter

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

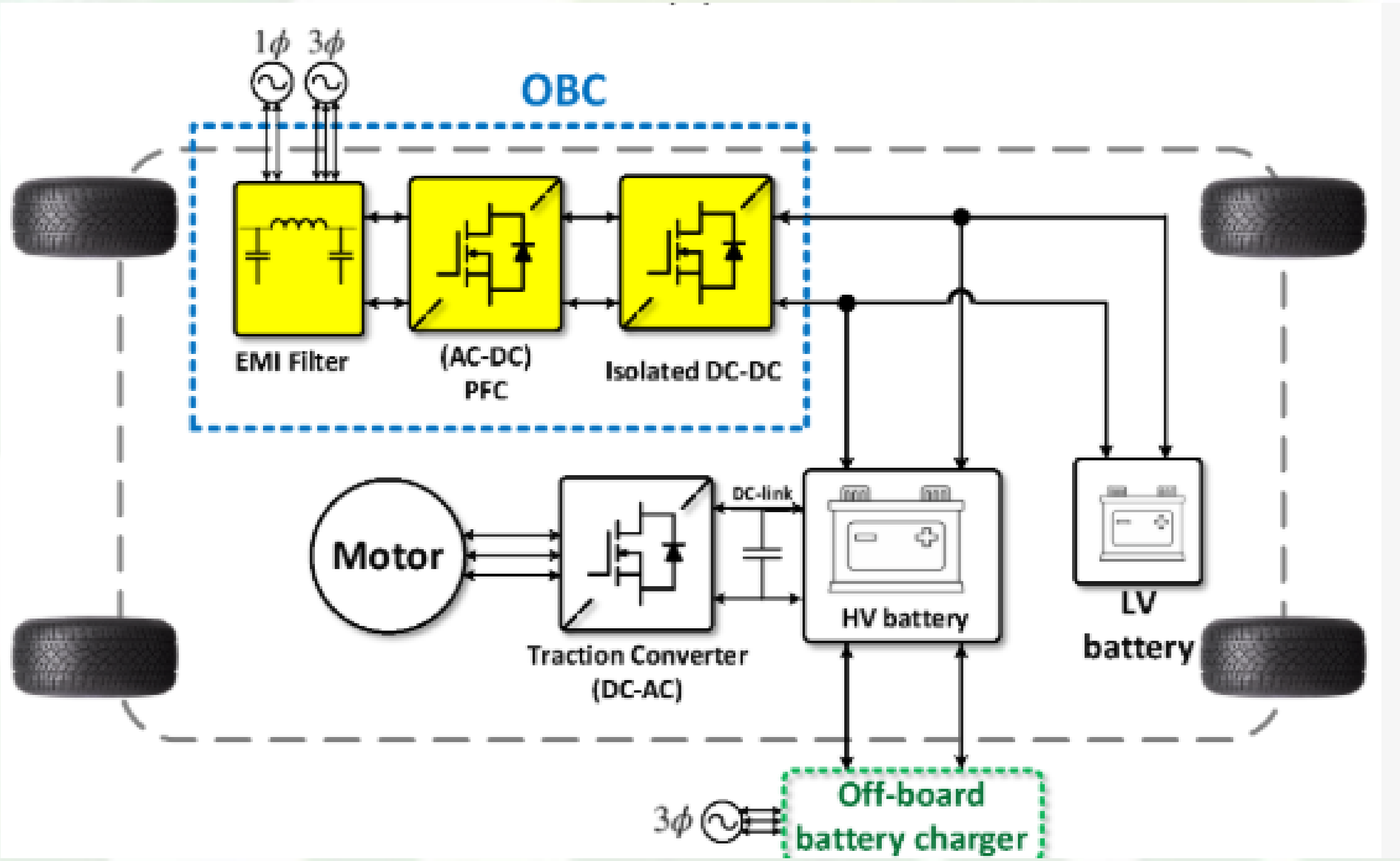
Integrated OBCs (iOBCs)



Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)



Auxiliary power module (APM) iOBC

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)

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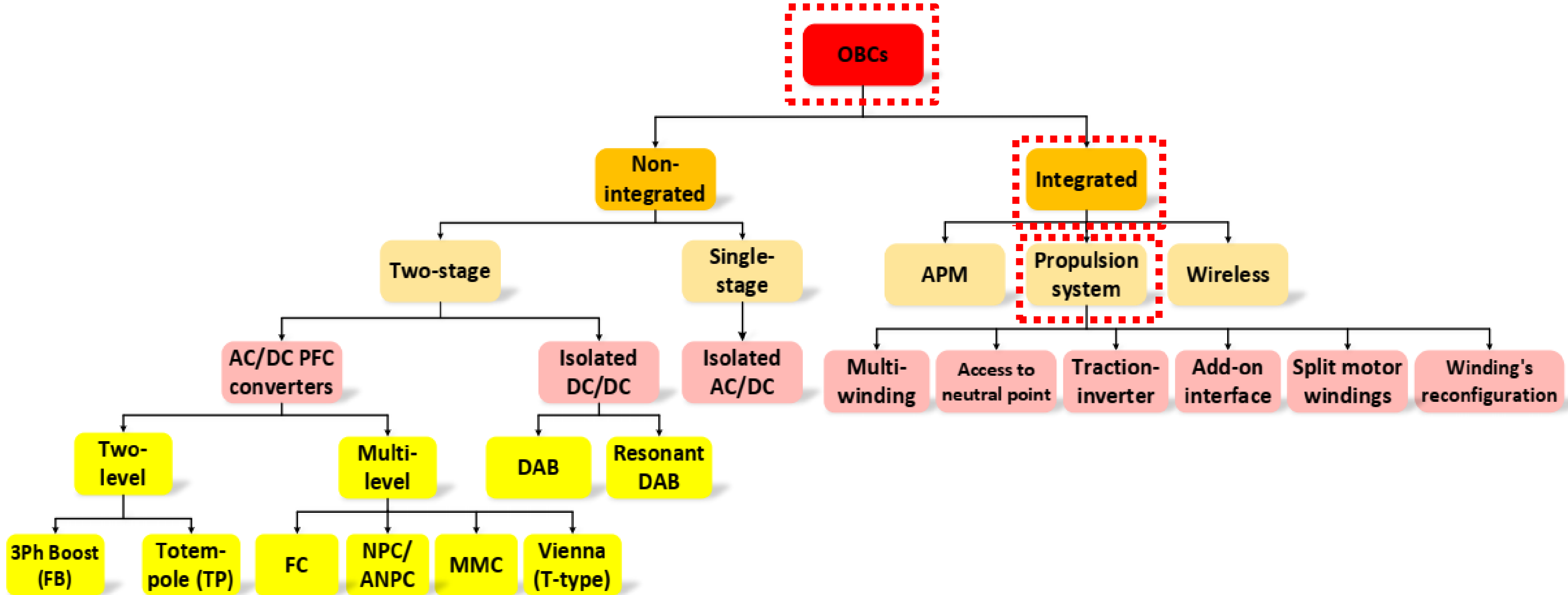
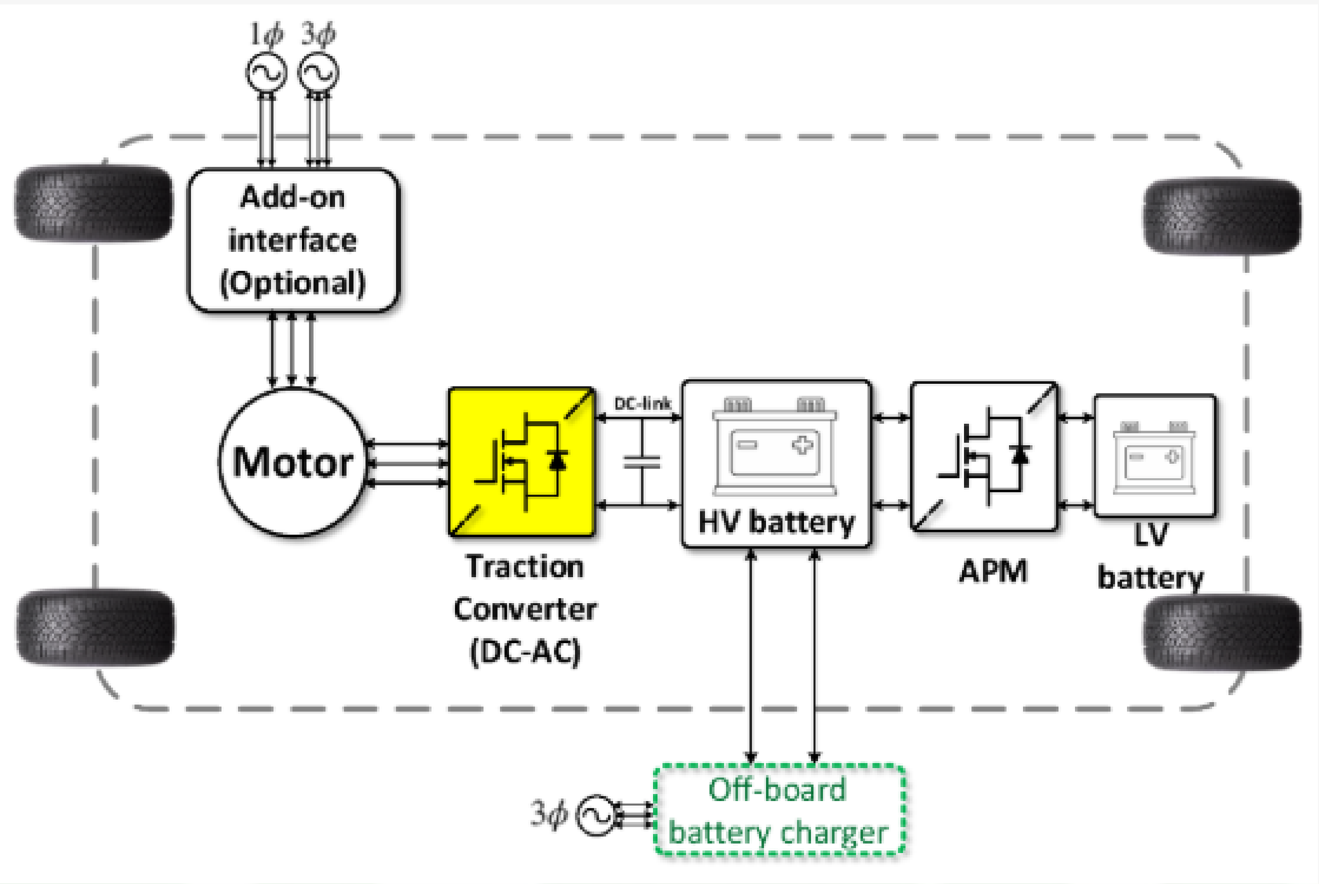


Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)



Propulsion system iOBC

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)

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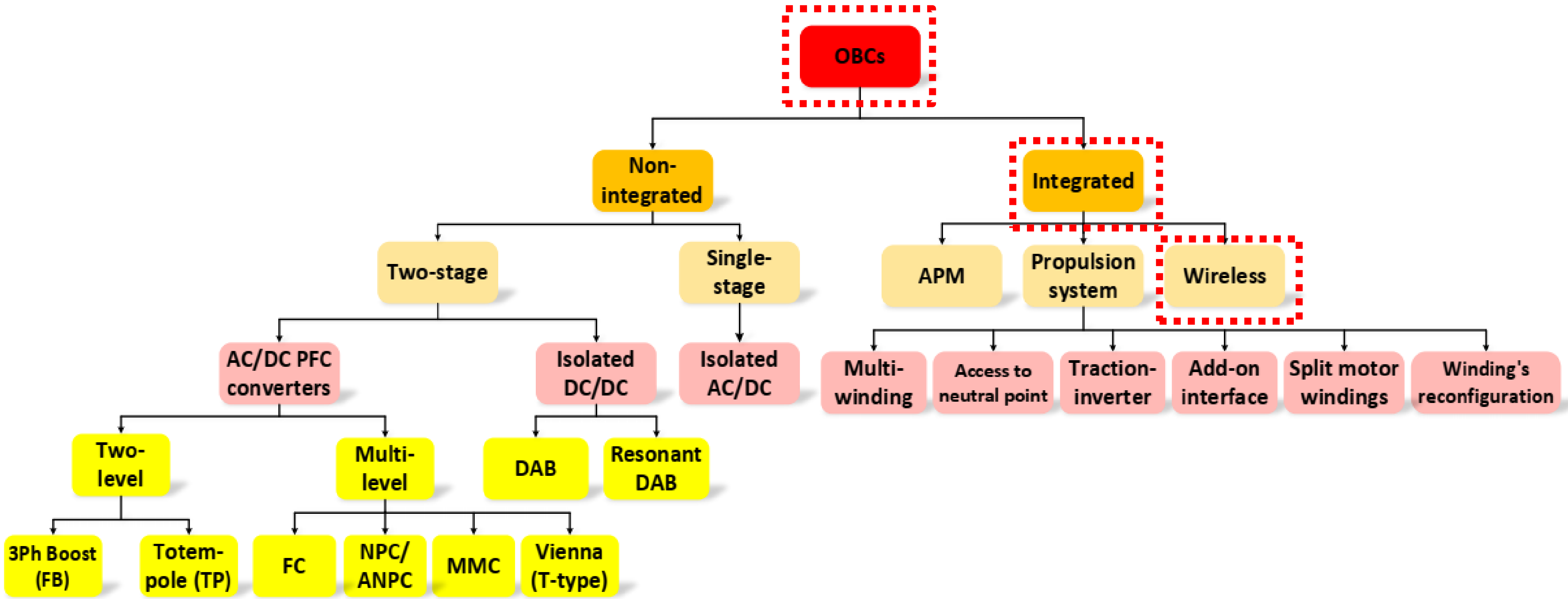

Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)

