Renewable & Energy Storage System Integration for Flexible Operation in Residential-based Applications

Sisteme Regenerabile cu Stocare de Energie Integrate in Retele Flexibile pentru Modernizarea si Eficientizarea Zonelelor Comunitare

2023

Emanuel Serban, PhD, PEng

Ministerul Cercetării, Inovării și Digitalizării

Ministerul Educației

Administrația Prezidențială

Academia Română

Agenda

1. Introduction

2. System Architectures

3. DC-Link-based System Architecture

4. Conclusions

Agenda

1. Introduction

2. System Architectures

3. DC-Link-based System Architecture

4. Conclusions

Introductions

Emanuel Serban, Ph.D., P.Eng.

Adjunct Professor, **ECE, University of British Columbia (2019 – present)**

- Research in Power Electronics Renewable & Energy Storage

THE UNIVERSITY OF BRITISH COLUMBIA

R&D Engineering Manager, **Power Conversion, EnerSys (2020 – present)**

- R&D Power Electronics & Energy Storage

EnerSys

Vancouver, Canada

UBC Electrical and Computer Engineering

UBC Electrical and Computer Engineering

Doctor of Philosophy (Ph.D.) , Electrical and Computer Engineering

Politehnica University Timisoara, Romania

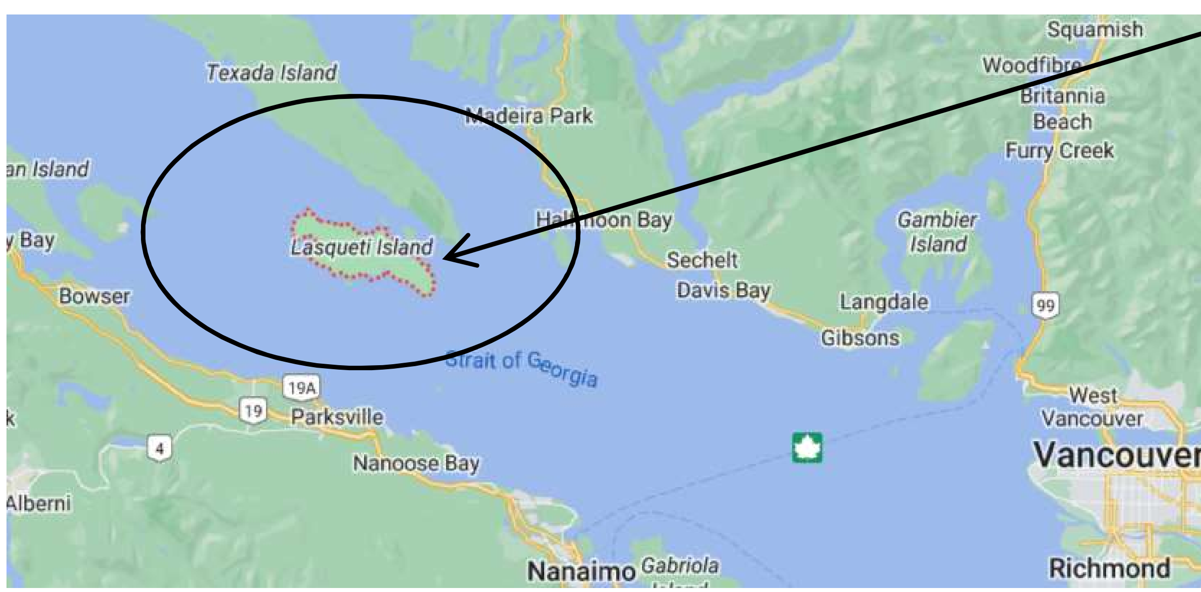
MScEE, Electric Machines, Drives and Power Electronics

Introduction

Examples of Remote *'Off-Grid'* Communities

Lasqueti Island – remote community (population: ~500)

- Learn from real-life experiences
- Voice of the Customer
- Observe, listen and learn
- Understand customer's perspective



Source: Google Maps

Introduction

Energy Appreciation – Rural/Remote *'Off-Grid'* Communities

- Self-energy generation (solar/hydro/wind)
- Example of micro-hydro generator (kitchen-ware based construction)
- Get 'more from less' energy
- Improve existing systems towards clean energy
- Develop robust, efficient and affordable systems

Source: Google Maps

Source: E. Serban

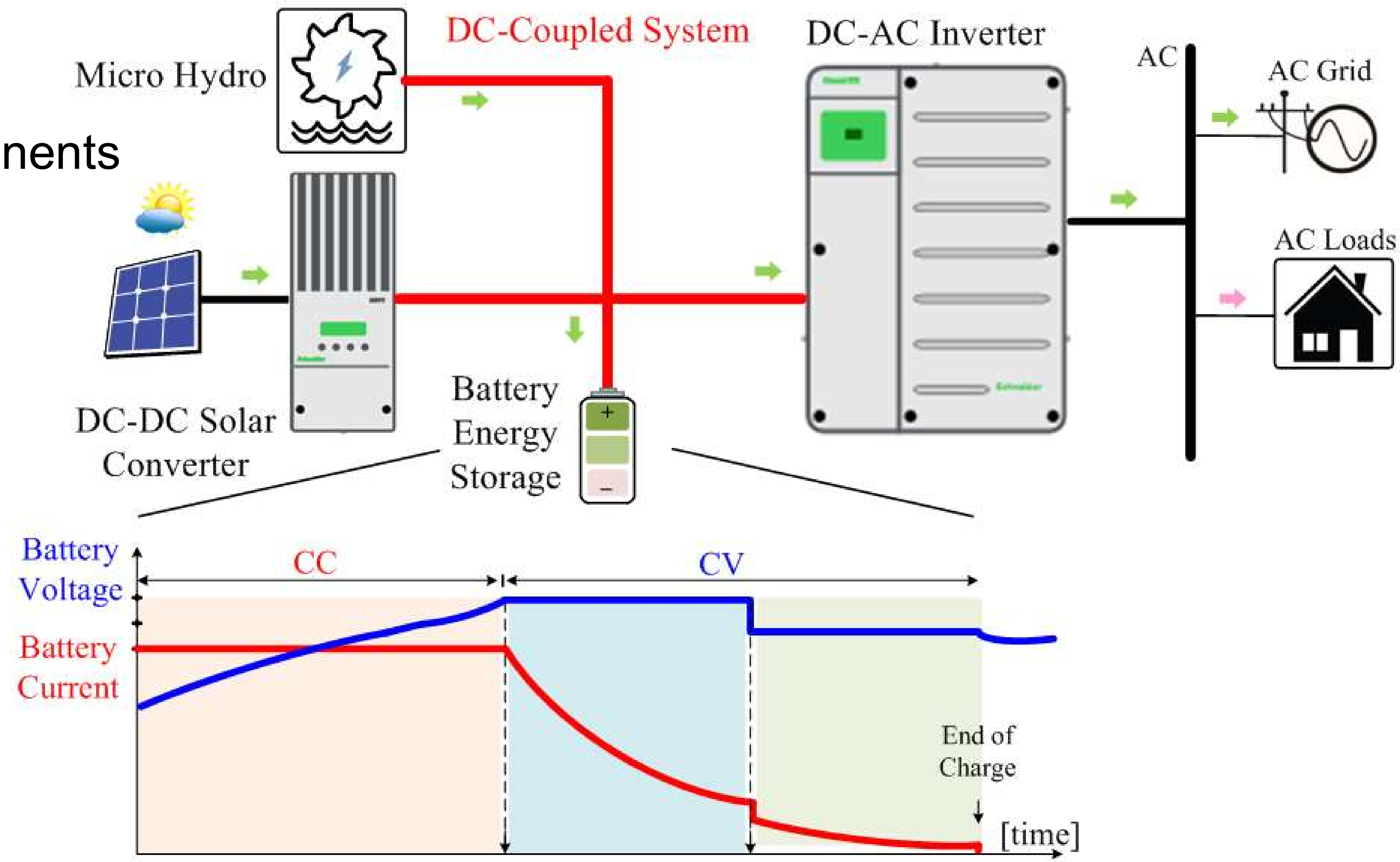
Renewable & Energy Storage System Integration

DC-Coupled System Architecture – Developed for Off-grid & Grid-connected

Energy Sources & Key Components

- Solar PV
- Solar MPPT Converter
- Energy storage
- DC-AC Inverter
- AC Grid
- AC Loads

- Option: Micro-hydro



Agenda

1. Introduction

2. System Architectures

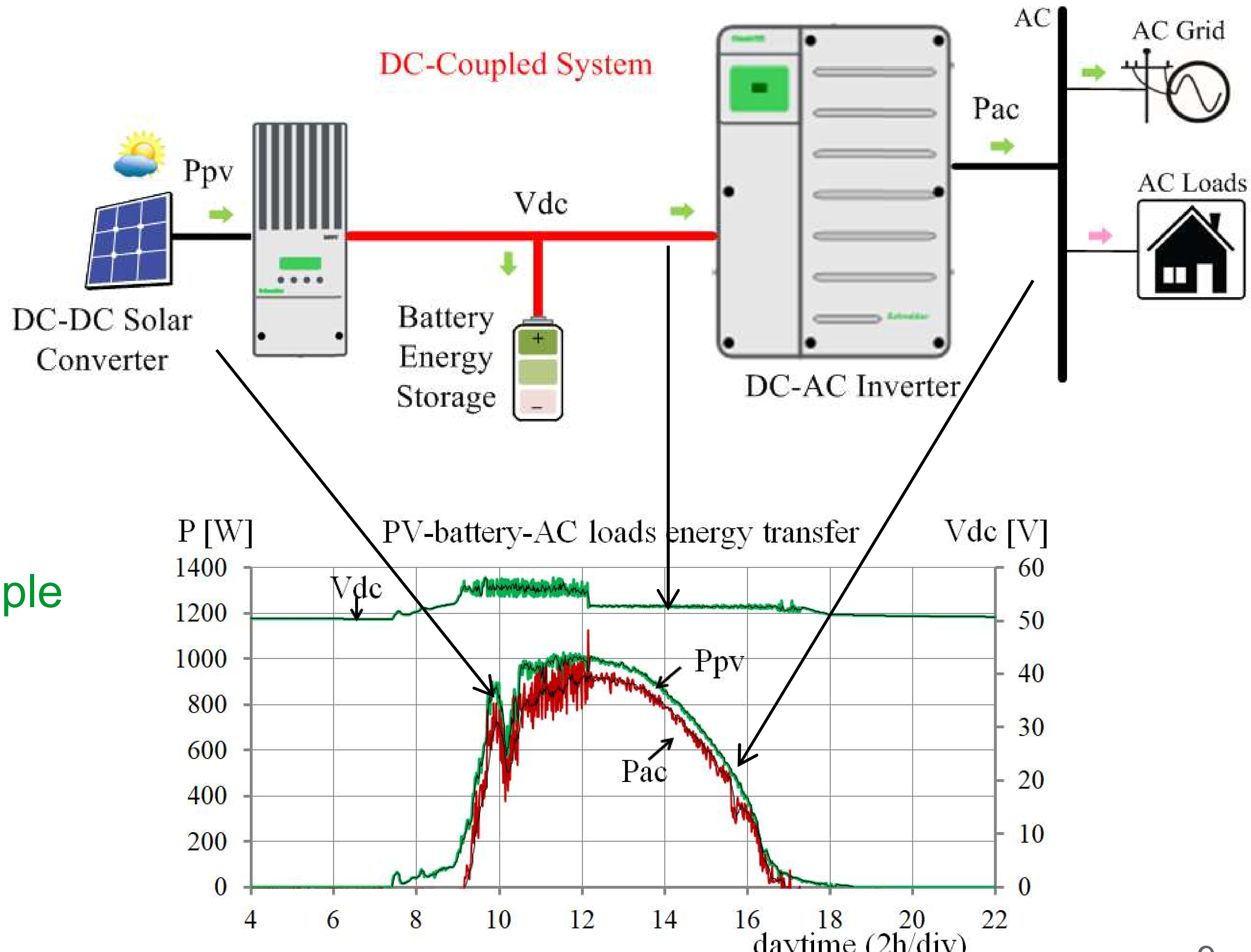
3. DC-Link-based System Architecture

4. Conclusions

Renewable & Energy Storage System Integration

DC-Coupled Systems

- Solar PV
- Solar MPPT Converter
- Energy storage
- DC-AC Inverter
- AC Grid
- AC Loads

