Central Valley Rural Energy Systems Workshop

Dec 9, 2025

# DC Distribution System

Dr. Eric Cheng
Electrical Engineering
UC Merced
ericcheng@ucmerced.edu

Power Electronics Research

# Existing AC Power Distribution

AC distribution has been used for around 200 years, we need to change

# Advantages of AC Distribution

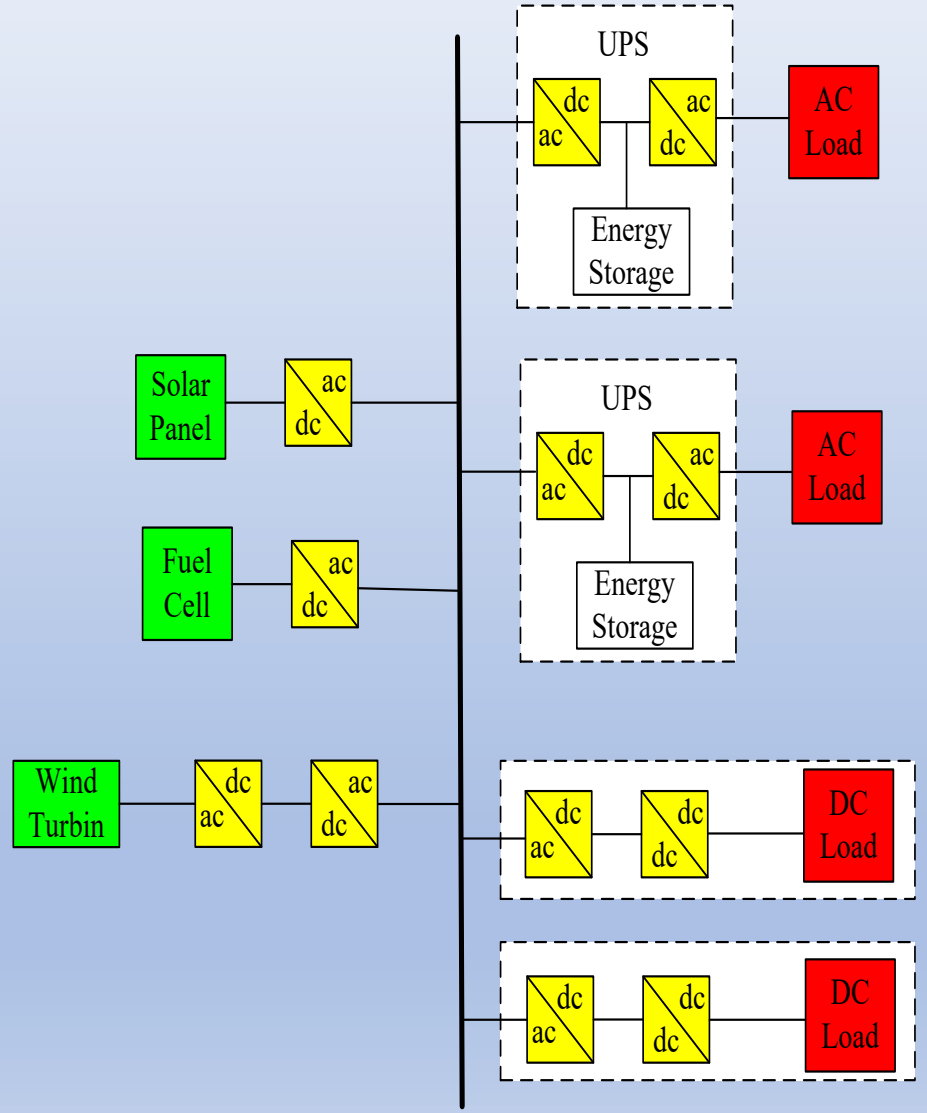
- Alternating current power transmission or distribution networks is commonly used.
- Well developed, matured technology.
- Supporting Devices such as UPS, DVR, APF are well developed

*Why AC distribution system* served us well?

*A. Voltage Transformation*

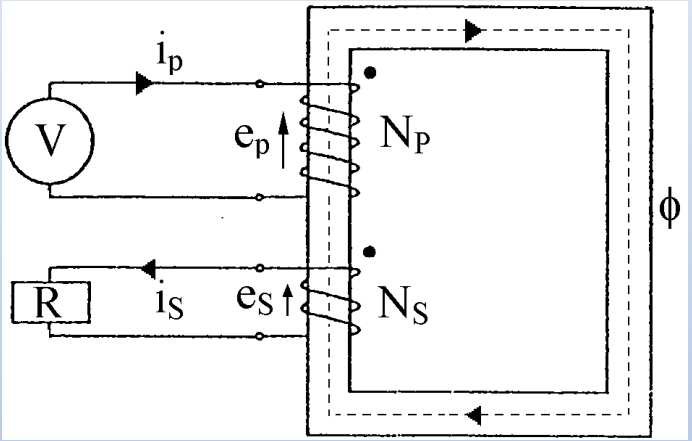
*B. Circuit Breaker Protection*

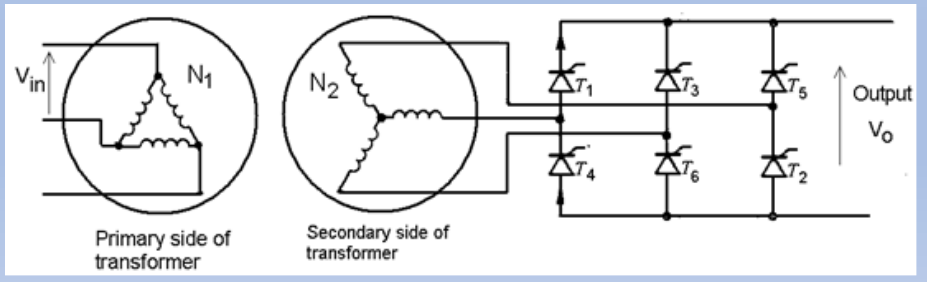
*C. Established Voltage Stability techniques*



# *Easy Voltage Transformation*

- The greatest benefit to ac systems is the ease with ac voltage conversion
- Transformer techniques have been used for good voltage conversion under various load conditions.
- High efficiency
- Voltage control from AC-AC is well established such as Transformer rectifier unit (TRU)