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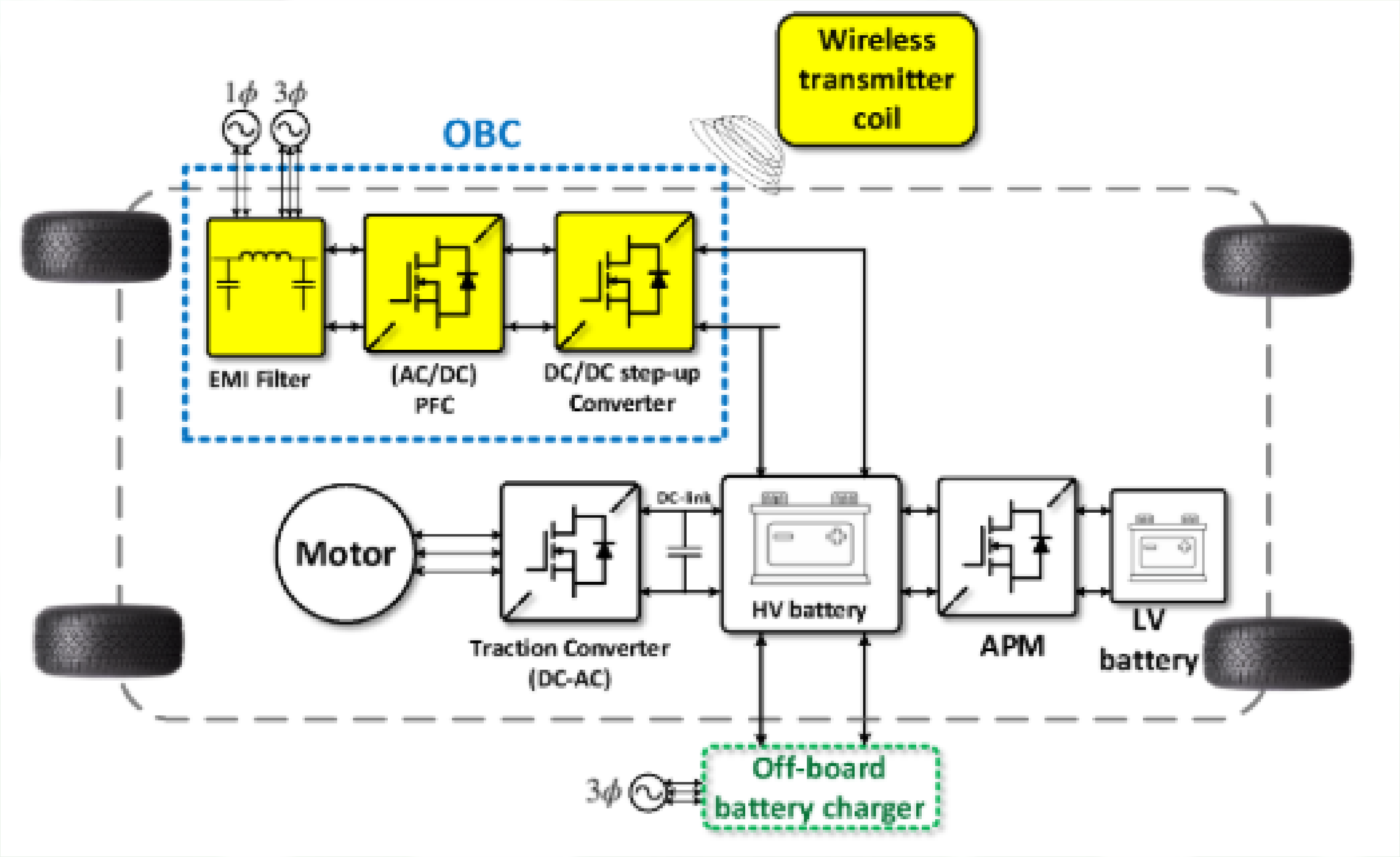

Wireless charger iOBC

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Electric Vehicle Power Converters Topology
On-Board Battery Chargers (OBCs)
Integrated OBCs (iOBCs)

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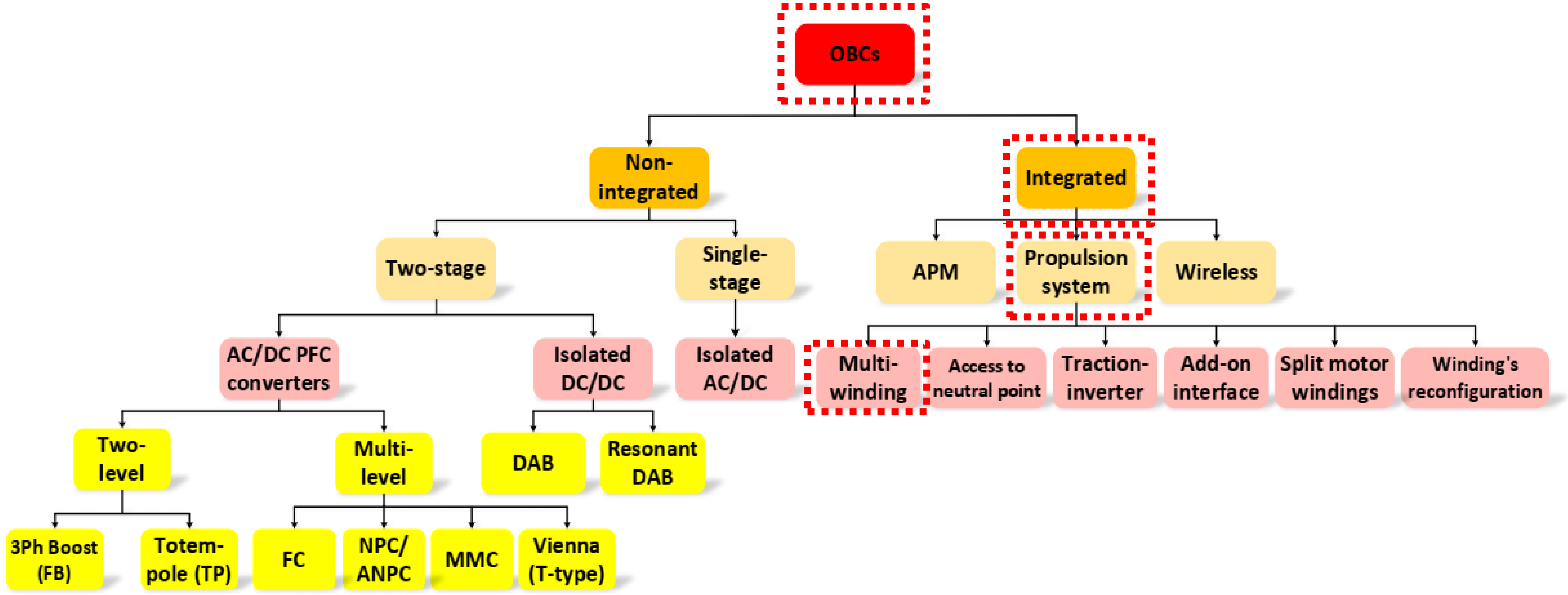
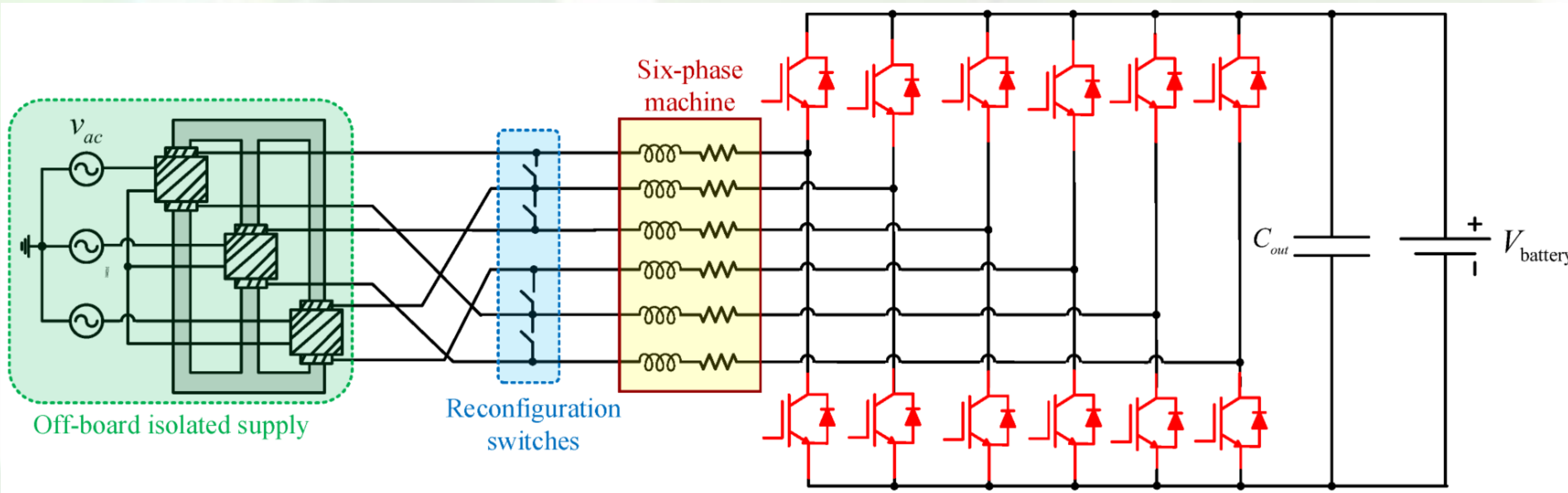


Multi-winding propulsion system iOBC using a symmetrical six-phase machine



Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)