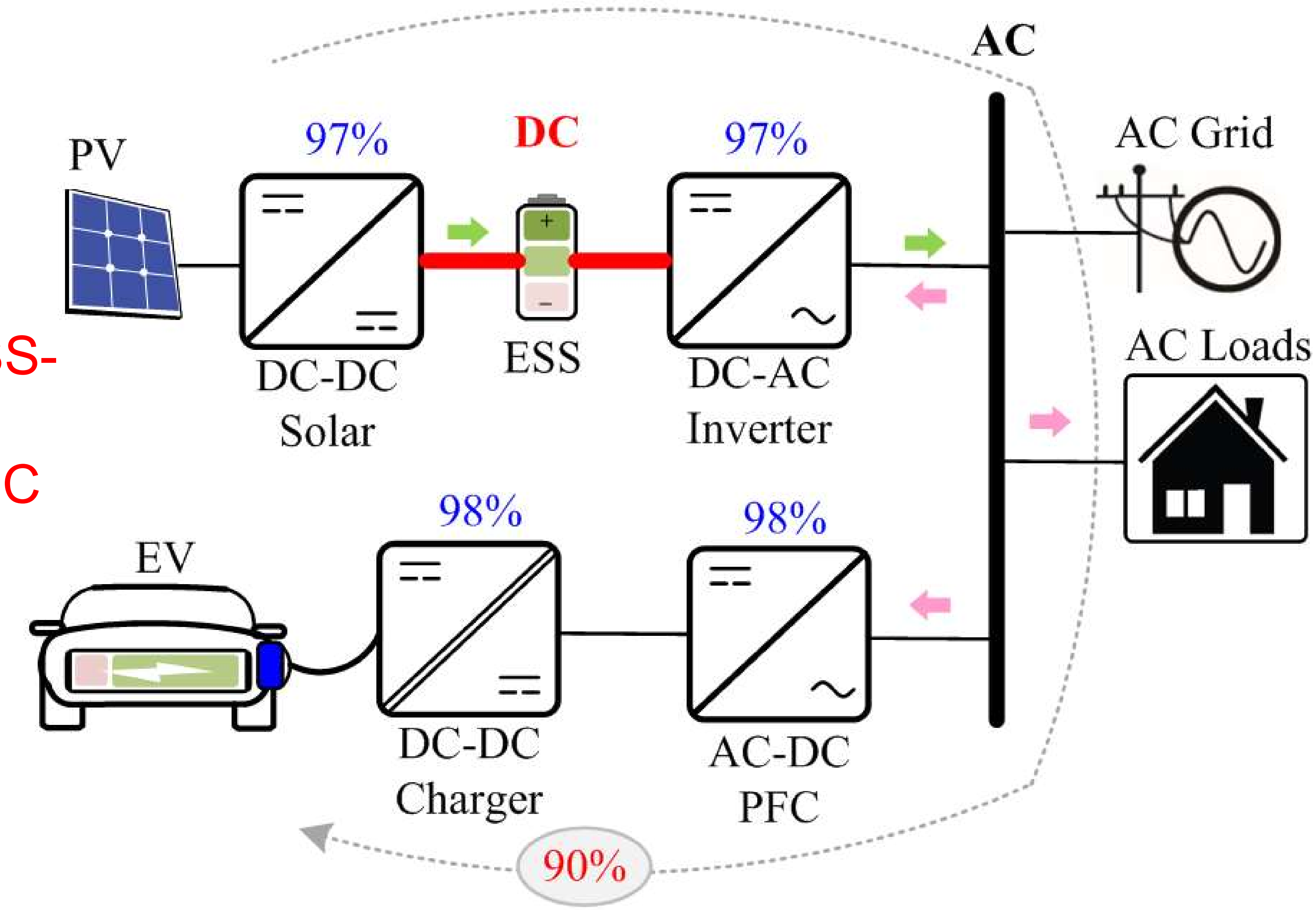


- Daily solar PV production example (Vancouver, Canada):

Renewable & Energy Storage System Integration

DC-Coupled Systems

- Advantages:
  - SoC & SoH maintenance
  - Installation & upgrade
- Disadvantages
  - Lower efficiency: PV-to-EV and BESS-to-EV
  - Location/distance of ESS with DC-DC Solar and DC-AC Inverter (need co-location)

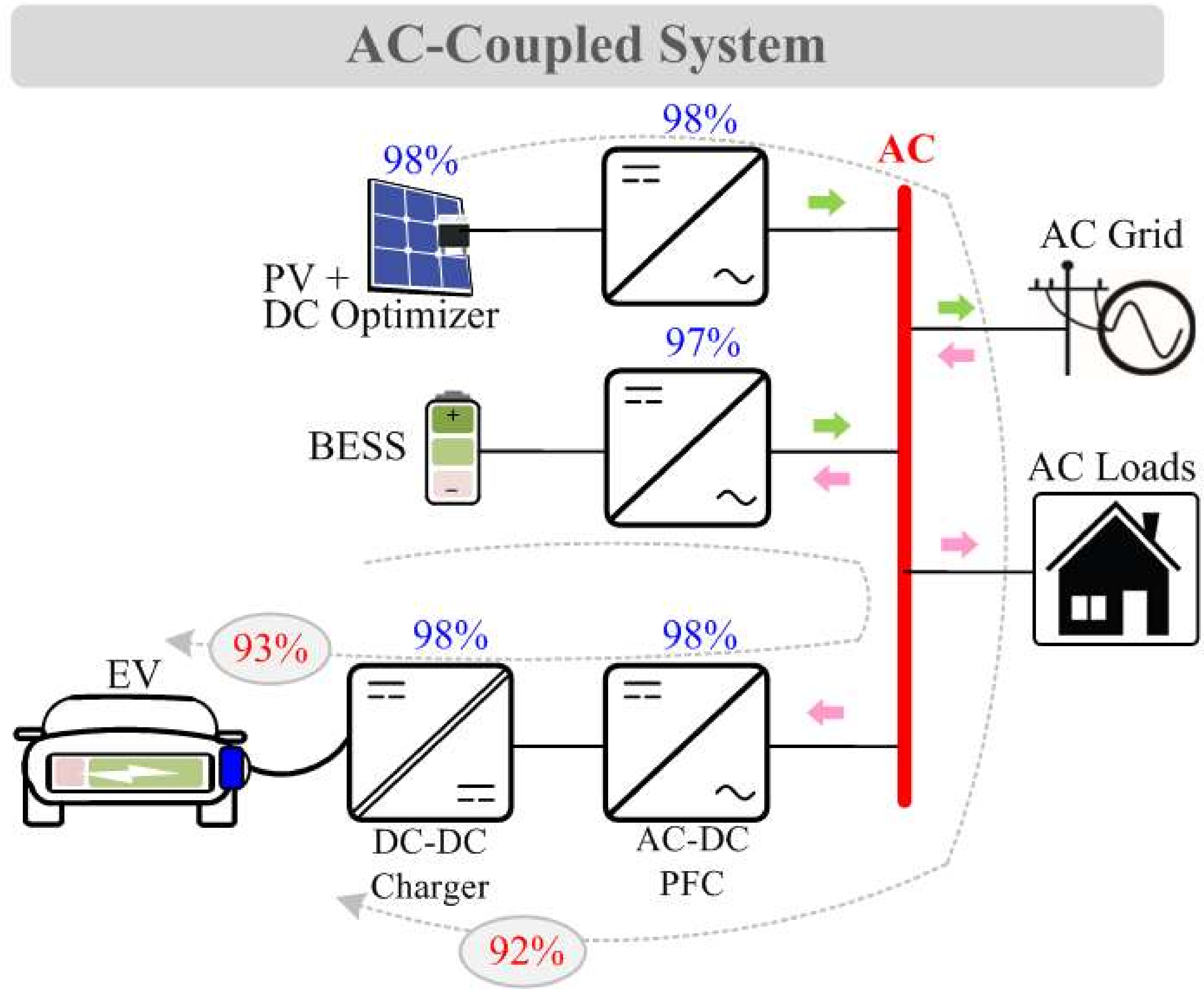


- Solar PV → BESS → AC → EV: ~90%
- BESS → AC → EV: ~93%
- AC → EV: ~96%

Renewable & Energy Storage System Integration

AC-Coupled Systems

- Advantages:
  - Distributed architecture
  - Ease of Installation & upgrade
- Disadvantages
  - SoC & SoH maintenance
  - Lower efficiency: PV-to-EV and BESS-to-EV



- Solar PV → AC → EV: ~92%
- BESS → AC → EV: ~93%
- AC → EV: ~96%

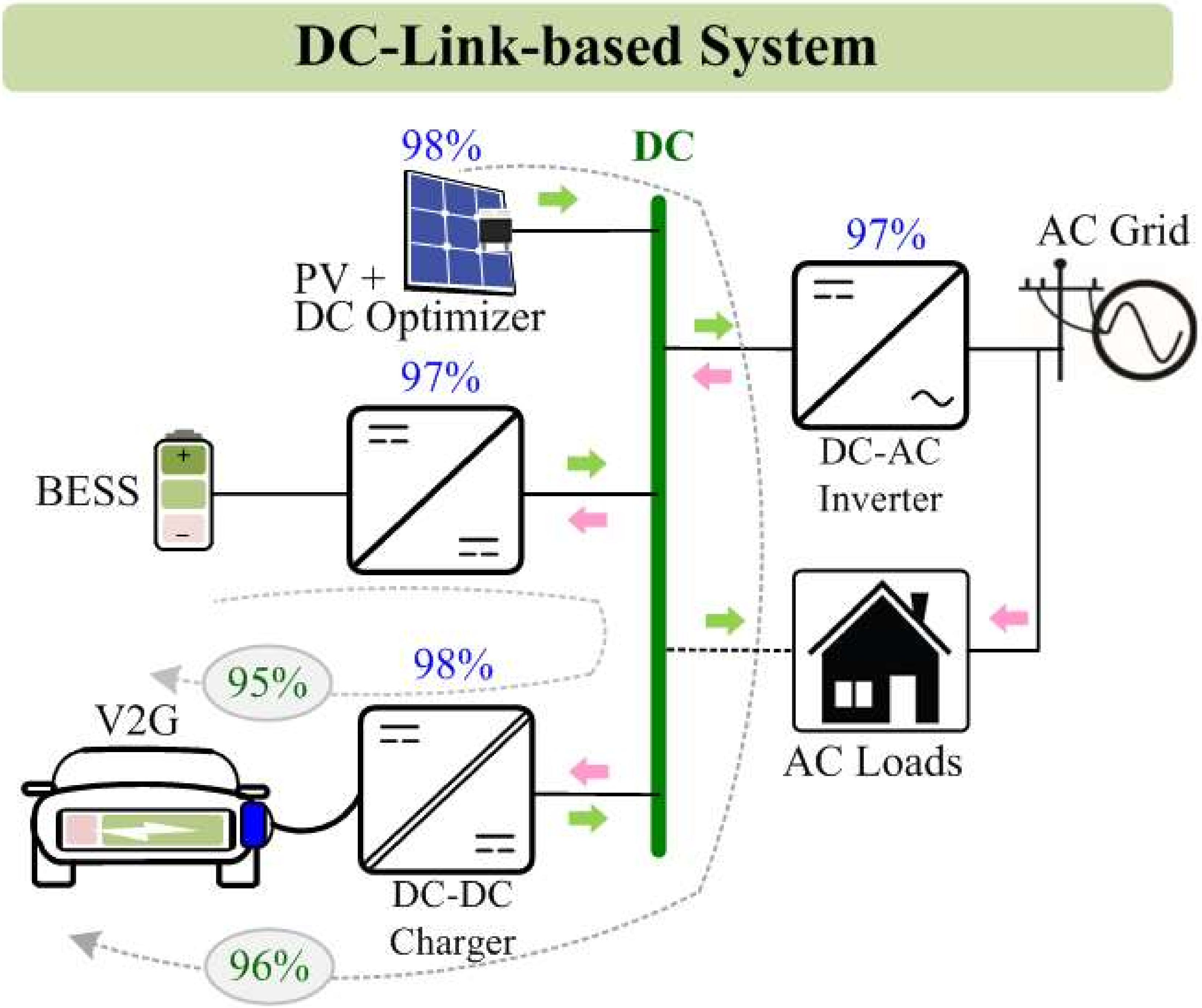
Renewable & Energy Storage System Integration

Proposed DC-Link-based Systems

Value proposition

- Advantages:
  - Flexible Configuration to DC-link
  - Higher system efficiency
  - SoC & SoH maintenance
  - Ease of Installation & upgrade
  - Distributed architecture
  - New DC Grid for Loads
- Disadvantages
  - No retrofit to older systems
  - DC Grid Standards ?