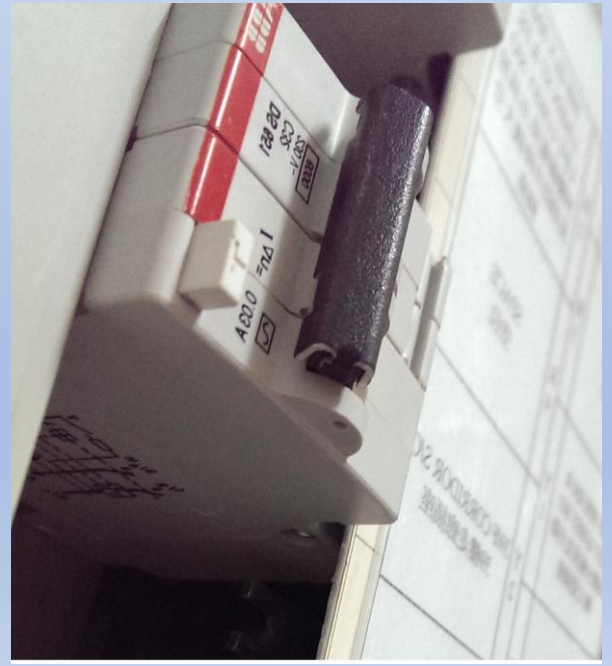


# Well developed protection system

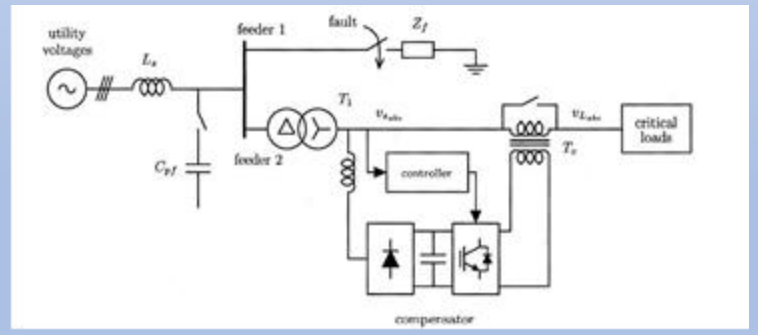
## Mature Circuit Breaker Protection

- Circuit protection is mature for ac distribution systems than for dc systems
- AC circuit protection schemes benefit from periodic zero voltage crossings,
- Extinguish a fault current arc.

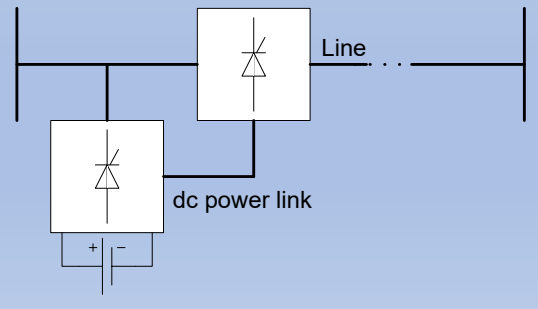


## Controlled Voltage Stability

- The advantage of an ac system is that the stable voltage can be controlled independently from real power through the management of reactive power.
- Voltage dip restorer can also be used for stability.
- Active power supply/filter could inject reactive power