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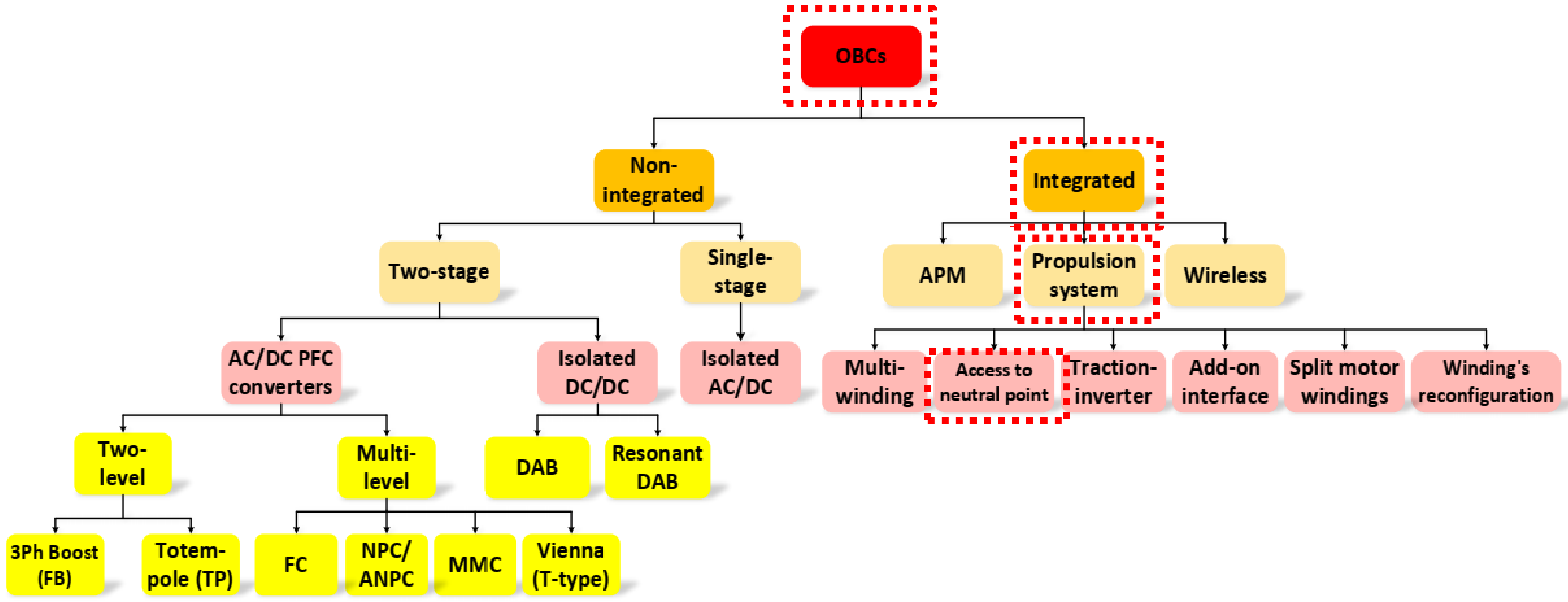
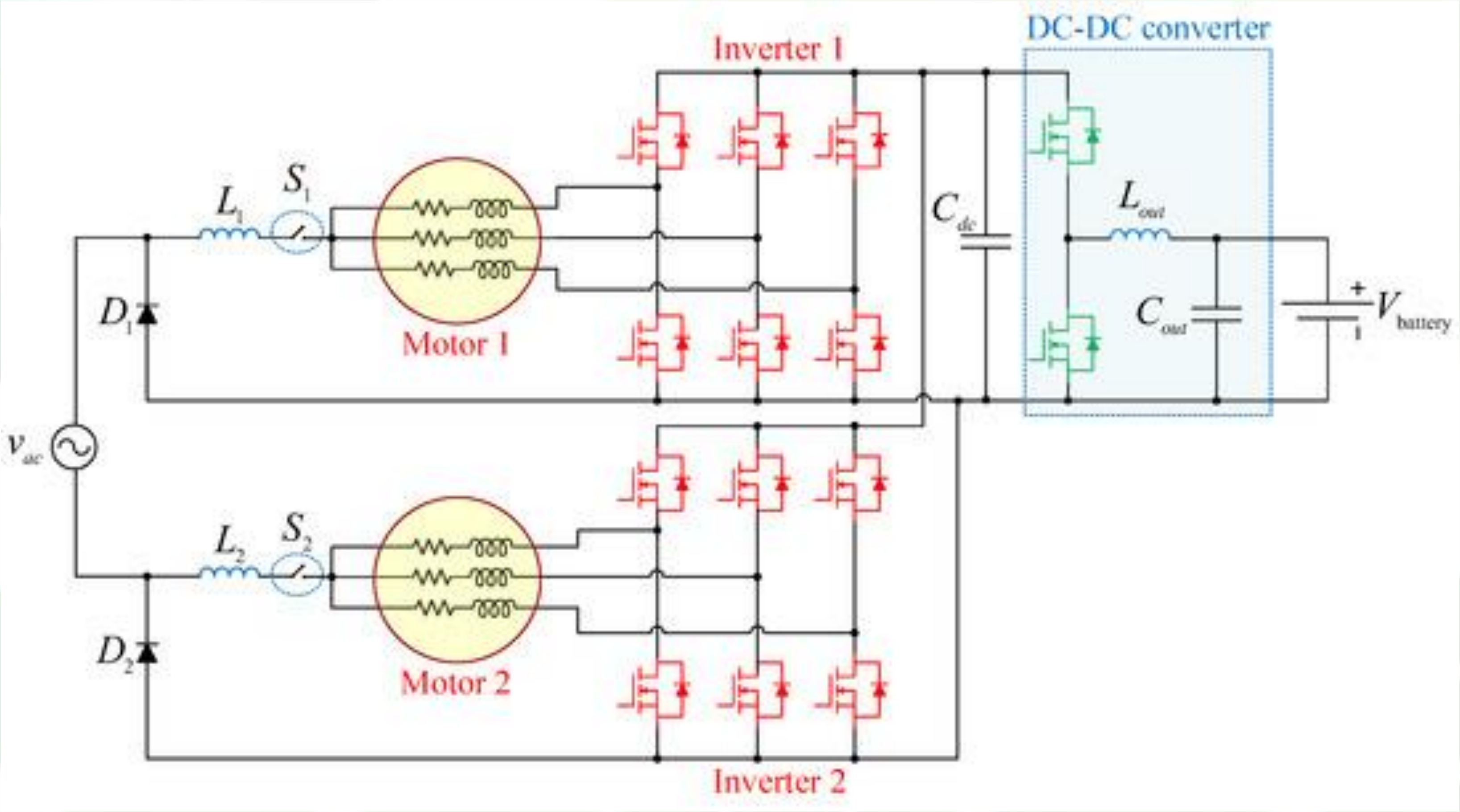


Integrated On-Board Battery Chargers (iOBCs)