- Solar PV → AC → EV: ~96%
- BESS → DC → EV: ~95%
- AC → EV: ~95%

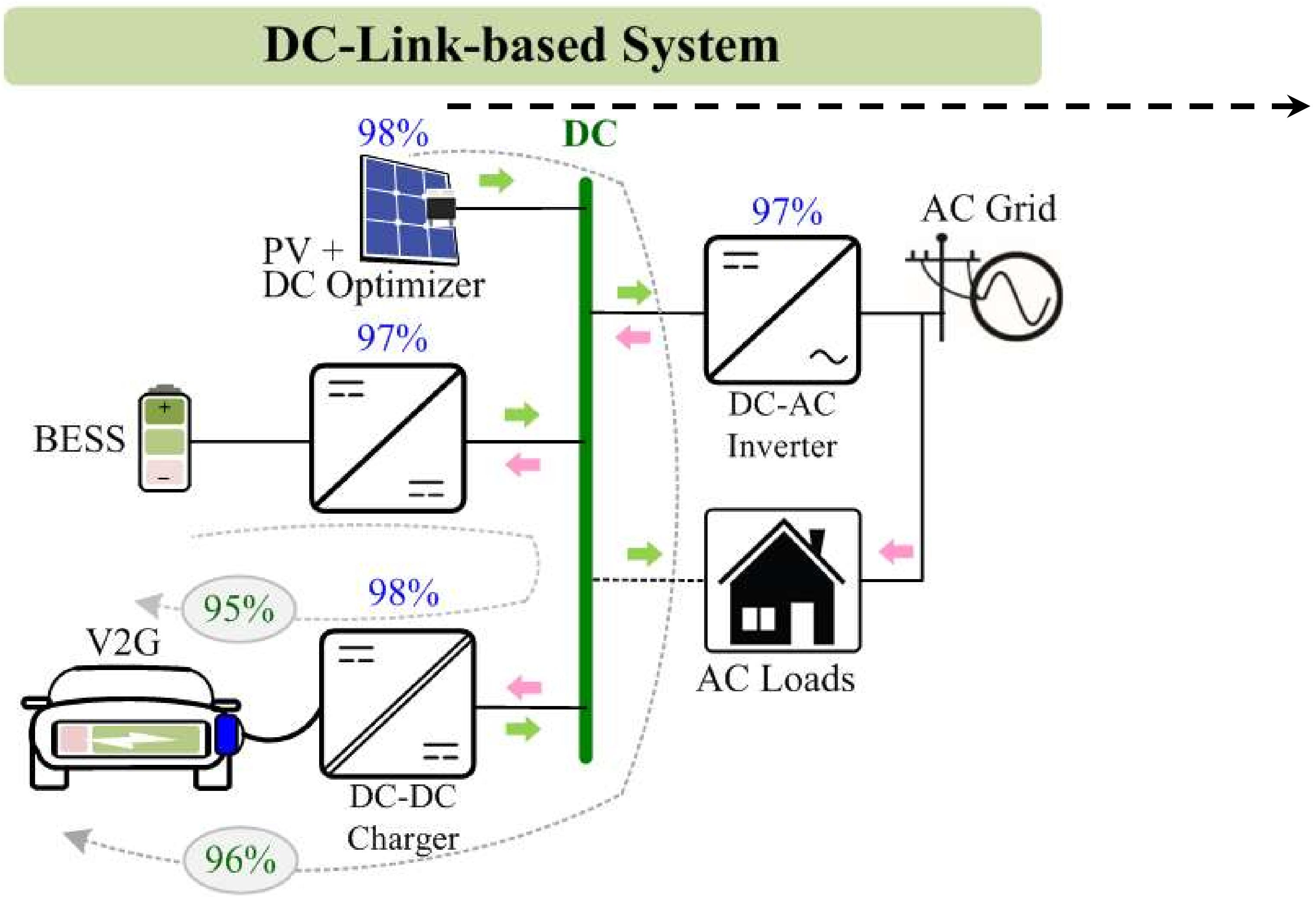


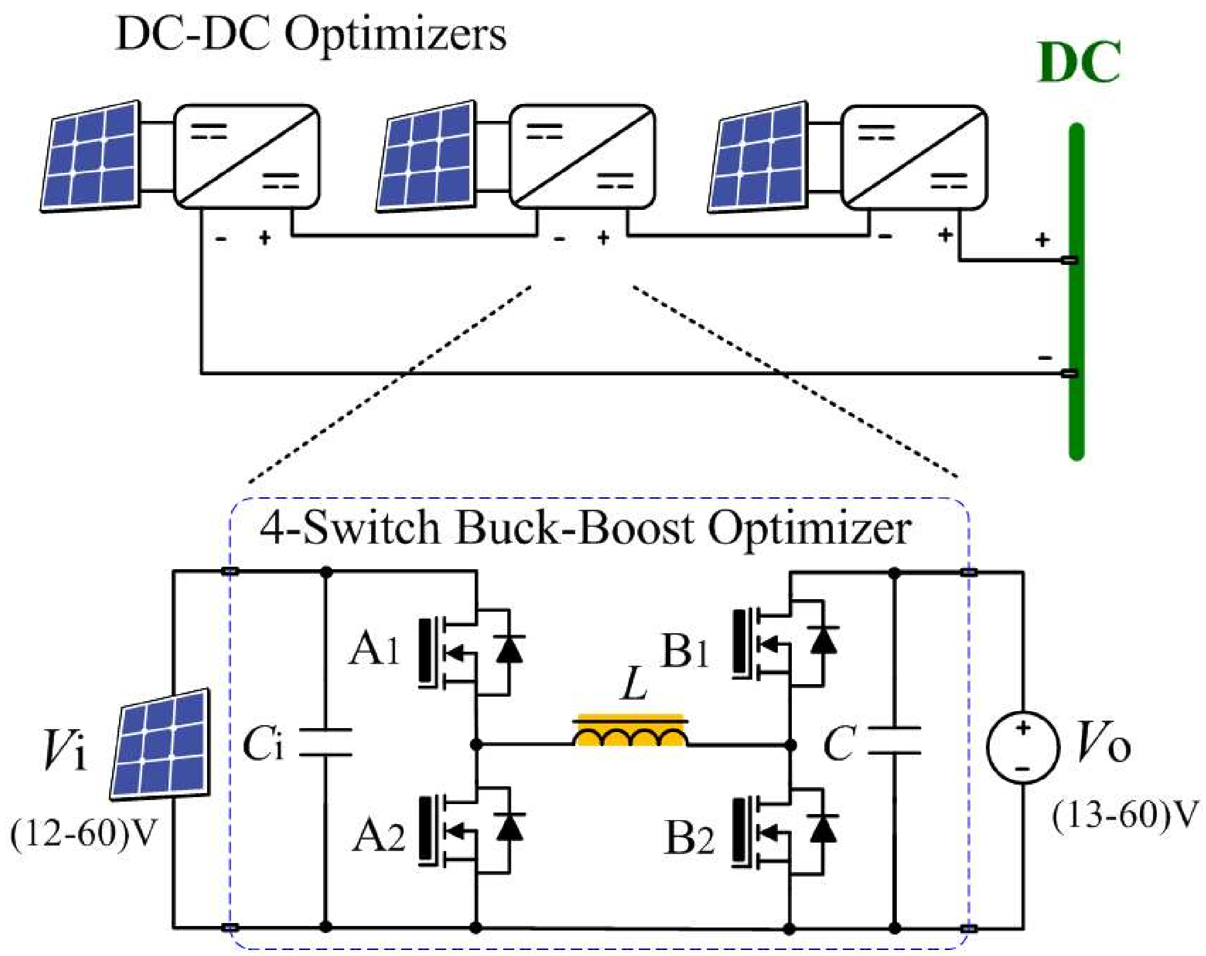
Renewable & Energy Storage System Integration

DC-Link-based System Components

Key Component

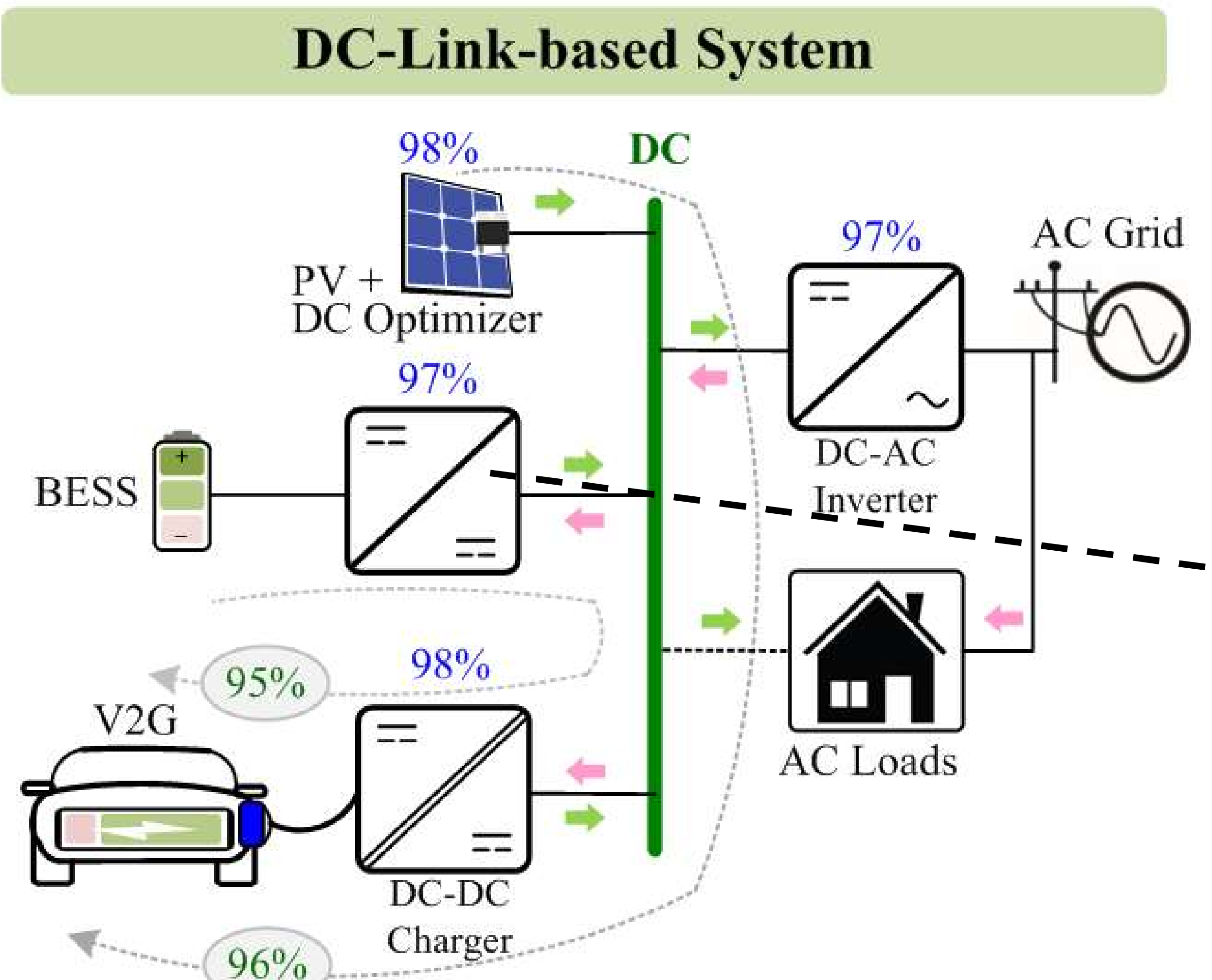
- Solar DC Optimizer: 4-switch Buck-Boost
  - Modules series connected





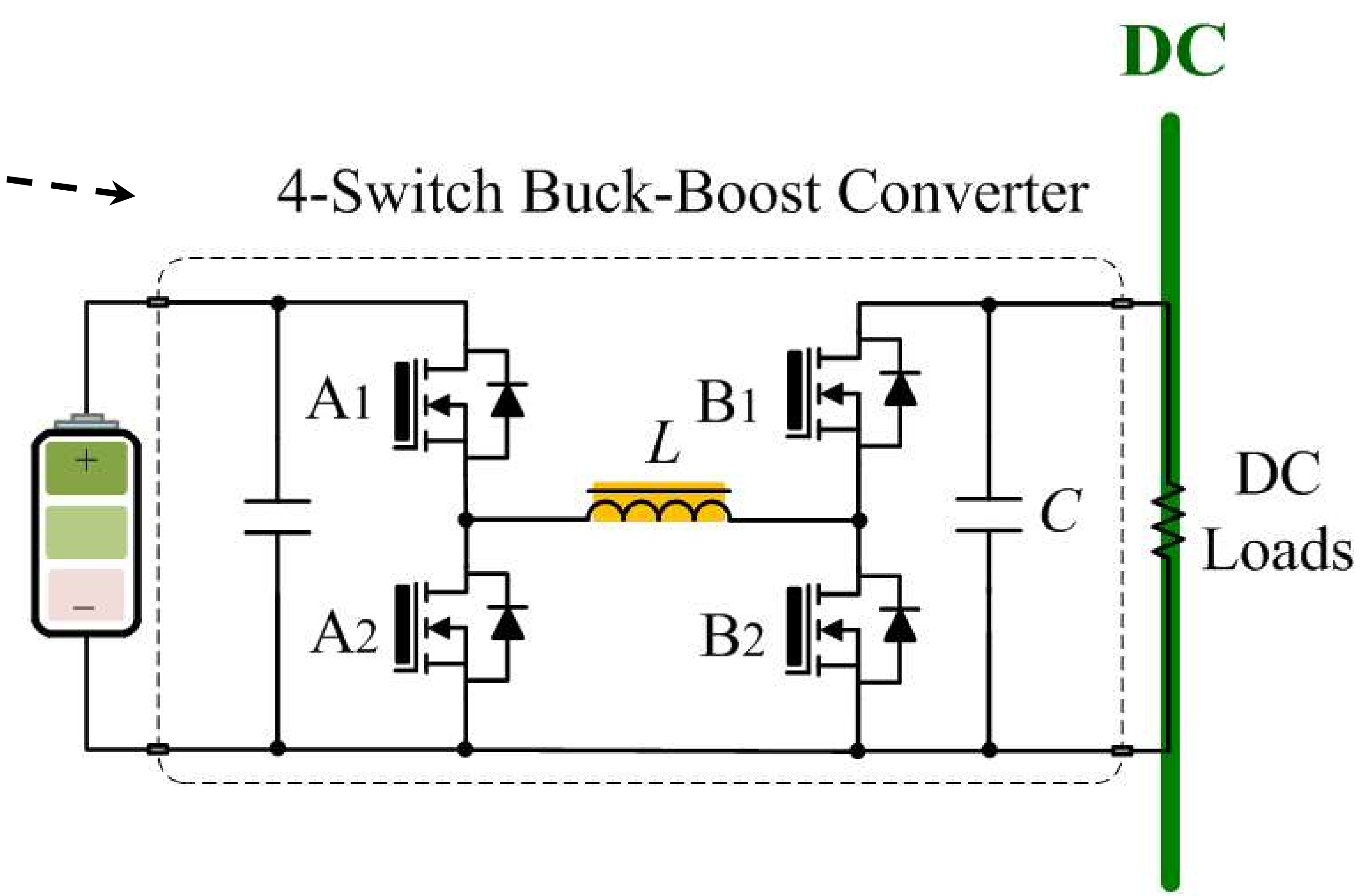
Renewable & Energy Storage System Integration

DC-Link-based System Components



Key Component

- Battery Converter: 4-switch Buck-Boost
  - Stationary Energy Storage (optional)
  - Battery power conditioning (SoC, SoH)