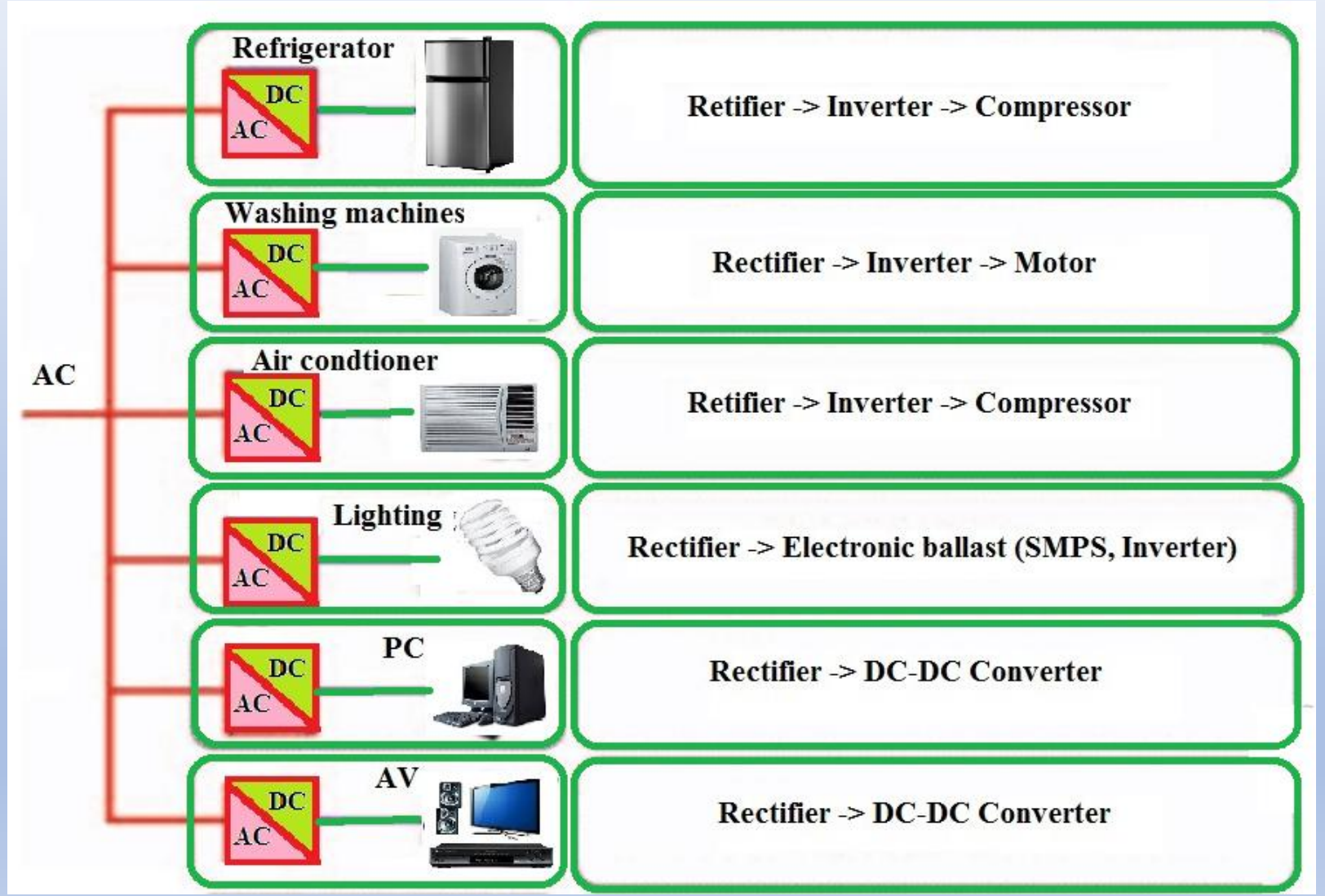



DVR




Reactive power compensation

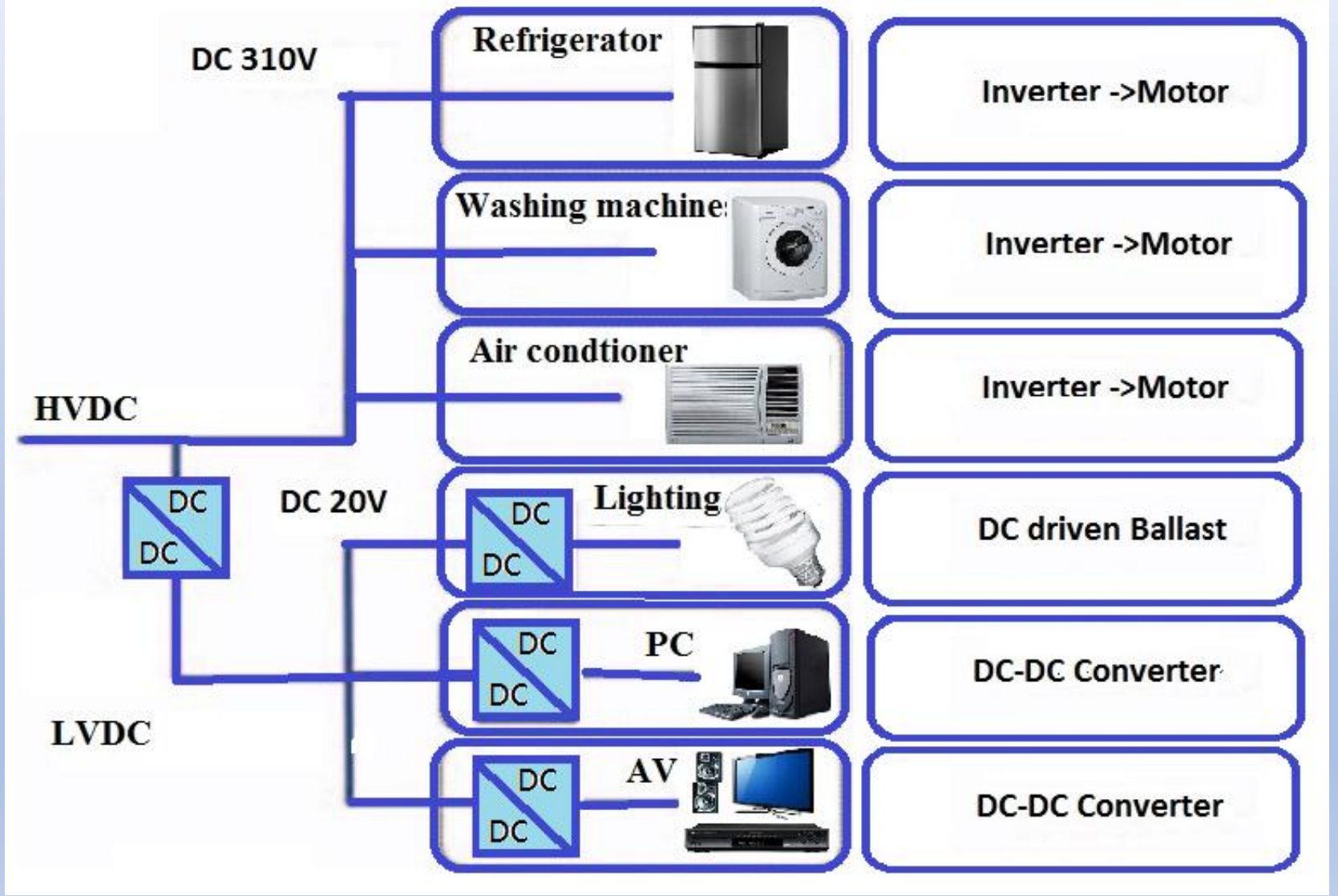
# AC Home with 120V and 60Hz (Existing system)