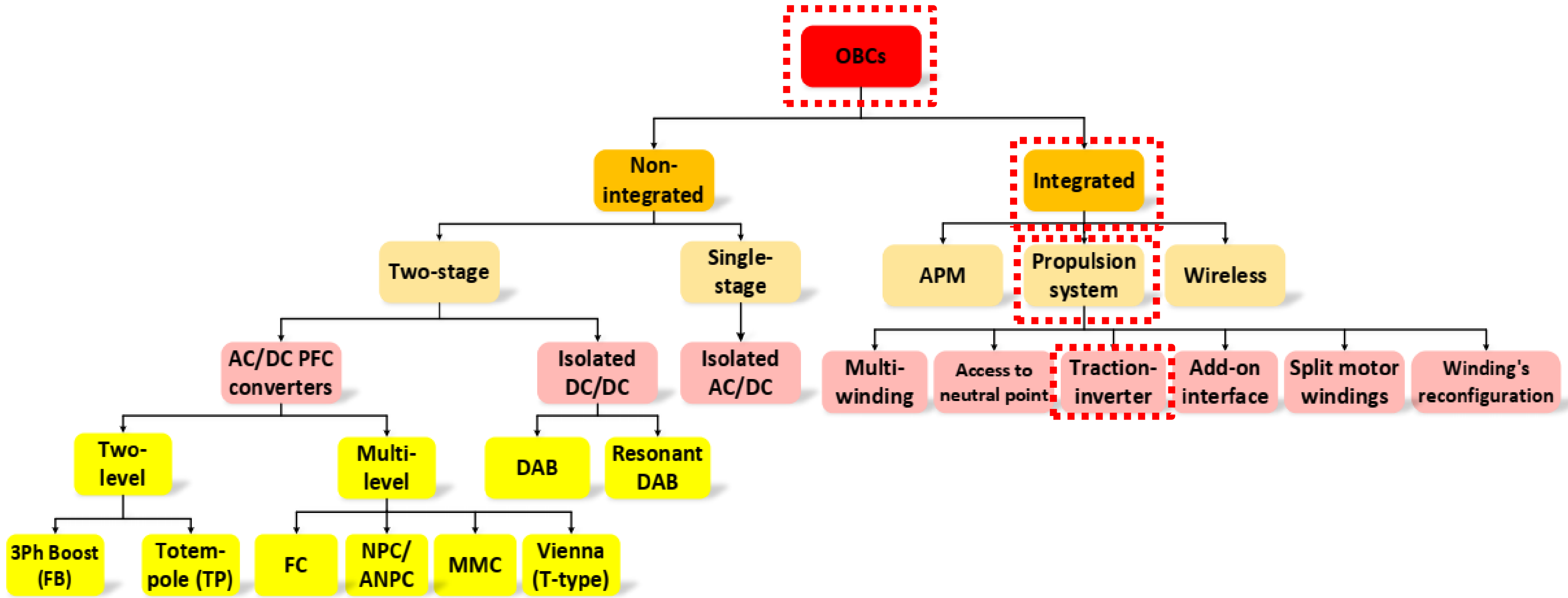
A dual-motor dual-inverter topology as access to the motor's neutral point iOBC



Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

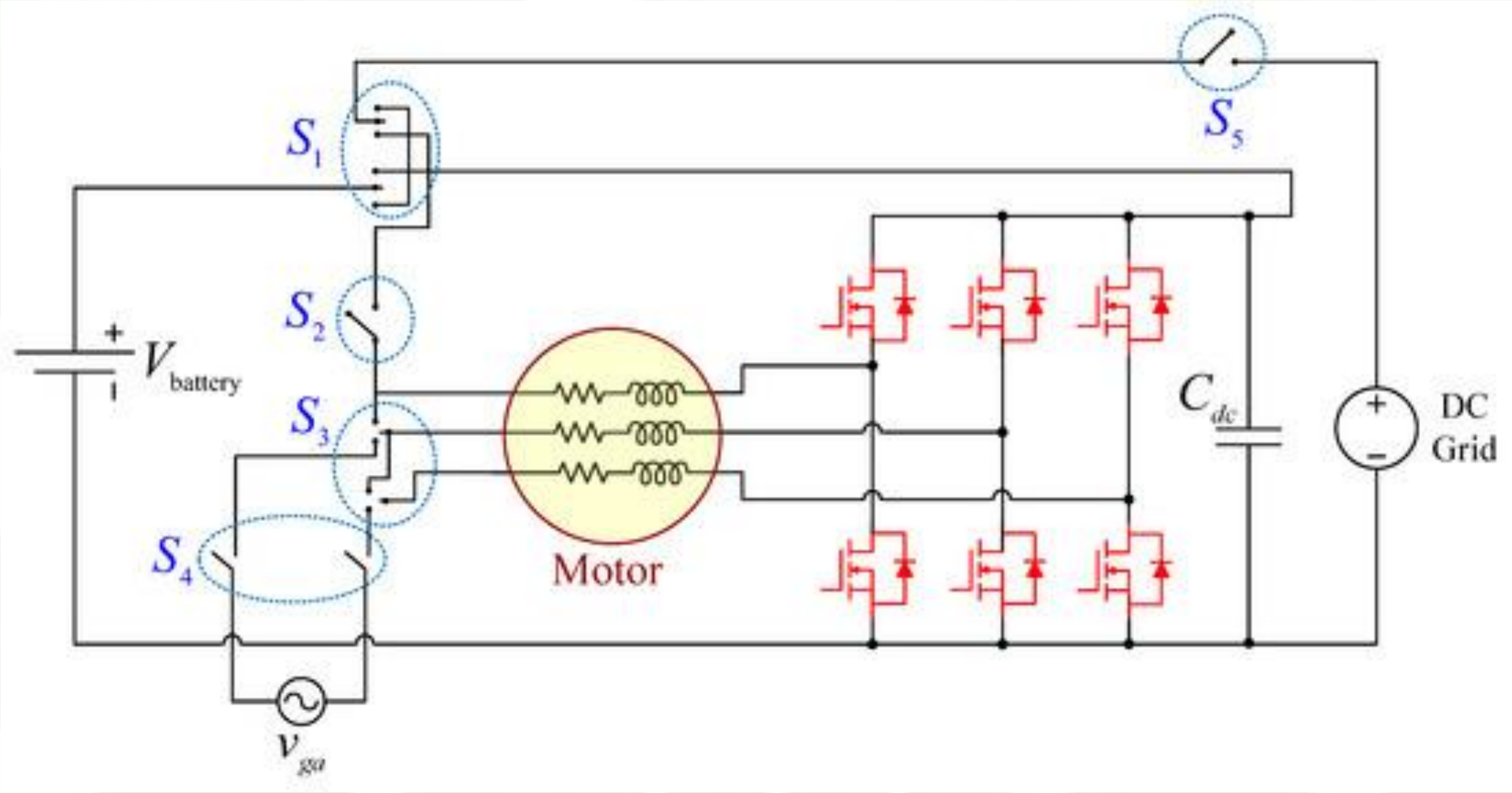
Integrated OBCs (iOBCs)



Integrated On-Board Battery Chargers (iOBCs)

Bidirectional traction inverter iOBC using an FB isolated boost converter and five additional auxiliary relay switches

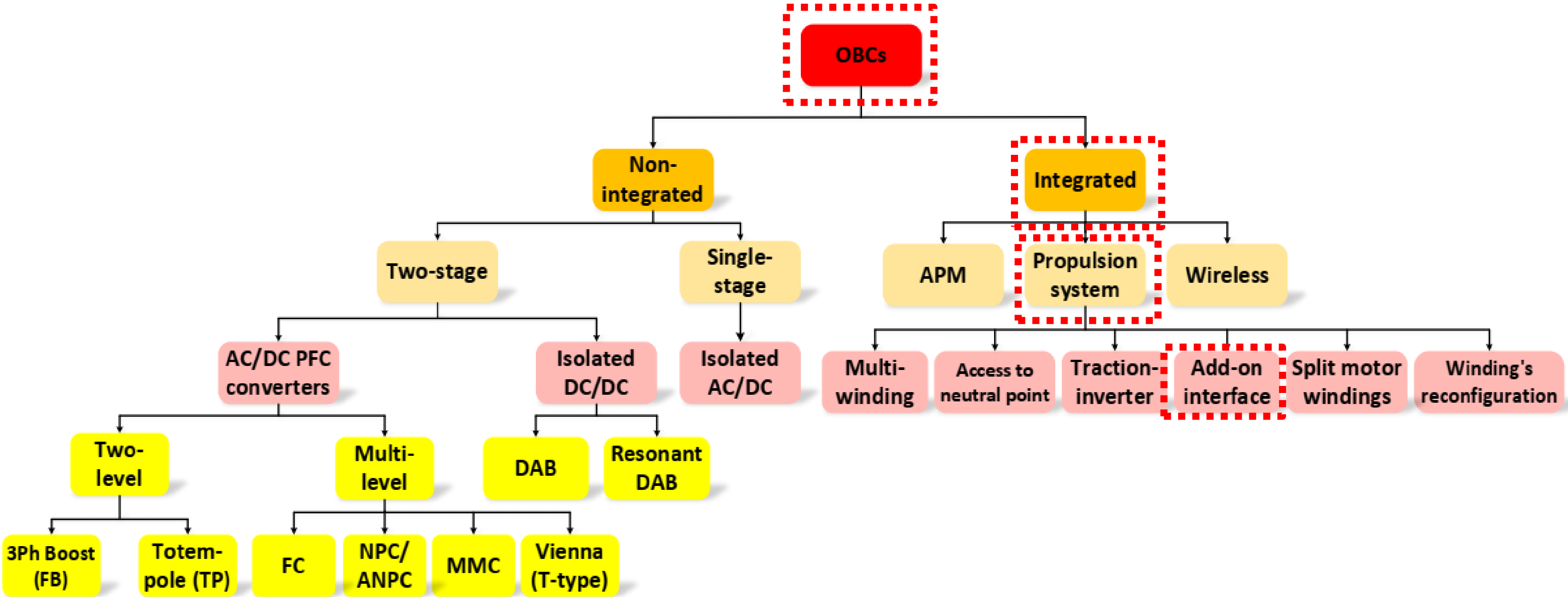
full-bridge (FB)