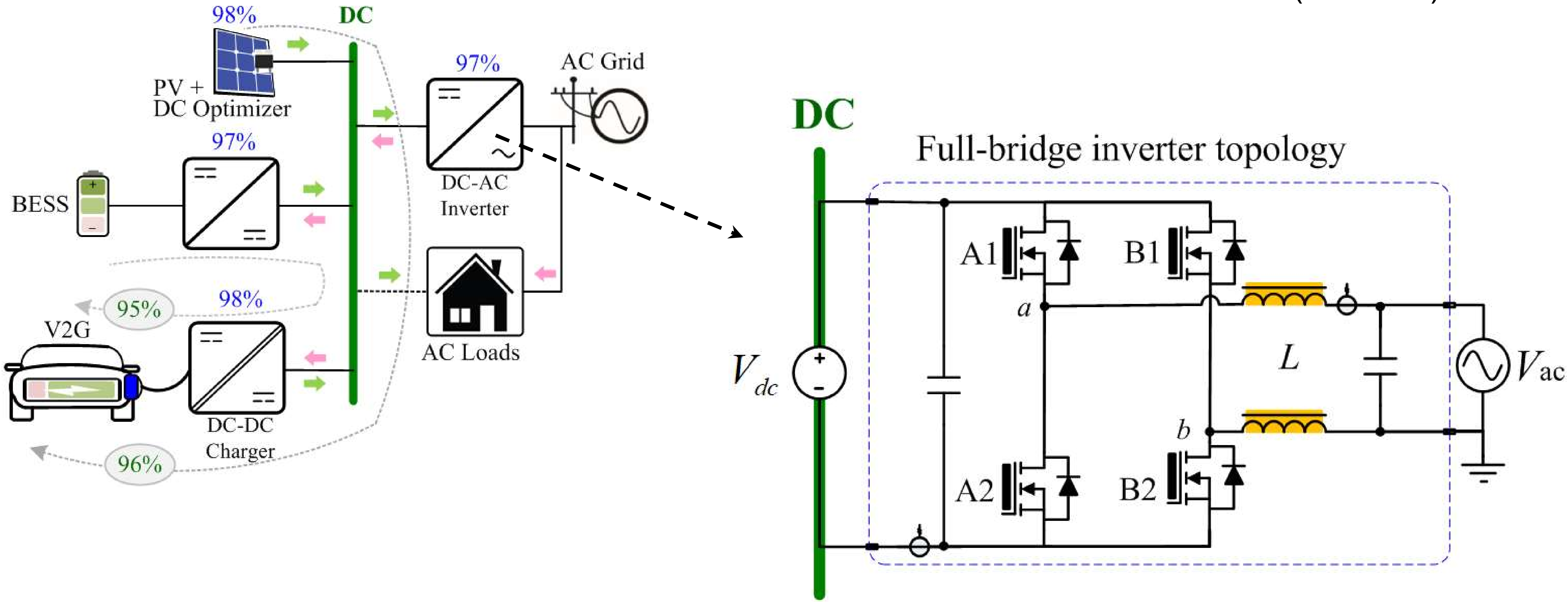
Renewable & Energy Storage System Integration

DC-Link-based System Components

DC-Link-based System

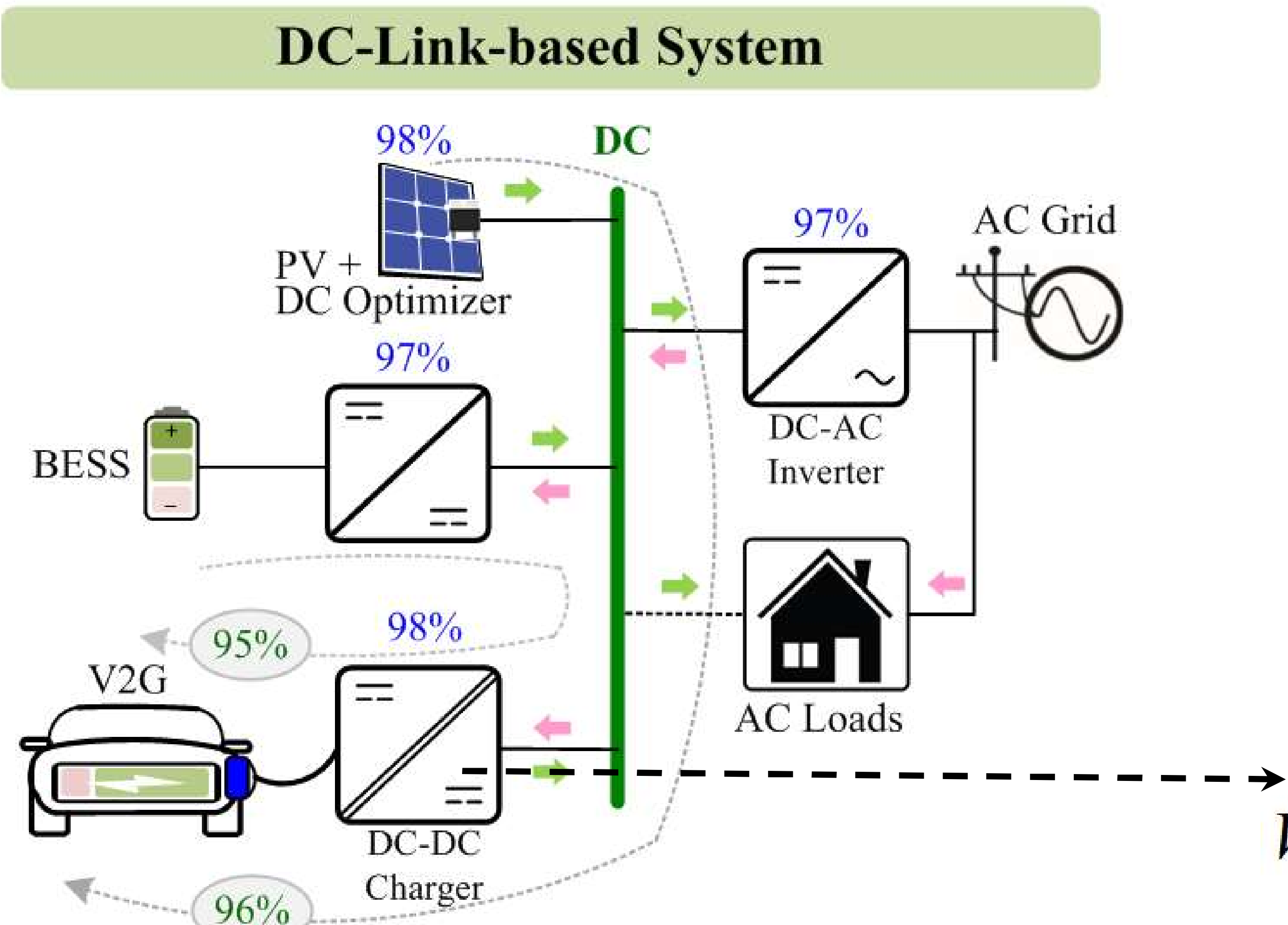
Key Component

- AC Inverter: Full-bridge
  - Bidirectional inverter (50/60Hz)



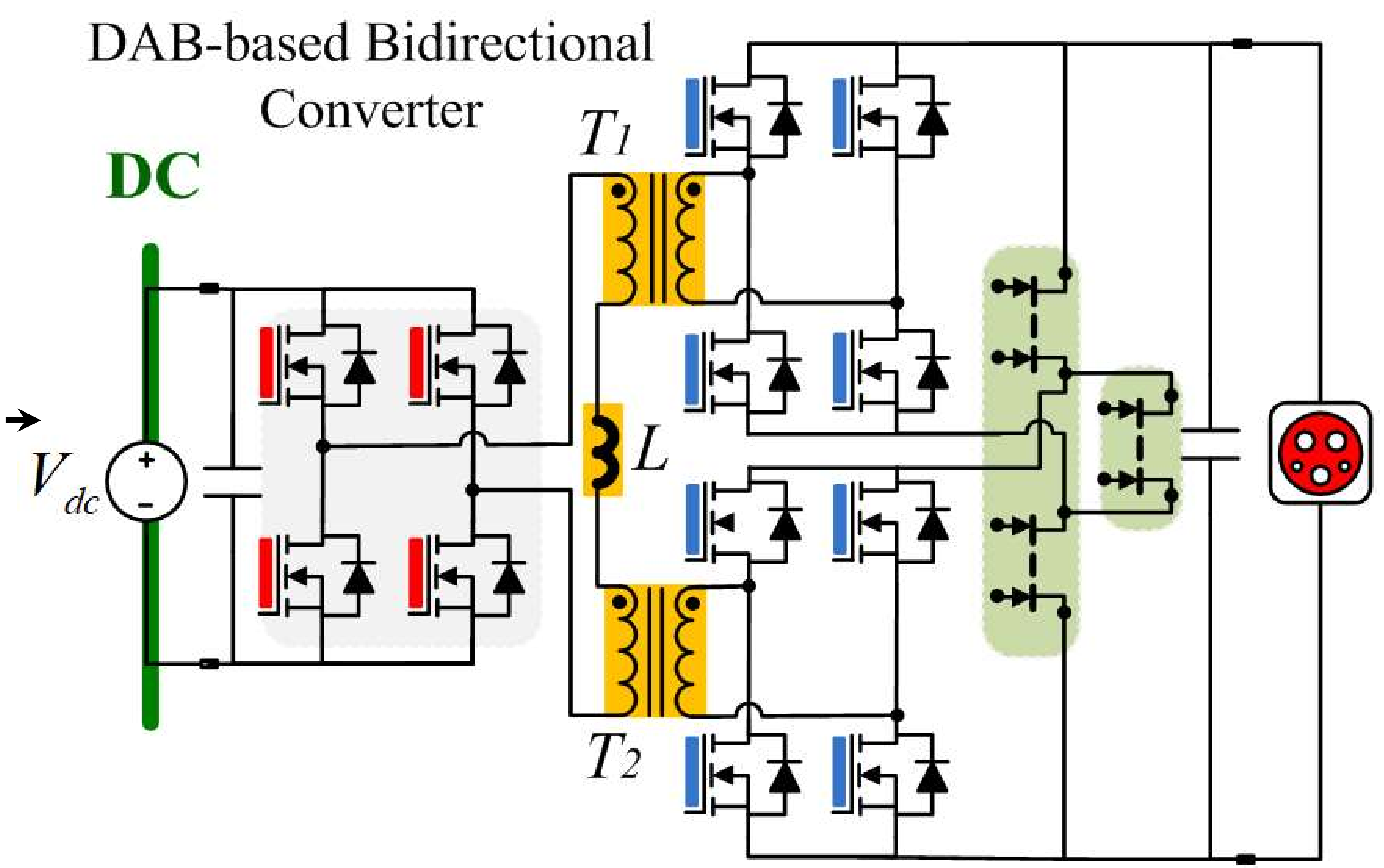
Renewable & Energy Storage System Integration

DC-Link-based System Components



Key Component

- EV Charger: DAB-based converter
  - DC-Link to EV Charger (elimination of AC-DC PFC stage)