# DC Distribution

A much more modern method of power distribution to meet all the present systems

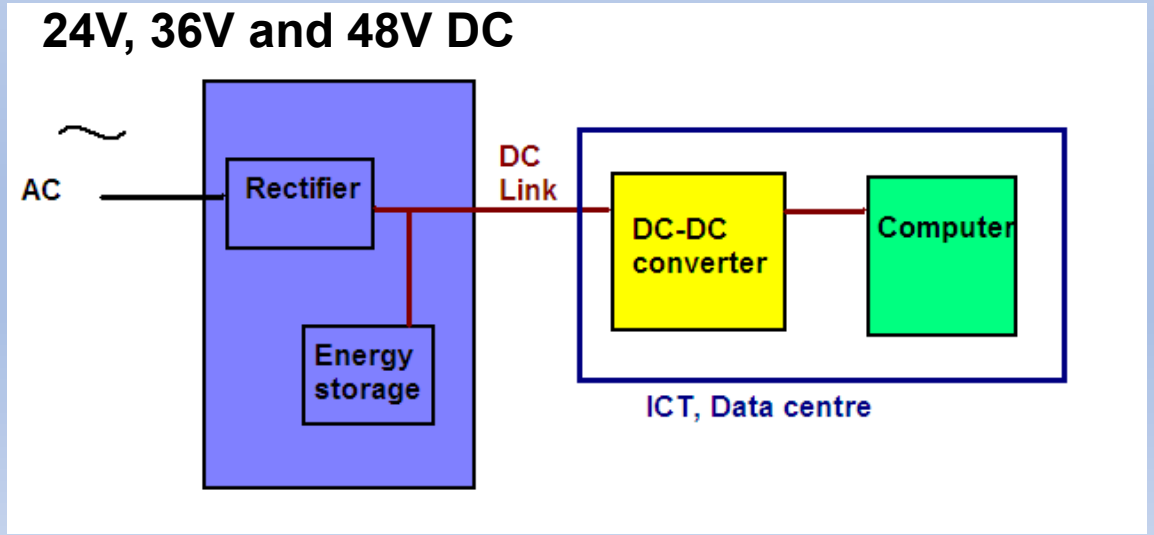
# DC Home with 310V + 20V



# Example of existing DC Mircogrid


Lockheed-Martin JSF X-35A/B/C

**Data Center System**
**24V, 36V and 48V DC**




- 1000V DC circuit
- A significant step forward in e
- 20 percent fuel efficiency imp

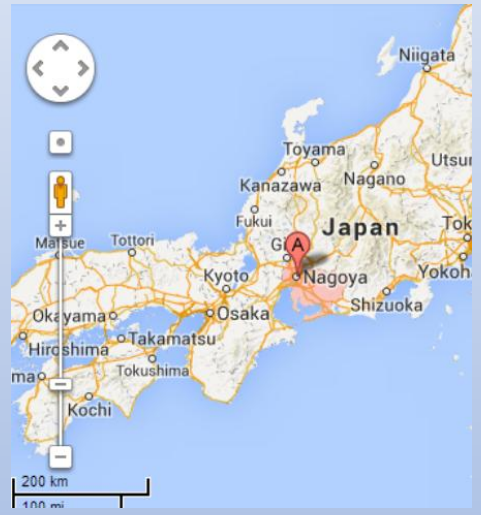
This is the **ABB** Onboard DC Grid.

http://www.abb.com/cawp/seitp202/3415983275230248c1257b64005080ef.aspx

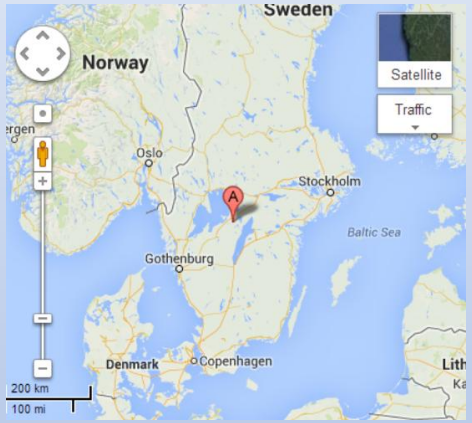
# DC in Various Cities

250V DC that Coexist with AC. A feeder head, rectifier, and output smoother atop a pole in San Francisco's South of Market

http://spectrum.ieee.org/energy/the-smarter-grid/san-franciscos-secret-dc-grid




DC 380V University Campus in Aichi, Japan




DC 380V, Chung Cheng University, Taiwan

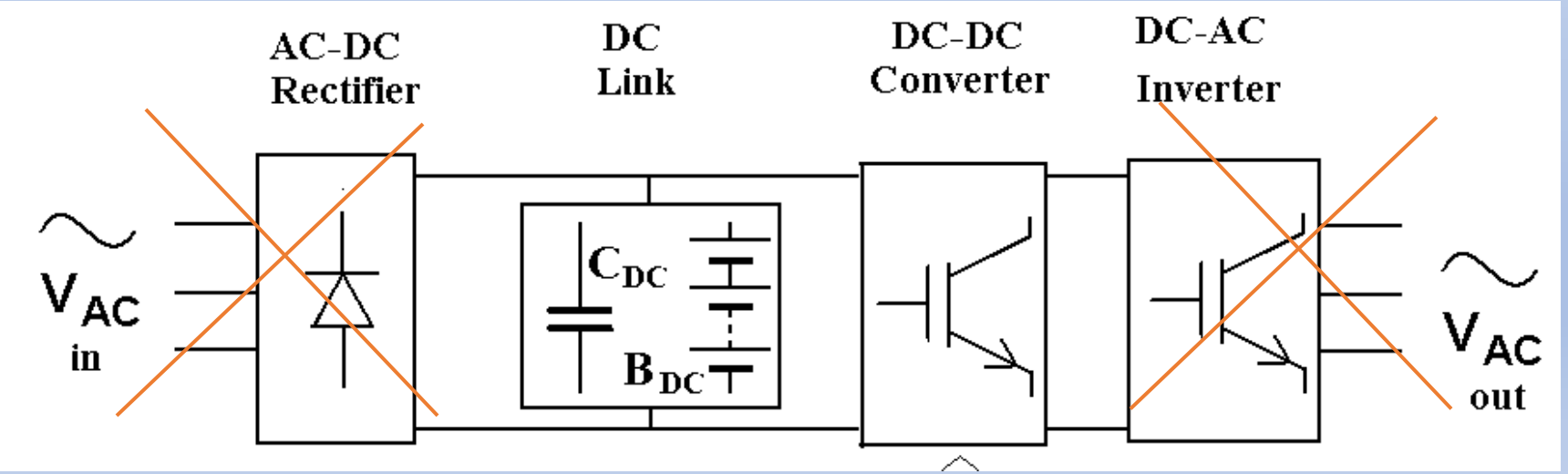
NTT East Saitama Shin-toshin Building 48VDC