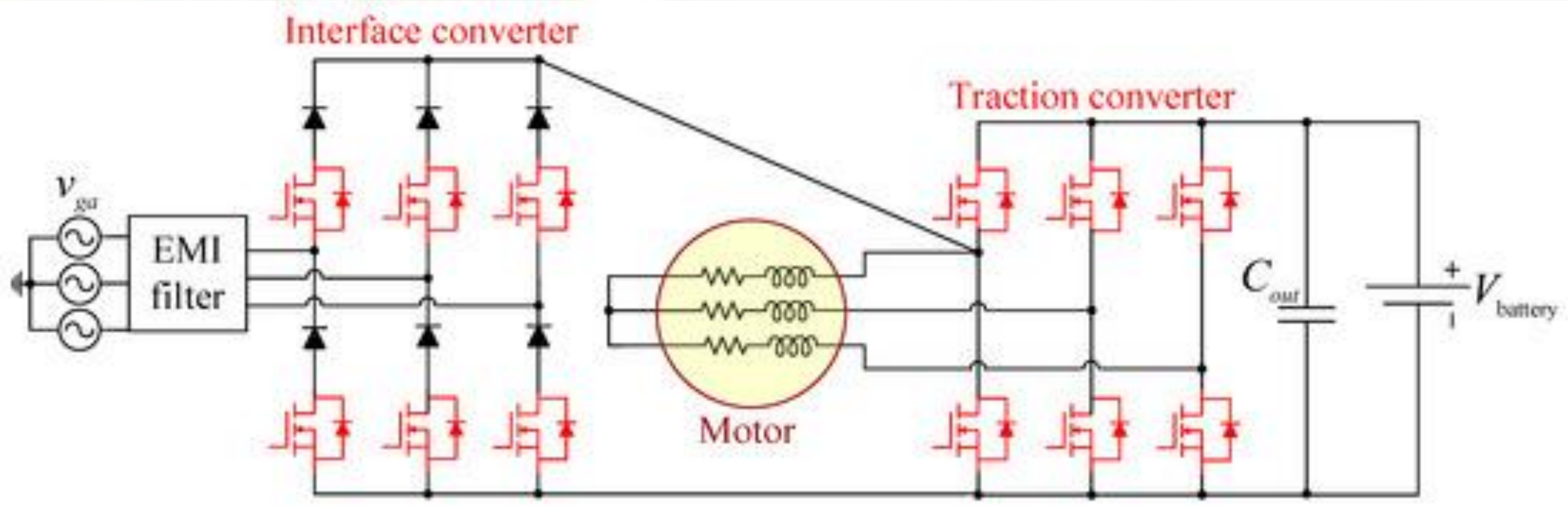
Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)



Add-on interface iOBC using three-phase step-down FB converter and an EMI filter



Electric Vehicle Power Converters Topology

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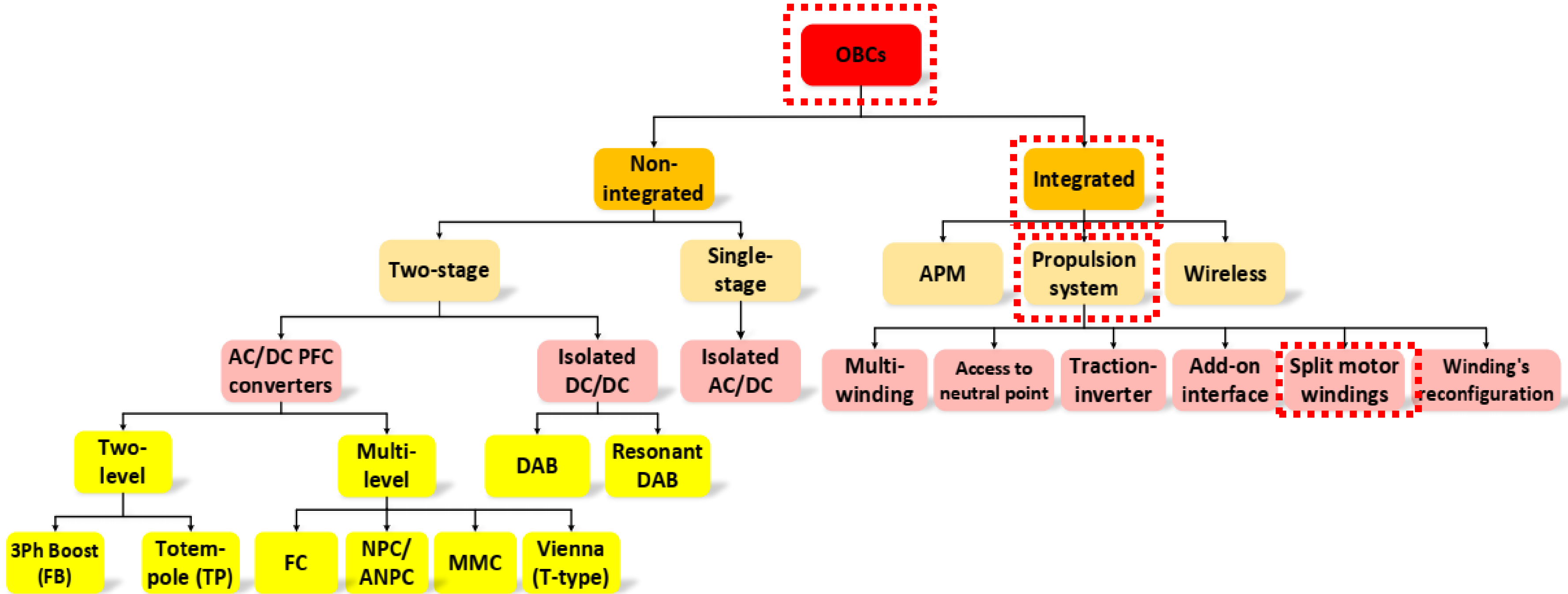
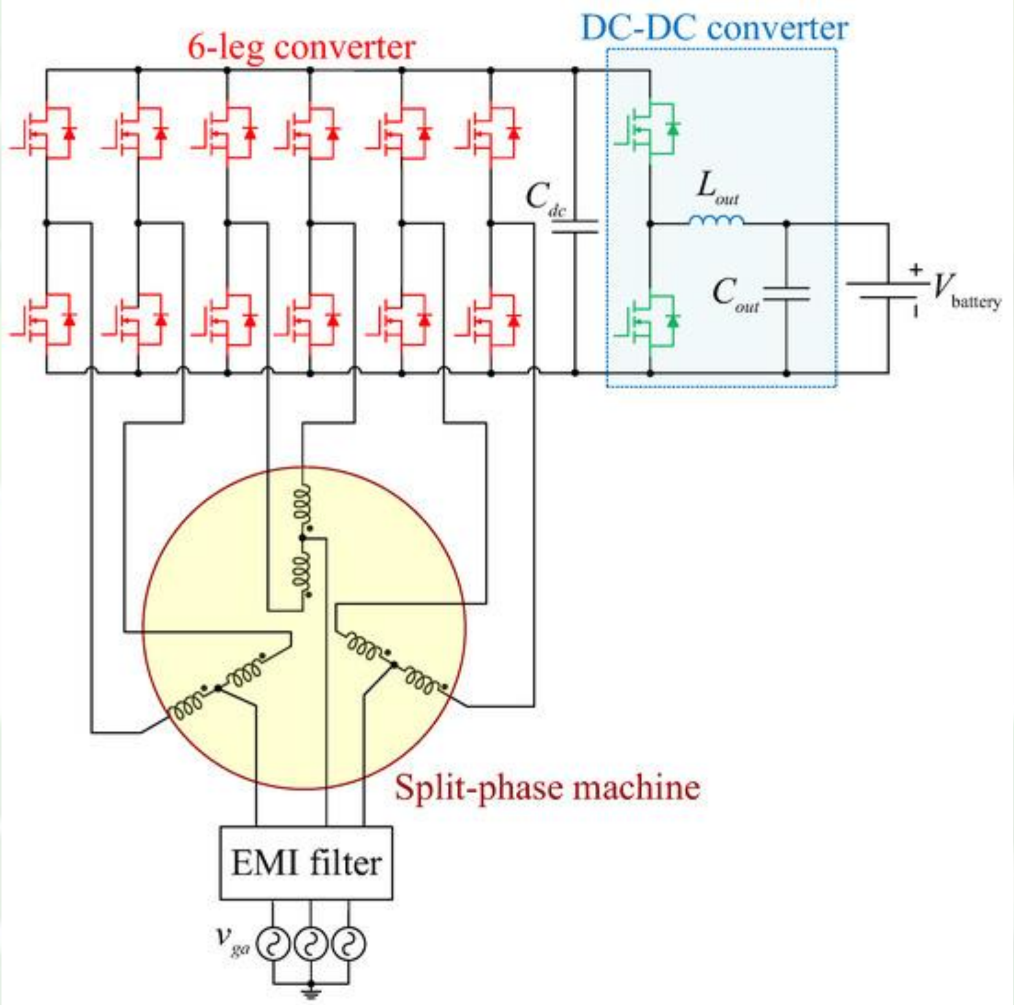
On-Board Battery Chargers (OBCs)