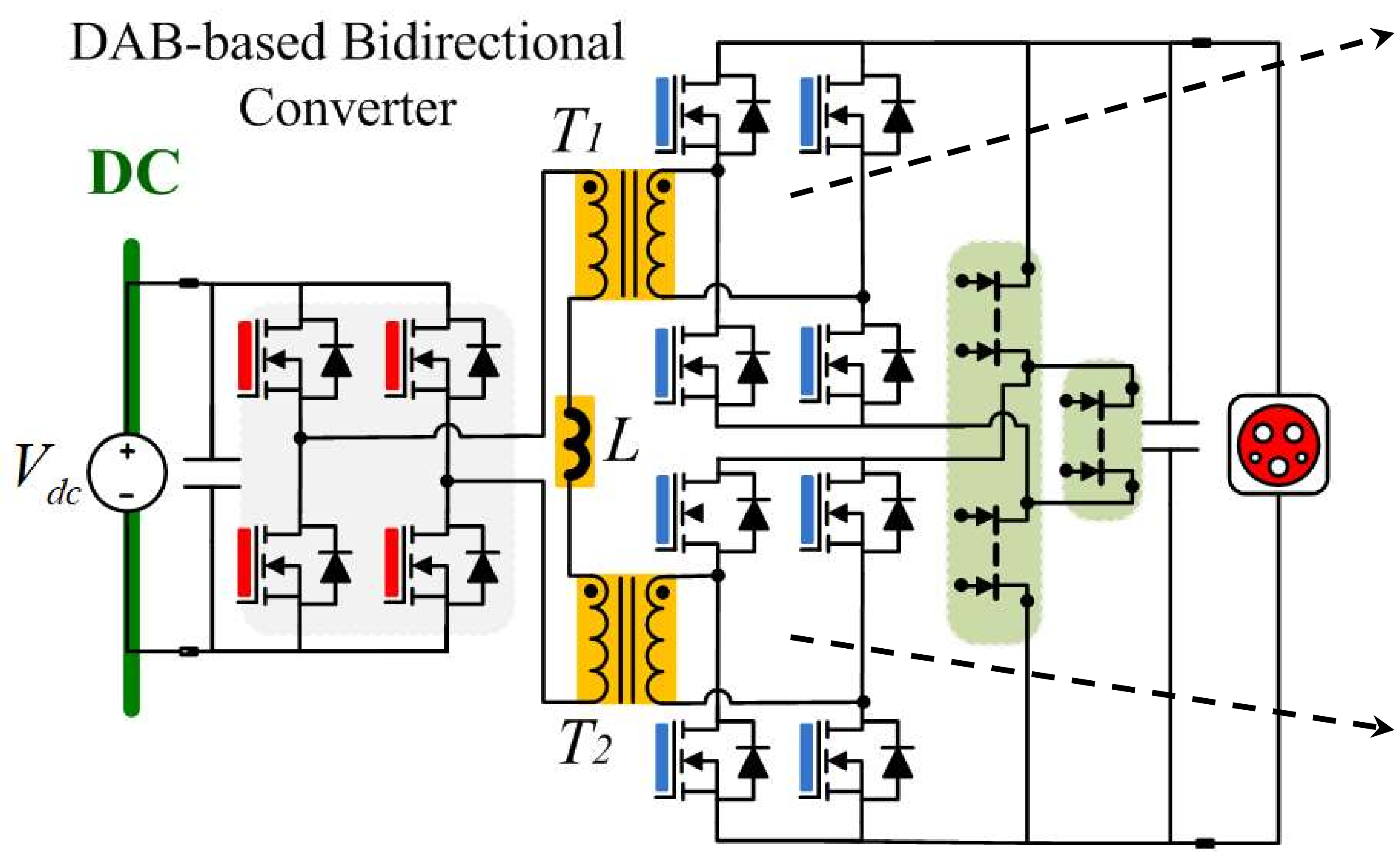


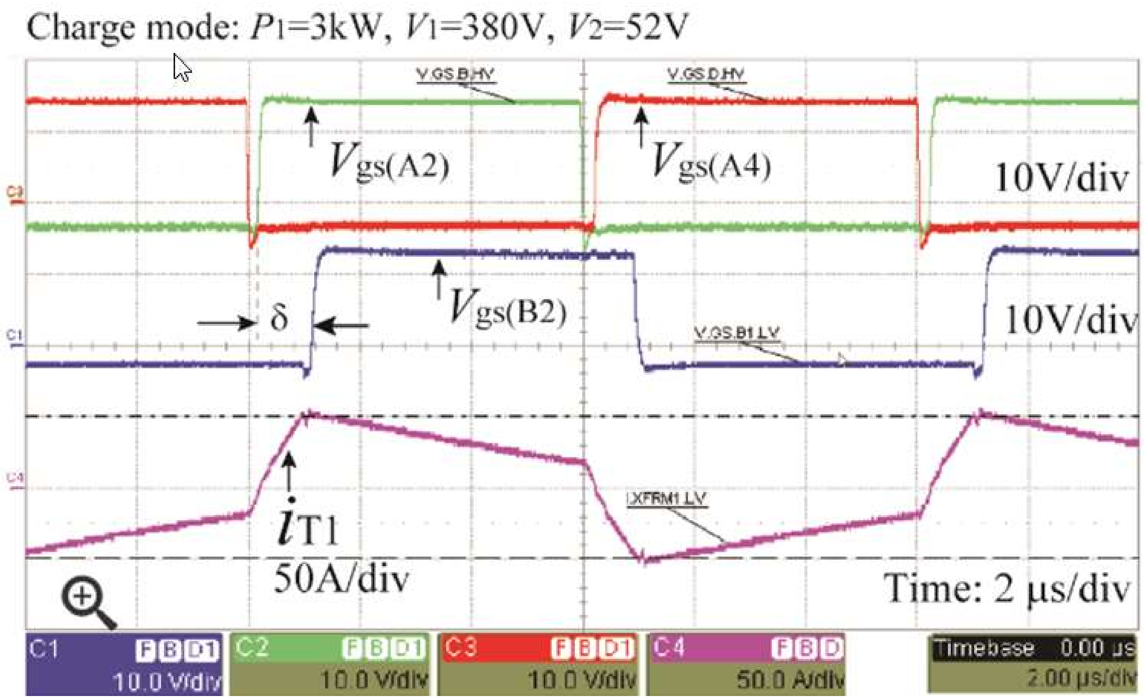
Renewable & Energy Storage System Integration

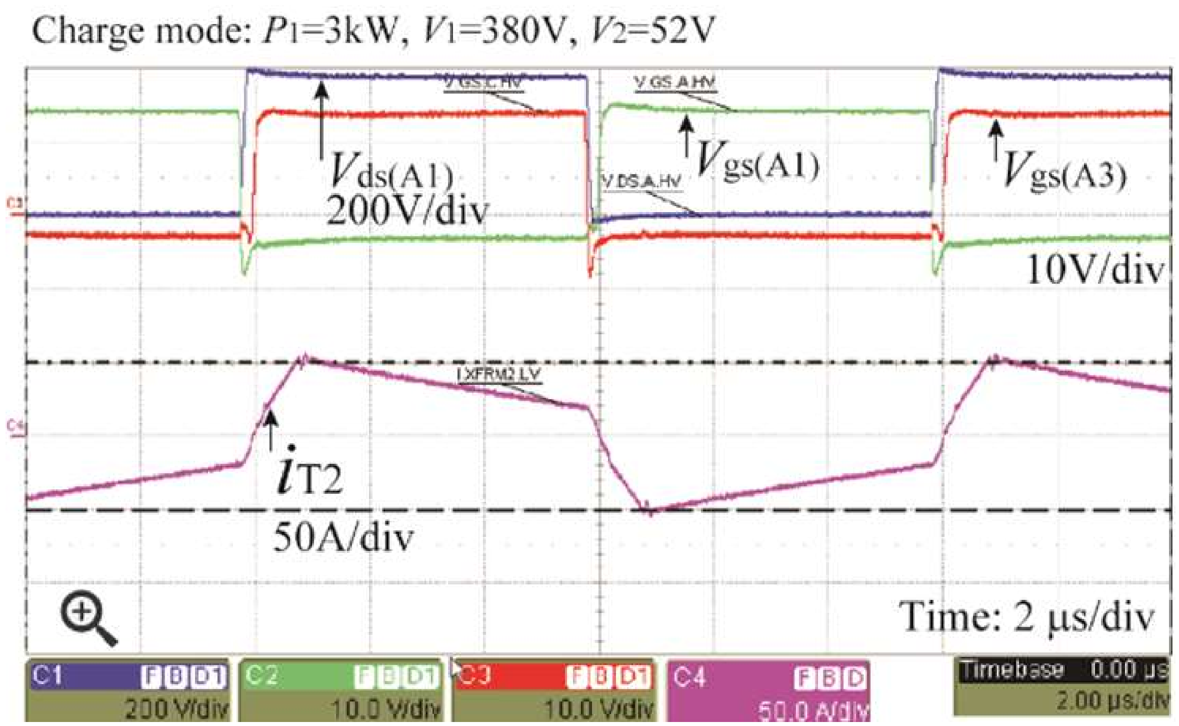
DC-Link-based System Components

- EV Charger: DC-Link to EV (elimination of AC-DC PFC stage)

- Key waveforms







Agenda

1. Introduction

2. System Architectures

3. DC-Link-based System Architecture

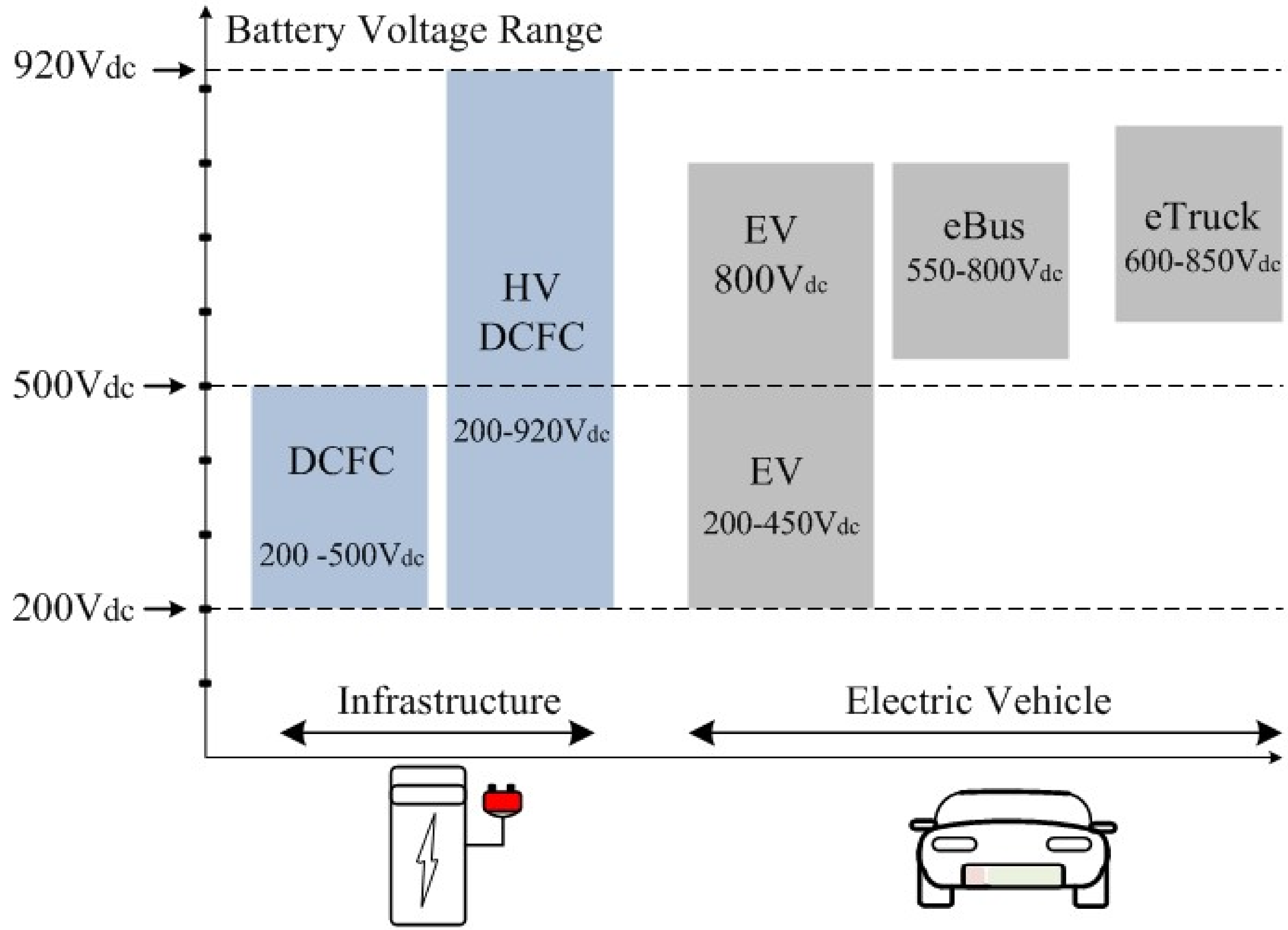
4. Conclusions

Charging Infrastructure & Electric Vehicles

Application & Motivation:

Challenges examples in Electric Vehicle Deployment

- Charging Infrastructure
- Increased Charge voltage range (e.g. 100-1000)V
- Grid Capacity Challenge



DC Grid Architecture

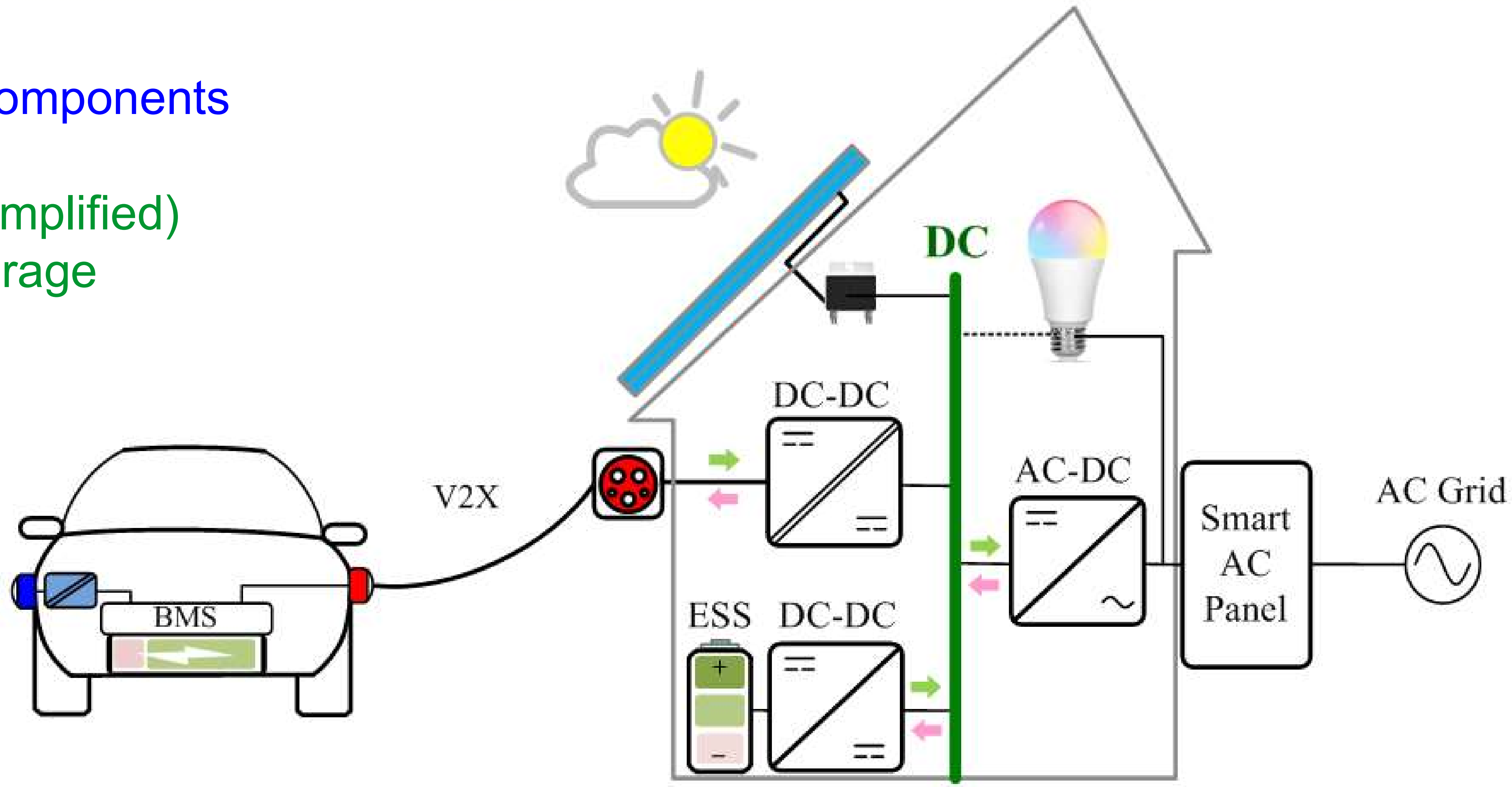
DC-Link-based System for Fast Charging (Level 2)