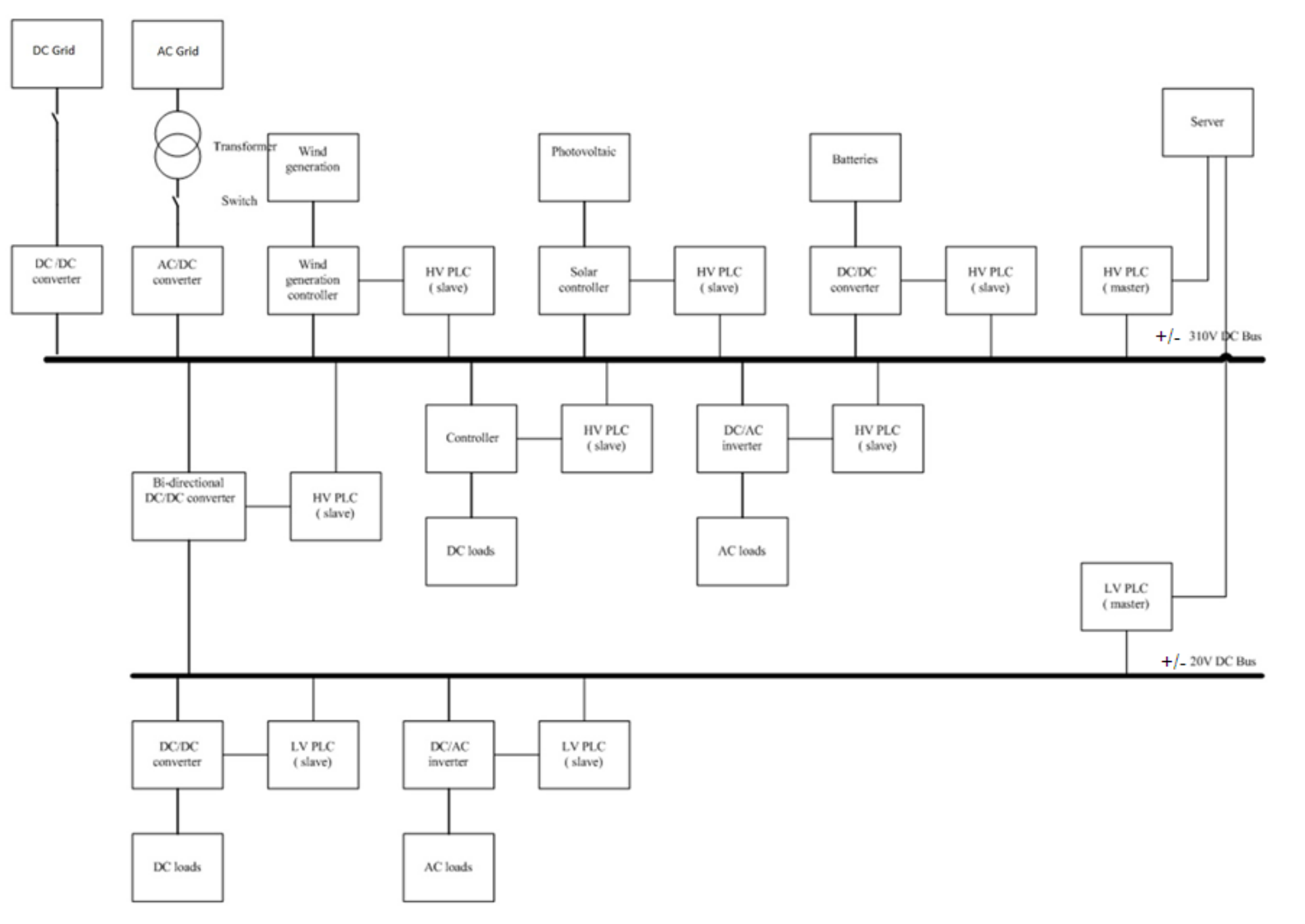
DC 380V, Chung Cheng University, Taiwan

# General concept of DC Distribution

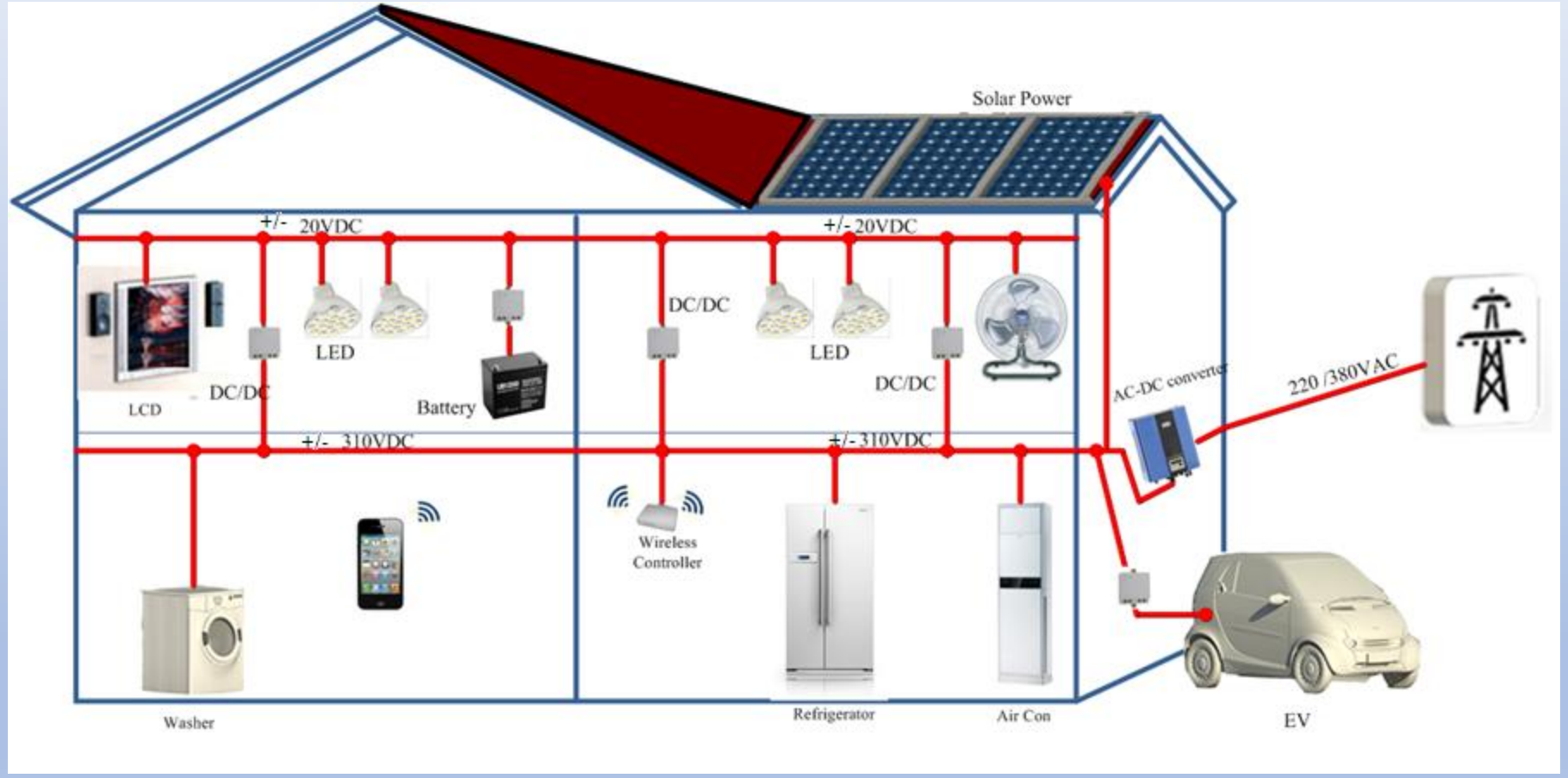
- The DC distribution system is an alternative method for delivering power.
- The method has been proved to have advantages over the conventional AC distribution in terms of energy saving, operation and cost.
- In the past, AC is used for most of the transmission and distribution system. Now DC can be made using power electronics
- The distributed renewable energy source: It is possible to skip one or two stage conversion and to use DC-DC conversion only by using DC for distribution systems .