Electric Vehicle Power Converters Topology

Integrated On-Board Battery Chargers (iOBCs)

Three-phase split motor windings iOBC



Electric Vehicle Power Converters Topology

On-Board Battery Chargers (OBCs)

Integrated OBCs (iOBCs)

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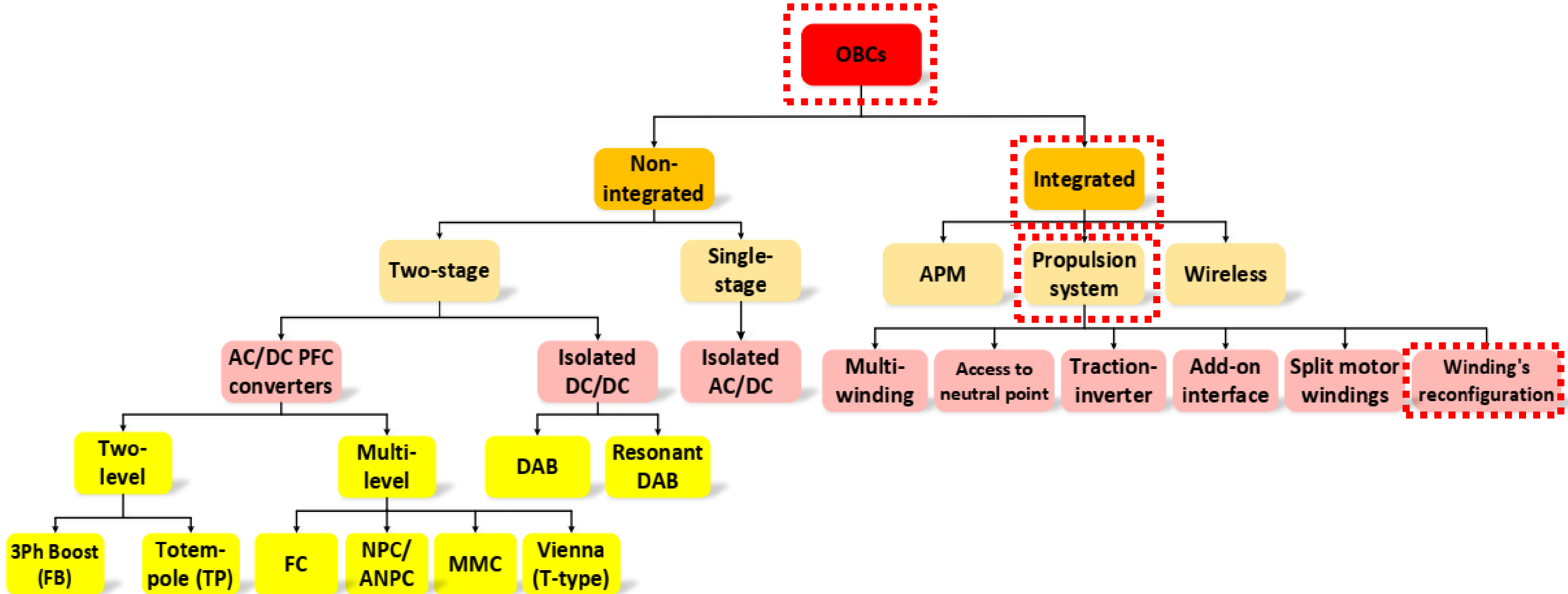
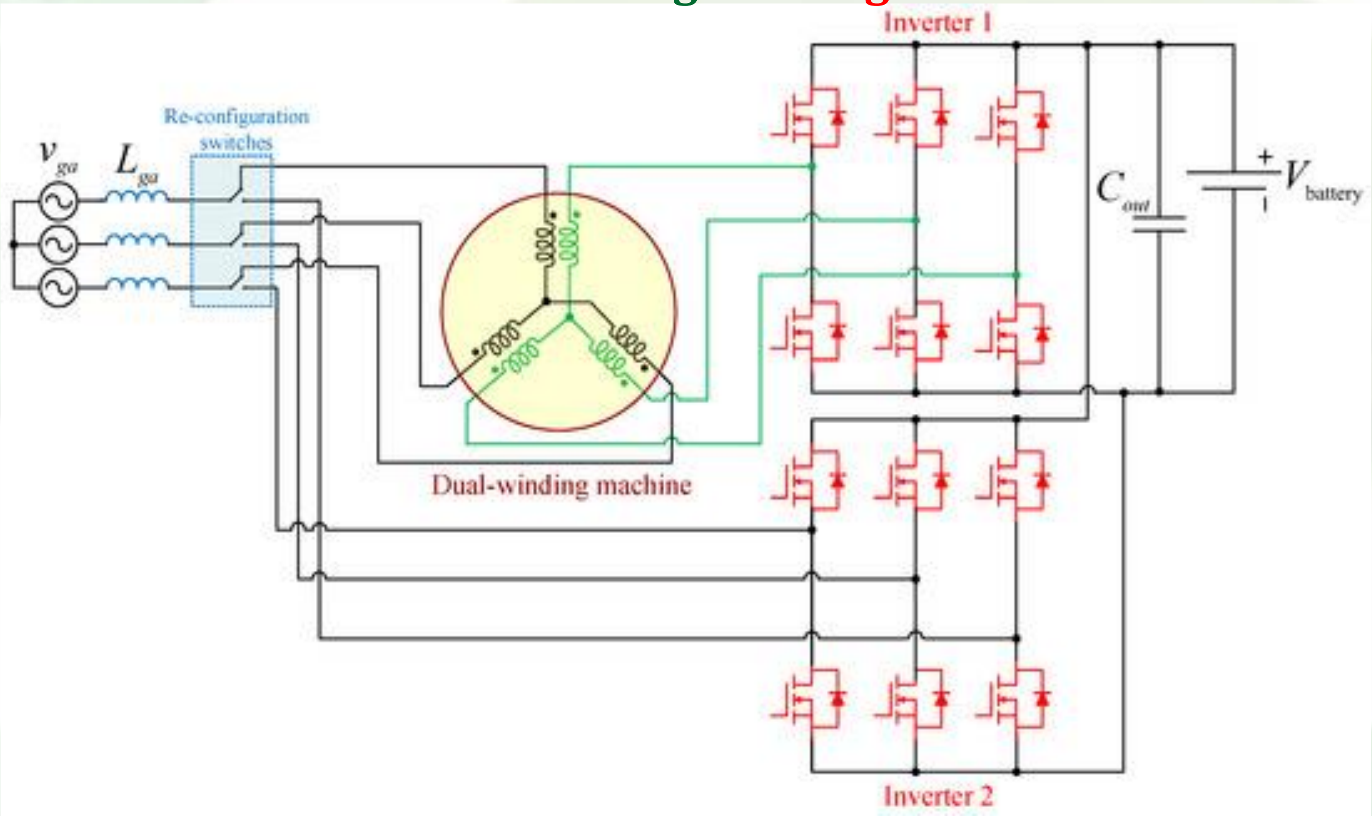