- Integrated System Approach
- Cost reduction (single-stage DC Fast charge due to AC-DC front end elimination)

Proposed DC-Link-based Architecture

DC-Link-based Key-components

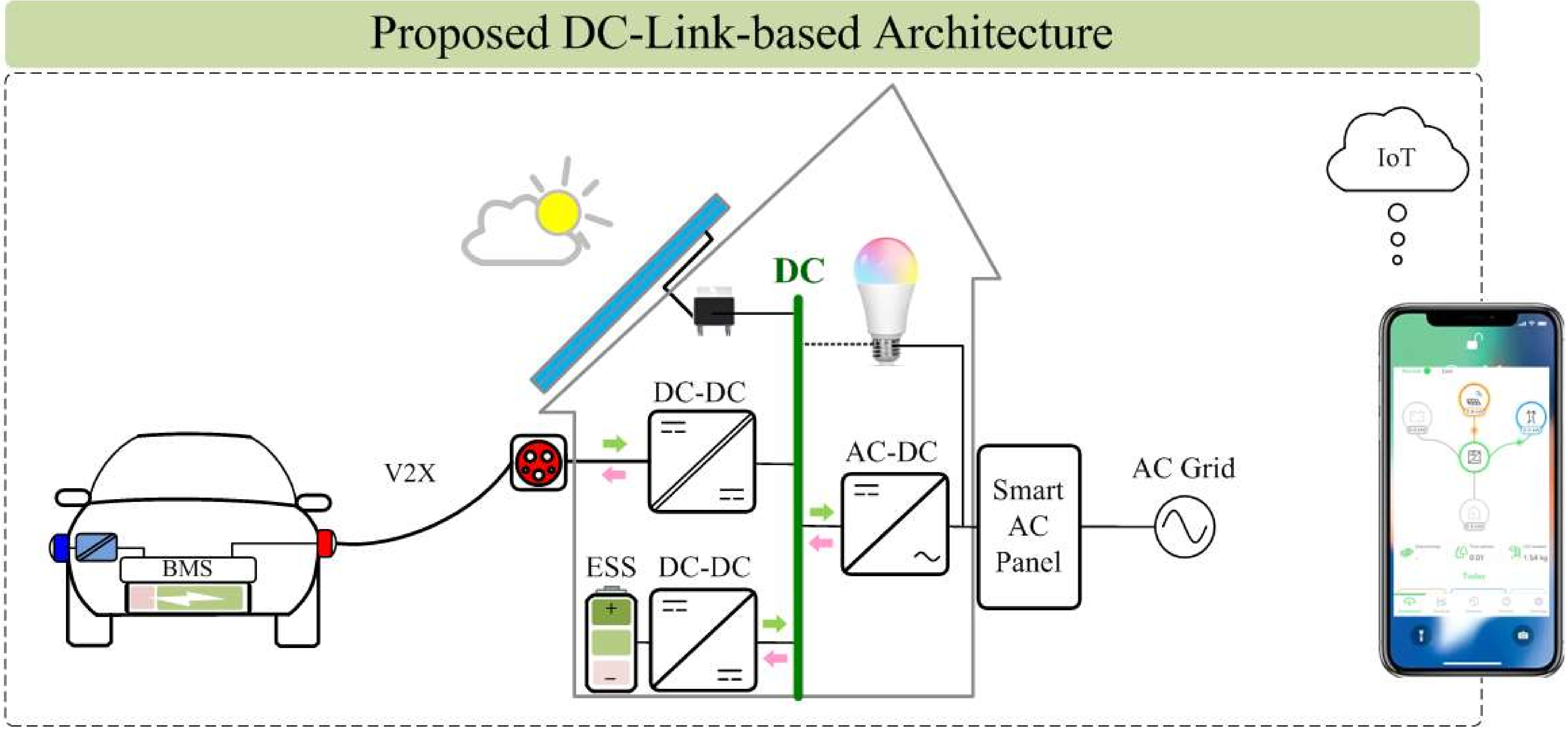
- Solar PV
- DC Fast Charger (simplified)
- Reserve Energy Storage
- DC-AC Inverter



DC Grid Architecture

DC-Link-based System Architecture

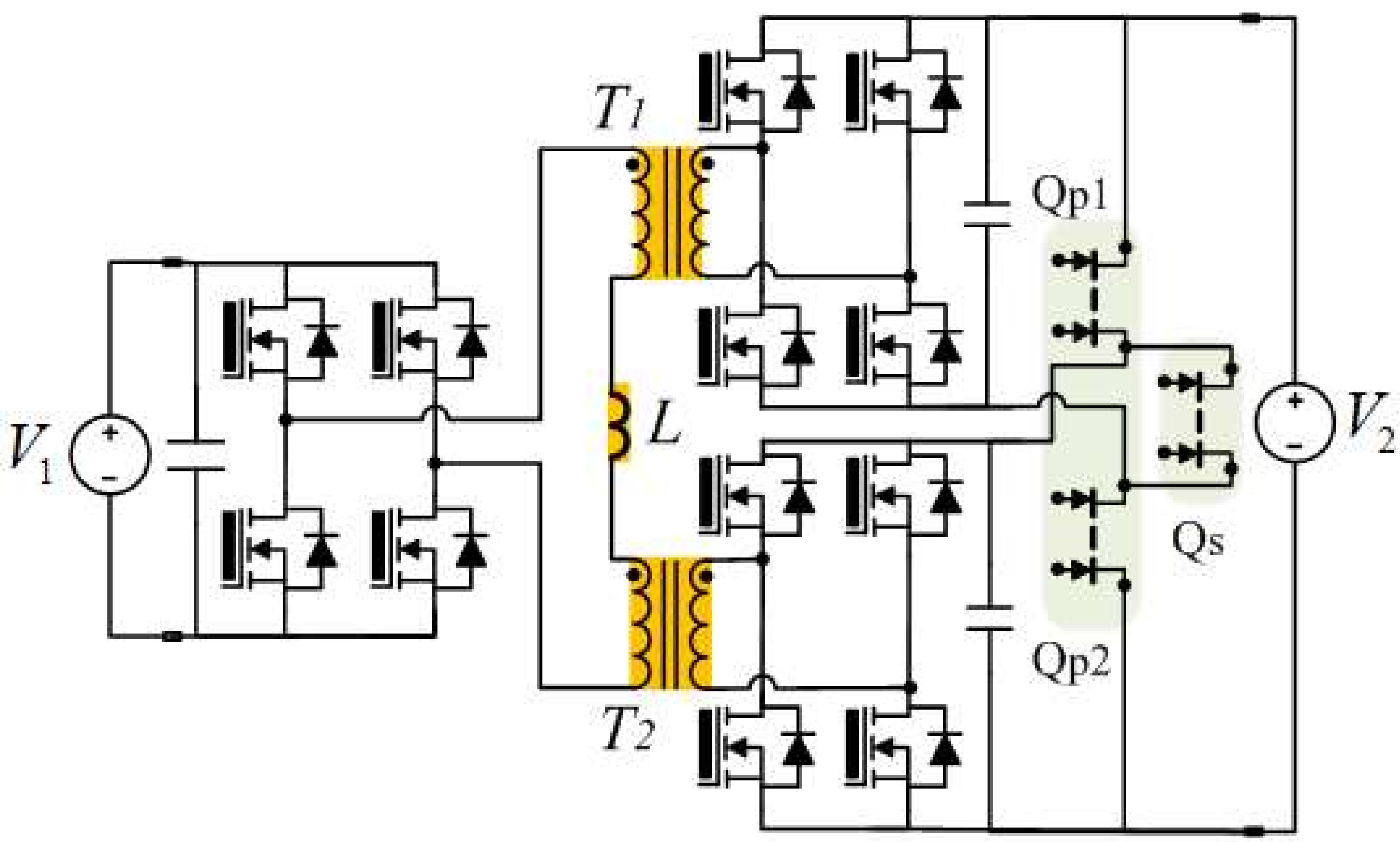
- Smart AC Panel
- IoT Communication

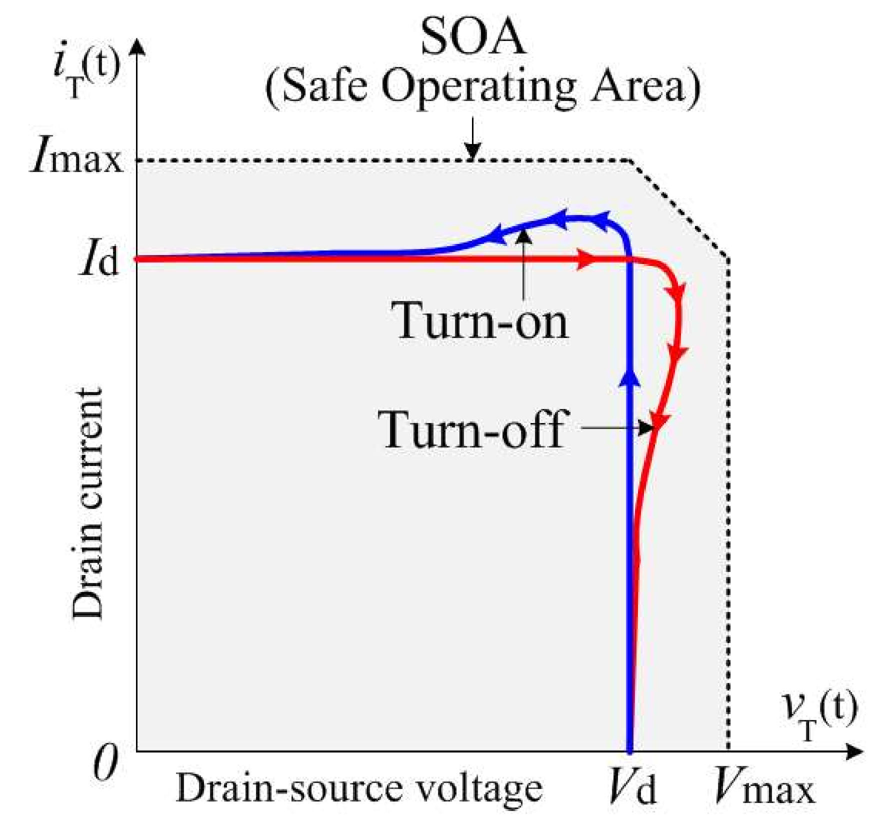


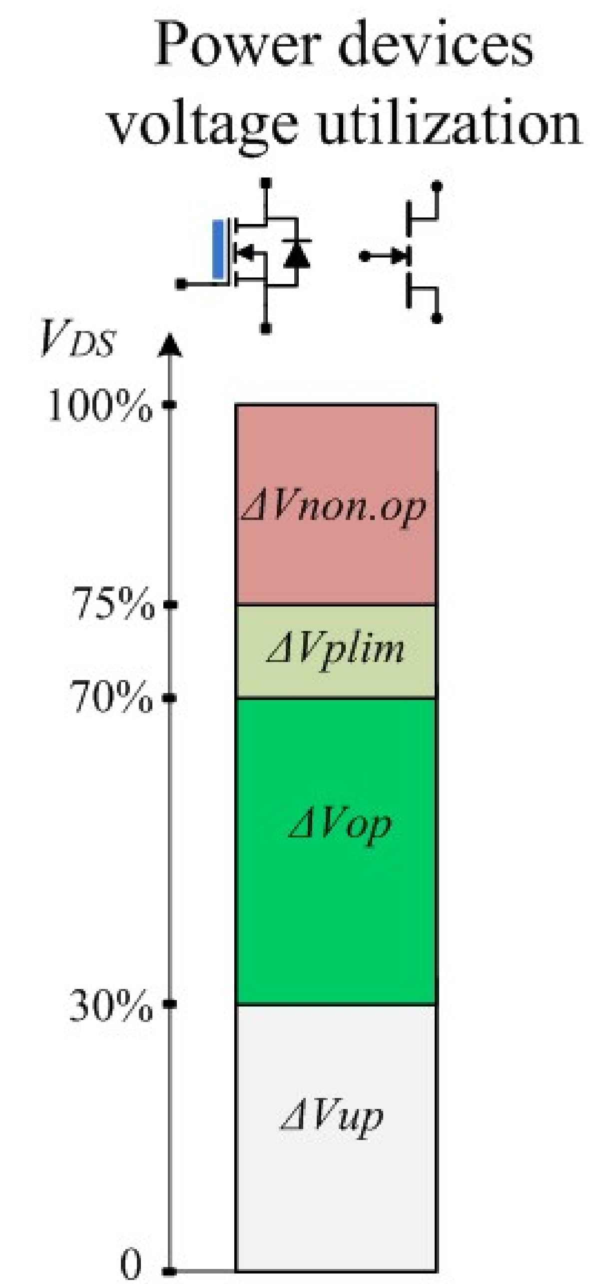
DAB-based Converter Example

DAB-based Converter Description

- Proposed DAB-based topology architecture
- Power devices normal operational (30…70)%V_{DS}
- Power derating/curtailment for V_{DCmax} = (70…75)% V_{DS}