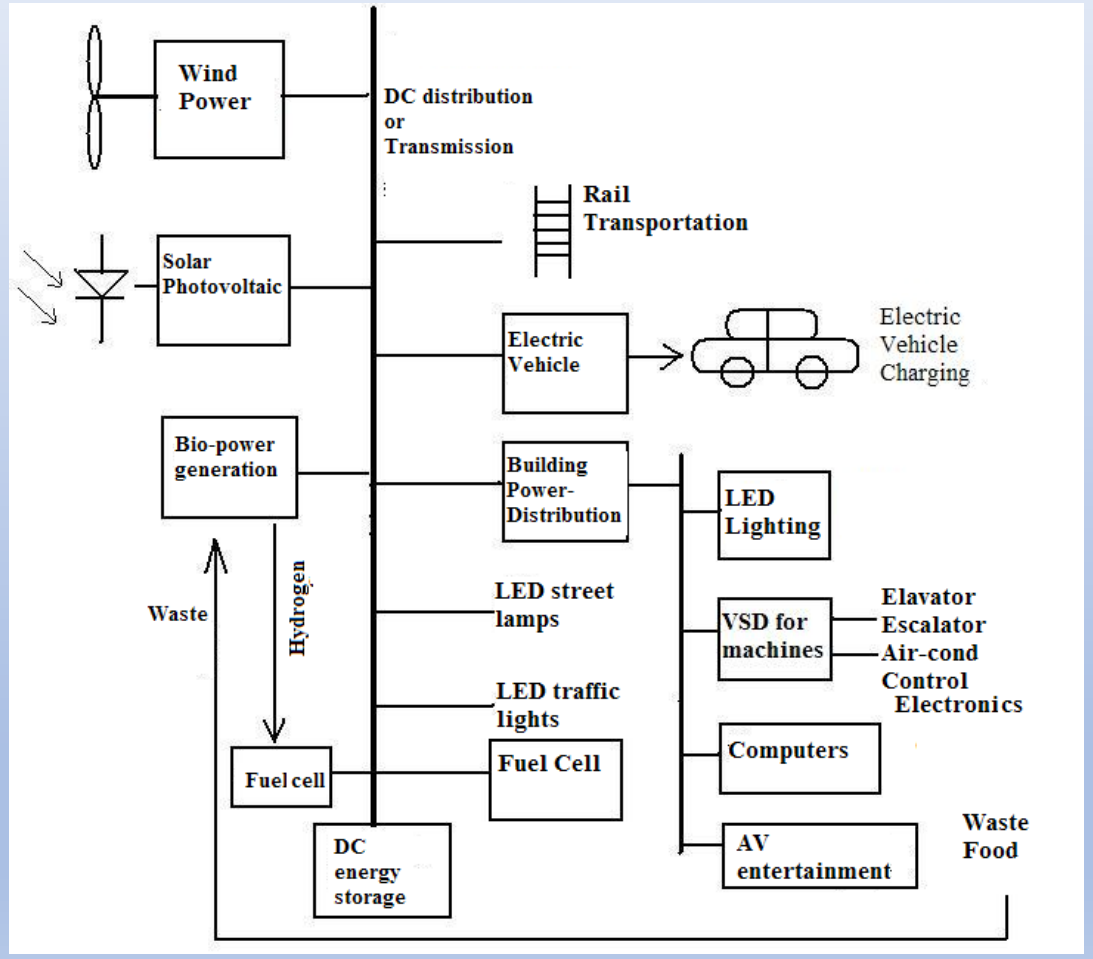
# DC distribution system with double-layer structure