Isolated bidirectional iOBC using reconfiguration of the motor's winding



Reconfiguration allows the motor to serve the purposes of driving the EV during normal driving and acting as a generator during braking or charging phases.

Using an off-board transformer, this method provides electrical isolation by reconfiguring the connections of the electrical machine to make it act as a transformer

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Electric Vehicle Power Converters Topology

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Comparative analysis of on-board chargers and off-board chargers

	On-Board Charger	Off-Board Charger
Installation	Easier to install.	More complicated to install.
Cost	Less expensive.	More expensive.
Space	Less.	More.
Efficiency	Lower.	Higher.
Maintenance	Less.	More.
Pros:	•It is easy to install and maintain. •It is more secure, since it is embedded within the vehicle. •It is convenient and does not require any external cords or cables. •It is typically more cost-effective than an off-board charger.	•It is more versatile, as it can charge multiple batteries at the same time. •It is more portable, as it can be moved and used anywhere. •It is typically more powerful than an on-board charger, allowing for faster charge times.
Cons:	•It may be difficult to access or replace if any problems arise. •It is not as versatile as an off-board charger, as it can only charge one battery at a time.	•It is more expensive than an on-board charger. •It is less secure, as it is not embedded within the vehicle. •It requires external cords or cables, which can be inconvenient.

Comparative analysis of on unidirectional and bidirectional chargers

	Power Flow	Power Level	Cost	Pros	Cons
Unidirectional Charger	One-way electric energy flow (basically, battery charging only).	Level 1, Level 2, Level 3.	Lower cost.	❖Less circuit complexity. ❖Compact size and less volume. ❖High reliability. ❖Long battery life.	❖G2V function does not support the smart grid function. ❖Conduction loss in the diode bridge rectifier in PFC converter. ❖V2G techniques are not possible.
Bidirectional Charger	Two-way electrical energy flow and communication.	Expected only for Level 2.	High cost.	❖Low harmonics in input supply. ❖Enables G2V, V2G, V2L, and V2V.	❖Negative impact on the charger power density. ❖Battery life is low; frequent charging and discharging cycles. ❖Circuit complexity and reliability problem. ❖Volume of the charger becomes larger.

Conclusion

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When selecting the optimal power converter topology for electric vehicles, the following key factors should be considered, which are presented in tabular form:

1. Power Level & Voltage

Application	Recommended Topology	Why?
Low-Power (≤7 kW)	**Vienna Rectifier + LLC**	**Cost-effective, simple 3-level PFC for 400V systems.**
Mid-Power (11–22 kW)	**Totempole PFC (SiC) + DAB**	**High efficiency (>98%), bidirectional, V2G-ready.**
High-Power (≥50 kW)	**ANPC/MMC (800V+)**	**Handles ultra-fast charging with low losses.**

Electric Vehicle Power Converters Topology

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Conclusion

When selecting the optimal power converter topology for electric vehicles, the following key factors should be considered, which are presented in tabular form:

2. Integration Needs

Goal	Solution	Example
Space/Weight Savings	Traction-inverter integration	Hyundai E-GMP (no separate OBC).
Auxiliary Power	APM-combined OBC	Tesla's integrated charger + DC/DC.
Wireless Convenience	Resonant inductive charging	Mercedes EQ (park-and-charge).

Electric Vehicle Power Converters Topology

Conclusion

When selecting the optimal power converter topology for electric vehicles, the following key factors should be considered, which are presented in tabular form:

3. Cost vs. Performance Tradeoff

Priority	Topology	Tradeoff
Lowest Cost	**3PH Boost (FB) + LLC**	**~95% efficiency, diode losses.**
Balanced	**Vienna + DAB**	**97% efficiency, moderate complexity.**
Premium Performance	**Totempole (GaN) + Resonant DAB**	**>99% efficiency, bidirectional, compact.**

Electric Vehicle Power Converters Topology

Conclusion

When selecting the optimal power converter topology for electric vehicles, the following key factors should be considered, which are presented in tabular form:

4. Future-Proofing

Feature	Topology Choice	Benefit
V2G/V2L Support	**Totempole/ANPC**	**Enables grid services and vehicle-to-load.**
Modular Upgrades	**Add-on interface (MMC)**	**Scalable for higher power without redesign.**
High-Voltage (800V+)	**ANPC/SiC MMC**	**Faster charging, lighter cables.**

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Conclusion

When selecting the optimal power converter topology for electric vehicles, the following key factors should be considered, which are presented in tabular form:

5. Thermal & Reliability

Challenge	Best Topology	Solution
High Heat	**Totempole (SiC/GaN)**	**Lower losses, cooler operation.**
Fault Tolerance	**MMC**	**Bypass faulty submodules.**
Motor Integration	**Split-winding designs**	**Uses existing components (e.g., Renault ZOE).**

Electric Vehicle Power Converters Topology

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Conclusion

Power converters are the **backbone of modern EVs**, enabling efficient energy conversion, fast charging, and seamless integration with vehicle systems. Key Takeaways:

- **Non-Integrated OBCs** offer flexibility and scalability:
  - ✓ **Two-stage systems** (e.g., **Totempole PFC + DAB**) dominate high-performance EVs with >98% efficiency.
  - ✓ **Multi-level topologies** (NPC, MMC) enable ultra-fast charging for 800V+ architectures.
  - ✓ **Single-stage designs** reduce complexity but face control challenges.
- **Integrated OBCs** optimize space and cost:
  - ✓ **APM integration** combines charging with auxiliary power delivery.
  - ✓ **Propulsion-system reuse** (traction inverter, motor windings) eliminates redundant hardware.
  - ✓ **Wireless charging** enhances convenience but lags in efficiency (~90%).
- **Future Trends:**
  - ✓ **Wide-bandgap devices (SiC/GaN)** boost efficiency in Totempole/ANPC converters.
  - ✓ **Bidirectional power flow** (V2G, V2L) becomes standard.
  - ✓ **Modular designs** (MMC, add-on interfaces) support future upgrades.