- Re-use the same low voltage devices for higher voltage applications
- Optimization of power devices voltage utilization for SOA operation

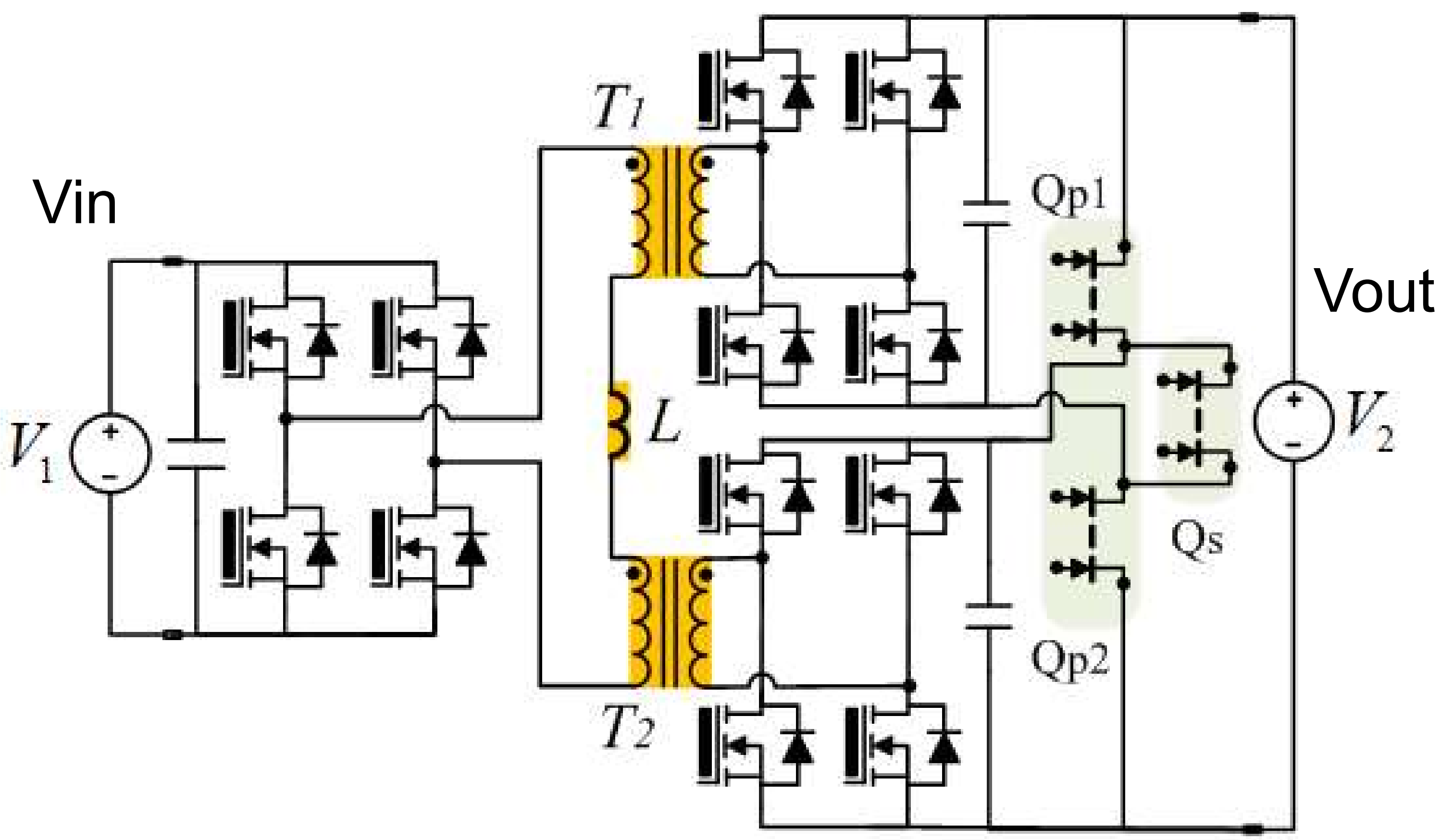
DAB-based Converter for Voltage Range Extension

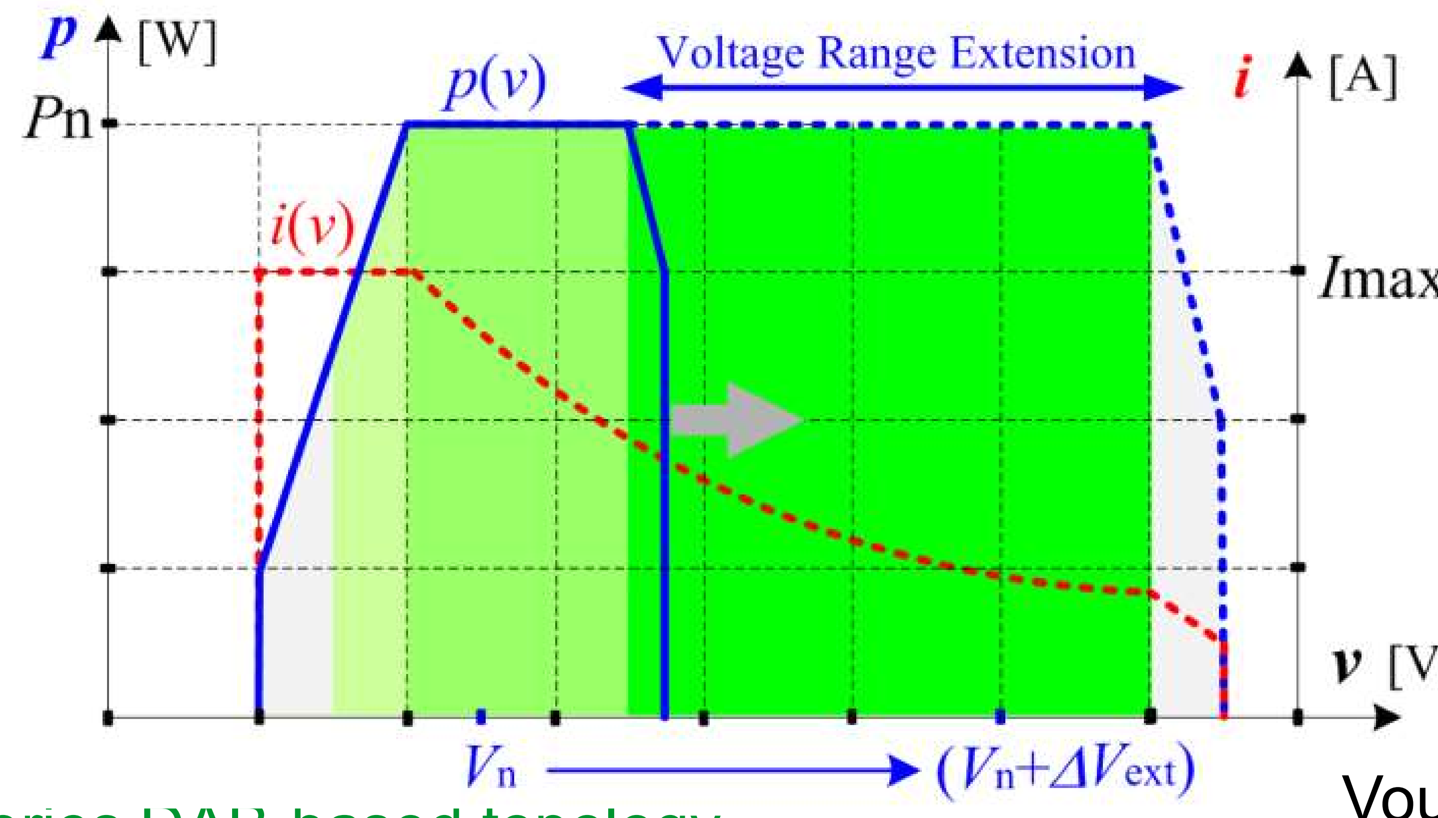
DAB-based Converter Description

- Employs three additional bi-directional switches
  - 400V (500Vmax): Qp1, Qp2= active on, while Qs=off
  - 800V (1000Vmax): Qs=active on, while Qp1, Qp2=off
  - Example: use of 650V/750V SiC power devices

$$q_{sp}(v_2) = \begin{cases} Q_{p1} \wedge Q_{p1} = 0, Q_s = 1, & if\ v_2 < V_{DSmax} \\ Q_{p1} \wedge Q_{p1} = 1, Q_s = 0, & if\ v_2 \geq V_{DSmax} \end{cases}$$

$$p_2(v_2) = \begin{cases} 0, & if\ v_2 < V_{min} \\ V_{min} I_{max}\left[1 + \frac{V_2 - V_{min}}{V_{limL} - V_{min}}\left(\frac{P_n}{V_{min} I_{max}} - 1\right)\right], & if\ V_{min} \leq v_2 < V_{limL} \\ V_n I_n, & if\ V_{limL} \leq v_2 < k_v V_{limH} \\ P_n\left(1 + \frac{1}{2}\frac{V_2 - k_v V_{limH}}{k_v V_{limH} - k_v V_{max}}\right), & if\ V_{limH} \leq v_2 < k_v V_{max} \\ 0, & if\ v_2 \geq k_v V_{max} \end{cases}$$



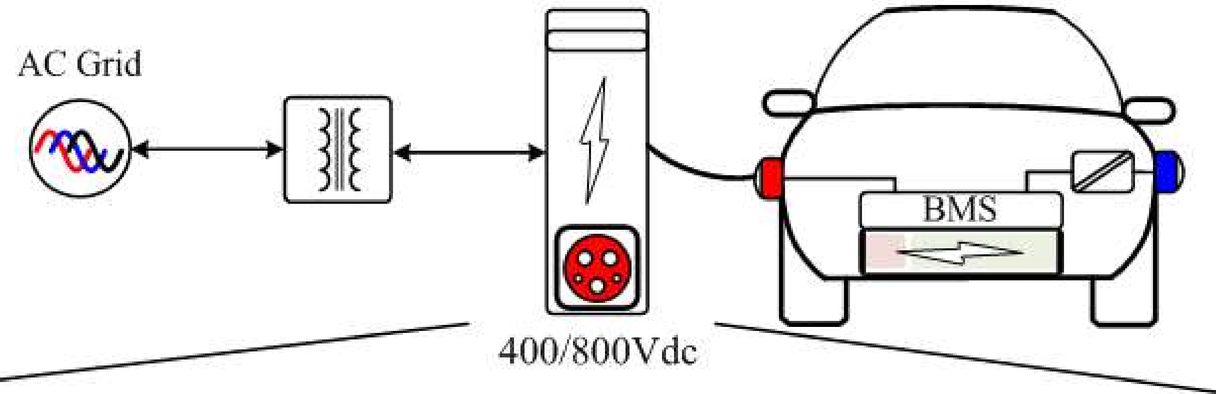


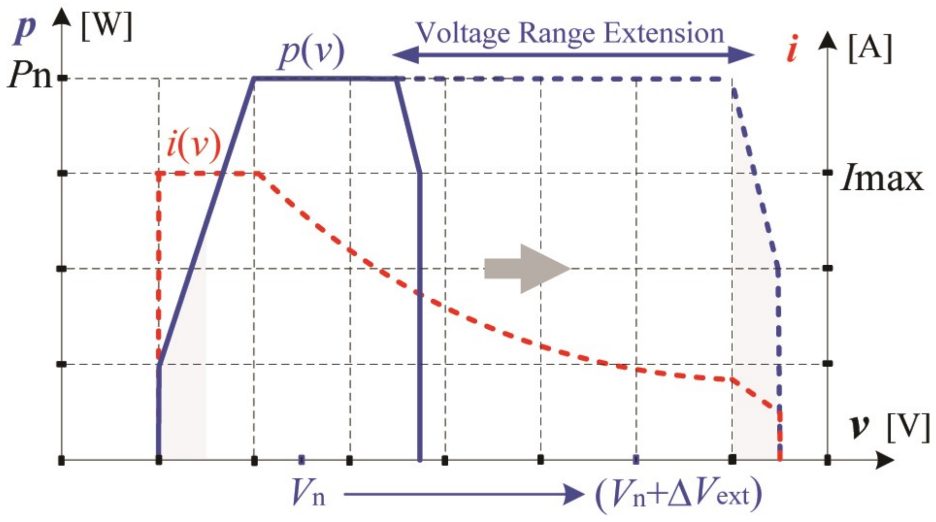
- Double voltage utilization extension with parallel-series DAB-based topology
- Expansion of power capability