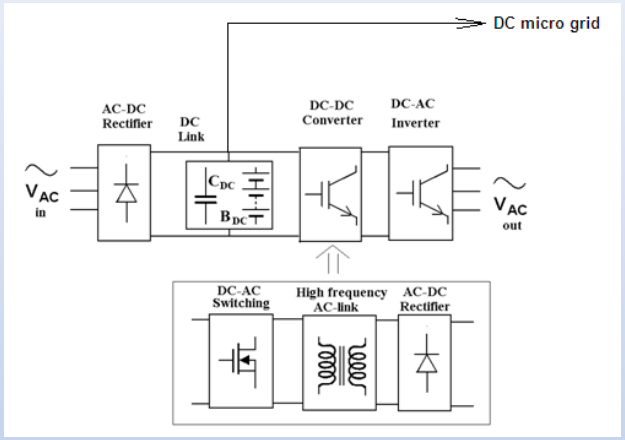


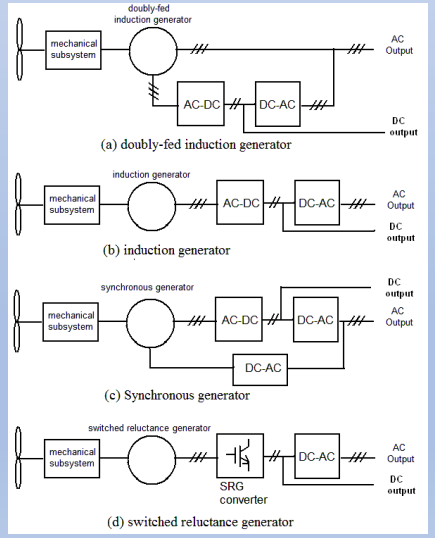
# The DC Smart Home



# Smart DC City



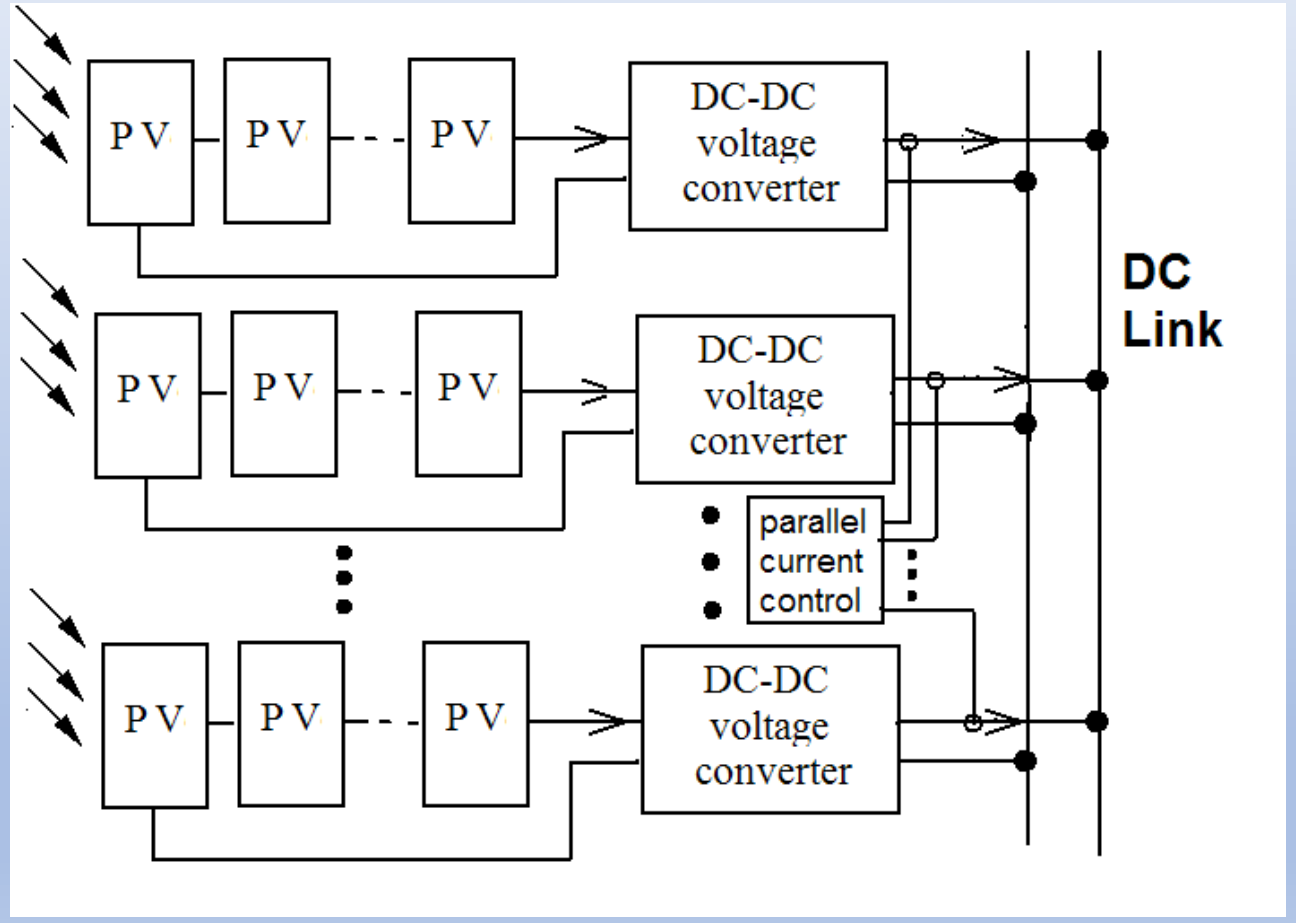



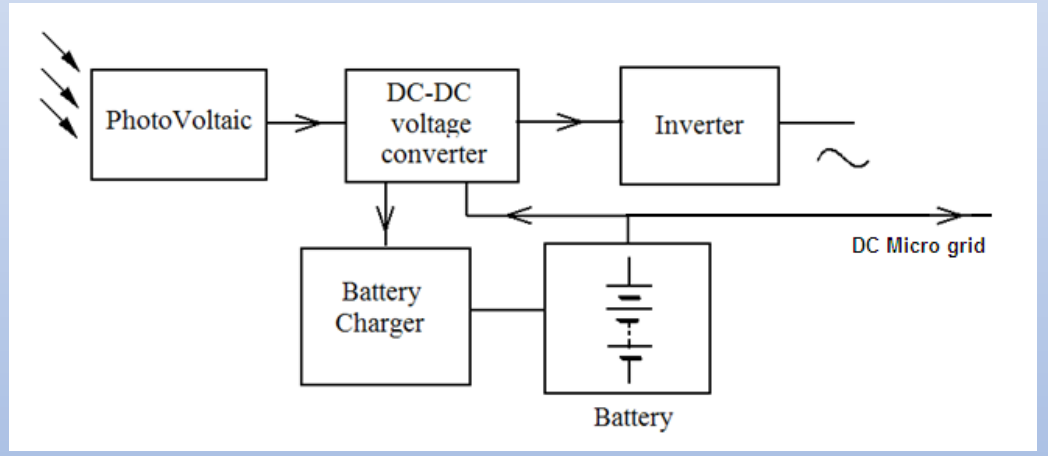



# Research Area

- High frequency DC/DC power conversion
- DC safety
- DC energy storage
- DC standard
- DC to AC actuation
- DC actuation
- Distributed DC power generation
- DC load