Electro-mobility: EV Chargers Example

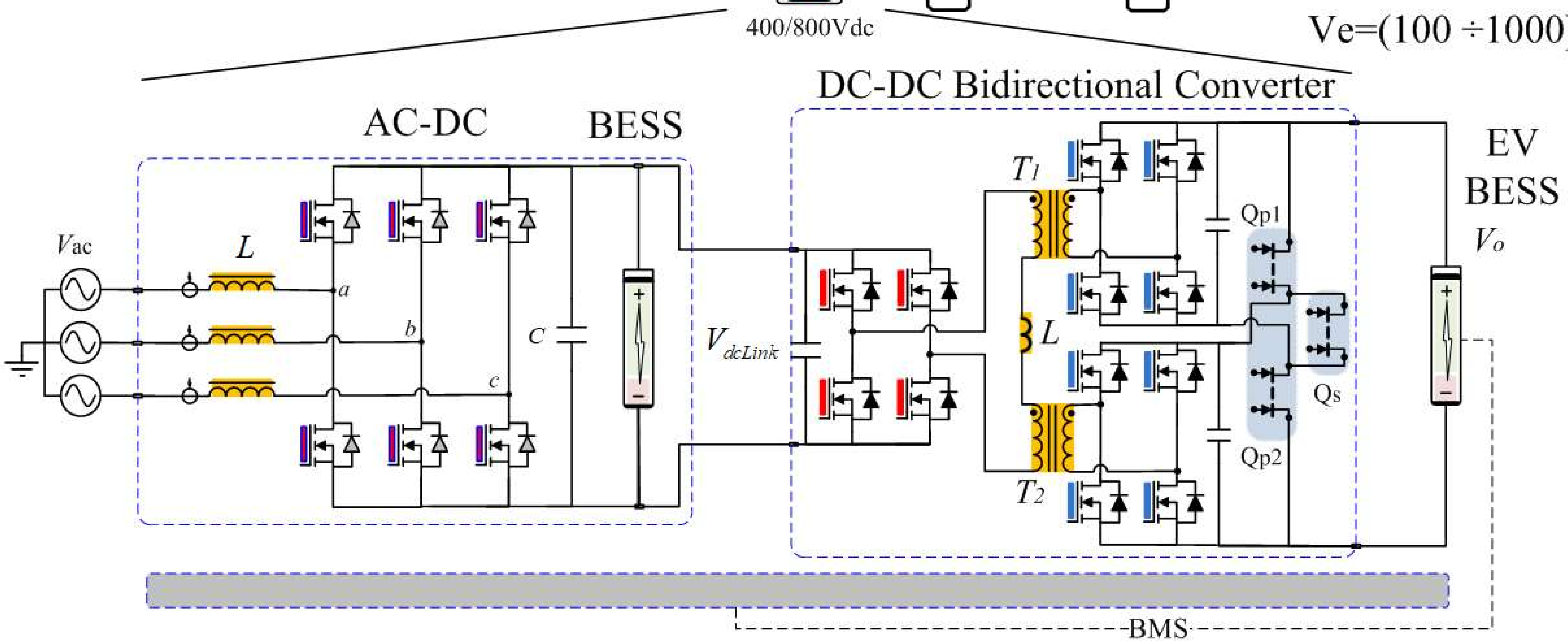
Off-Board Chargers

- Unidirectional Power Conversion - current
- Bidirectional Power Conversion - future





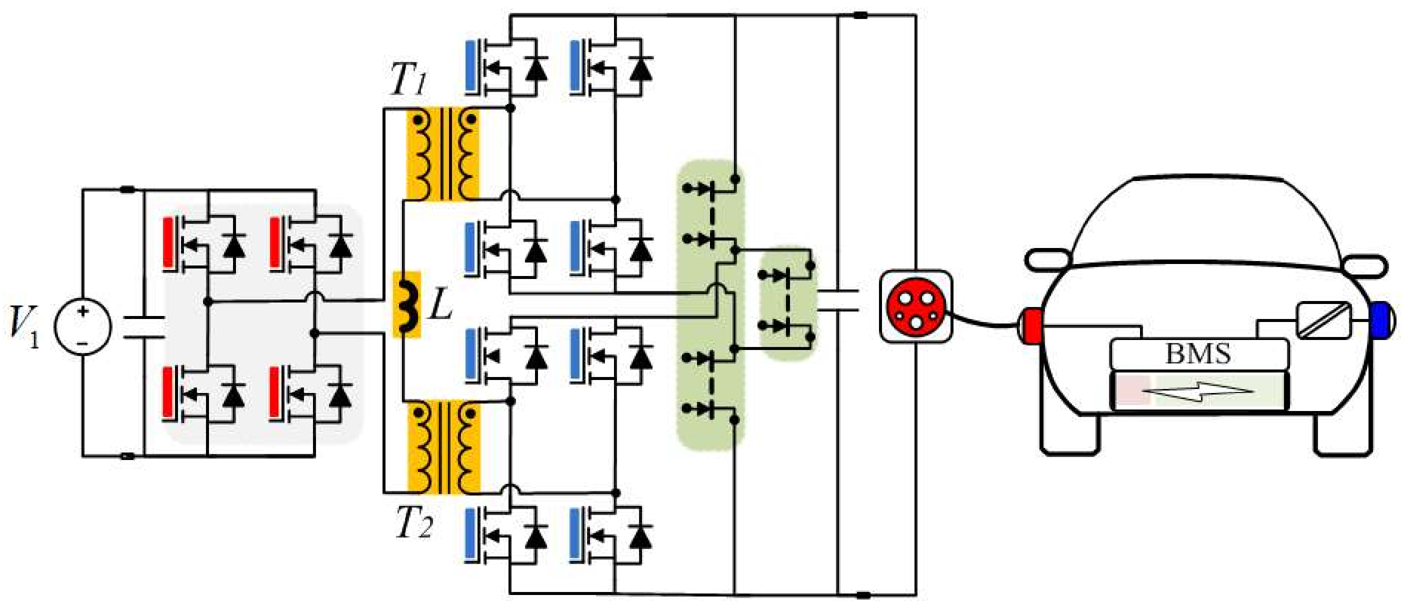
Ve=(100 ÷1000)V

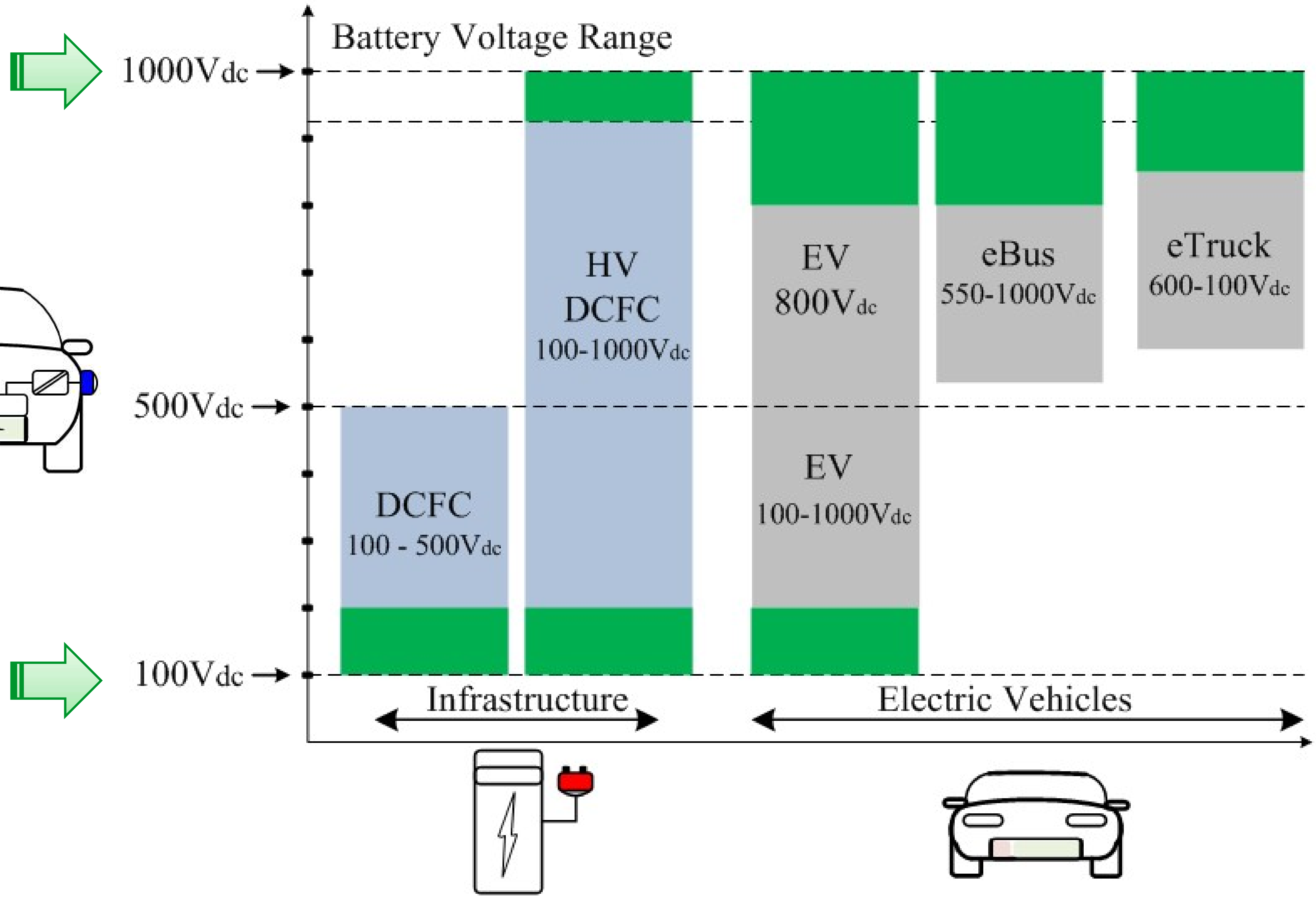


Charging Infrastructure & Electric Vehicles

Electric Vehicle Chargers

- Charger Voltage extension – it can accommodate wide battery-types
- 100V to 1000V voltage extension





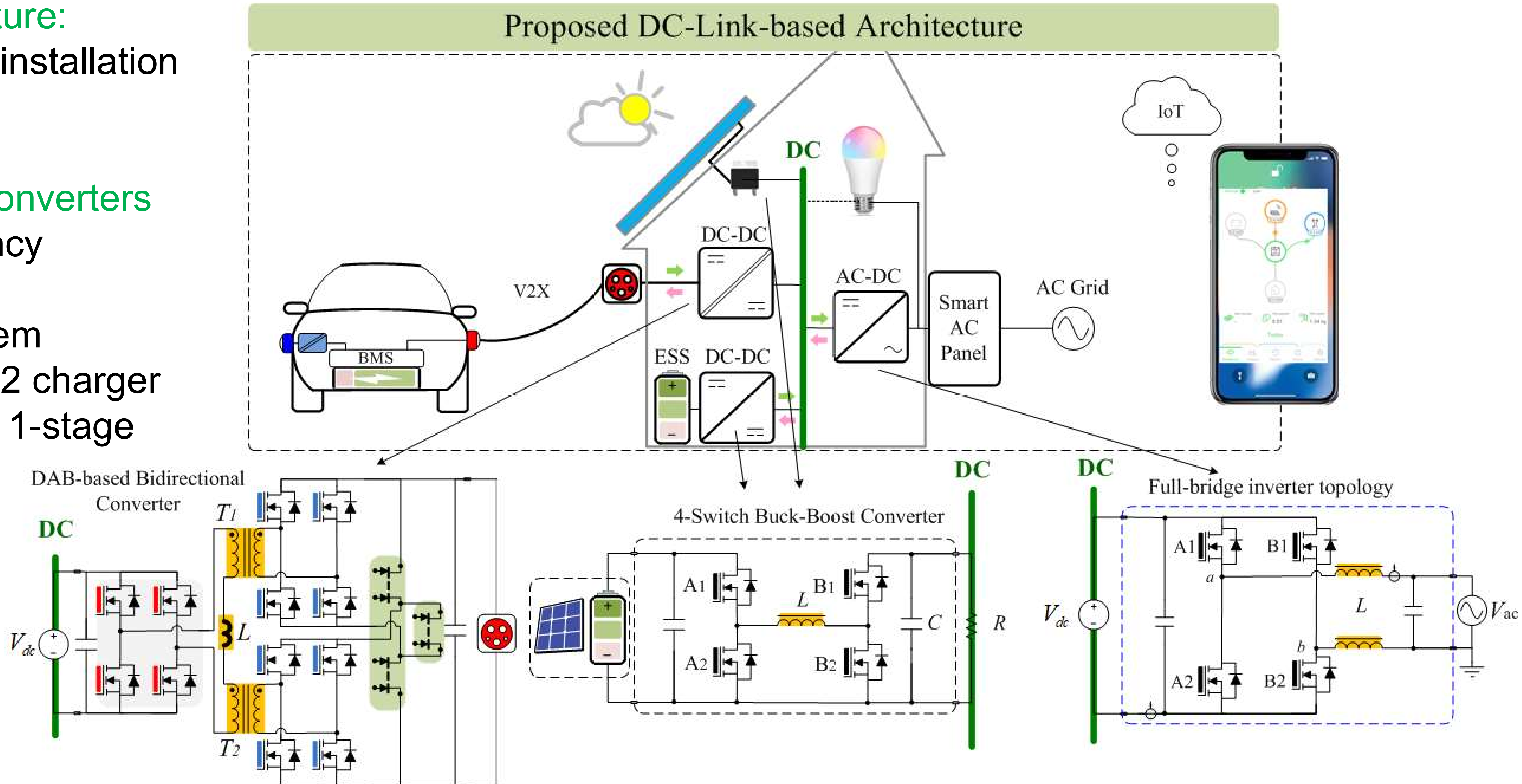
Agenda

Conclusions

Renewable & Energy Storage System Integration for Flexible Operation in Residential-based Applications
Energy appreciation → Energy availability → Energy security/reliability

DC-Link-based architecture:

- Modular → Flexible in installation and operation
- Reduced number of Converters →Higher system efficiency
- Cost reduction →System simplification (AC Level 2 charger reduced from 2-stage to 1-stage conversion)
- Integration of System Monitoring & Communication



Thank You.

Questions?

Emanuel Serban, Ph.D, P.Eng

Maui, Hawaii - ES