# Parallel sharing of PV systems



# Other Typical DC equipment

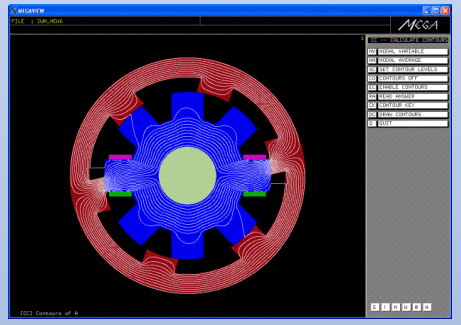
- Phone
- Vehicles
- Energy Storage
- Renewables
- Motor

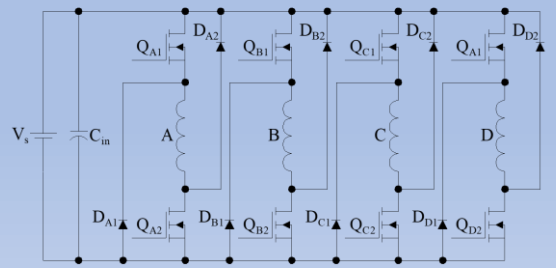
Phone

LED lighting

Electric Vehicles

Battery and energy storage






Power Electronics Research

# Estimated Power Loss & Efficiency Improvement with DC Distribution in a Building

| Apparatus / System | Typical Load (kW) | AC System (Before DC) | DC System (After DC) | Power Loss Saving (kW) |
|---|---|---|---|---|
| **IT Equipment / Servers** | 100 kW | SMPS: 90% Efficient **Loss: 11.1 kW** | DC-DC Converter: 96% Efficient **Loss: 4.2 kW** | **6.9 kW** |
| **LED Lighting** | 50 kW | AC-DC Driver: 88% Efficient **Loss: 6.8 kW** | DC-DC Driver: 95% Efficient **Loss: 2.6 kW** | **4.2 kW** |
| **Variable Frequency Drives (HVAC, Elevators)** | 150 kW | AC Rectifier + Inverter: 94% Efficient **Loss: 9.6 kW** | DC-AC Inverter only: 97% Efficient **Loss: 4.6 kW** | **5.0 kW** |
| **Audio/Video Equipment** | 10 kW | Internal AC-DC: 85% Efficient **Loss: 1.8 kW** | DC-DC Converter: 94% Efficient **Loss: 0.6 kW** | **1.2 kW** |
| **EV Charging Stations** | 100 kW | AC-DC Converter: 93% Efficient **Loss: 7.5 kW** | Direct DC Charging **Loss: ~1.0 kW** (connectors/wiring) | **6.5 kW** |
| **Building Control Systems** | 5 kW | Various PSUs: 85% Efficient **Loss: 0.9 kW** | DC-DC Converters: 93% Efficient **Loss: 0.4 kW** | **0.5 kW** |

# Estimated Power Loss & Efficiency Improvement with DC Distribution in a Building

| Apparatus / System | Typical Load (kW) | AC System (Before DC) | DC System (After DC) | Power Loss Saving |
|---|---|---|---|---|
| **Subtotal: Apparatus Losses** | **415 kW** | **Total Loss: ~37.7 kW** | **Total Loss: ~13.4 kW** | **~24.3 kW** |
| **Building Power Distribution** | **415 kW** | **Losses:**<br>• $I^2R$ Losses<br>• Transformer Loss (~2%)<br>• Power Factor Penalty (~1-2% effective loss)<br>**Total Est. Loss: ~20.8 kW** | **Losses:**<br>• $I^2R$ Losses (Lower for same power)<br>• No Transformer Loss<br>• No Power Factor Loss<br>**Total Est. Loss: ~12.5 kW** | **8.3 kW** |
| **GRAND TOTAL** | **415 kW** | **Total System Loss: ~58.5 kW**<br>**Overall System Efficiency: ~85.9%** | **Total System Loss: ~25.9 kW**<br>**Overall System Efficiency: ~93.8%** | **~32.6 kW** |

# What has been improved : 7.9%

- Apparatus saving:
  - In an AC system: Grid AC -> Building AC -> (AC-DC Rectifier inside device) -> Device's Internal DC.
  - In a DC system: Grid DC-> Building DC -> Device's Internal DC.
- **Distribution-Level Savings**
  - Elimination of Power Factor (PF) Correction Losses
  - Elimination of Harmonic Distortion Losses
  - Reduced $I^2R$ Losse
  - Elimination of Distribution Transformer Losses

# Projected Power Loss & Efficiency Improvement with City-Scale DC Distribution

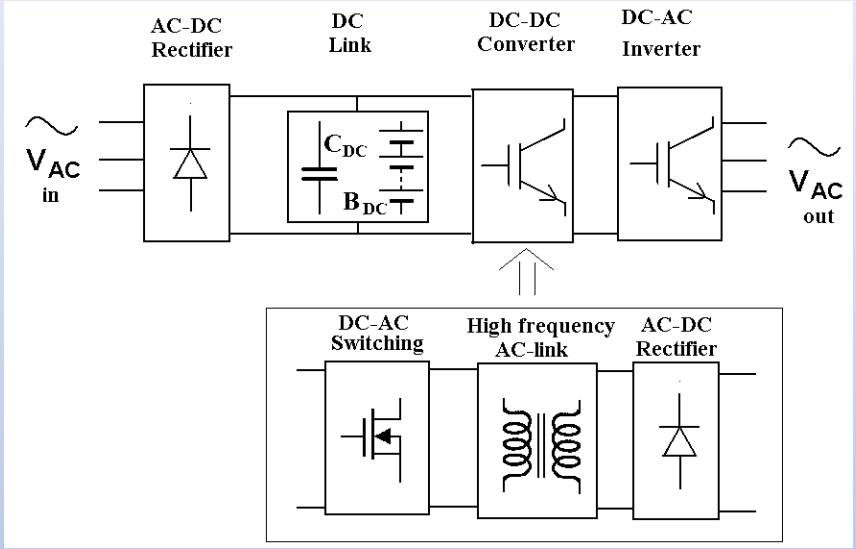
| System Component | Scale (MW) | AC System (Before DC) | DC System (After DC) | Power Loss Saving (MW) |
|---|---|---|---|---|
| **End-Use Apparatus** (Buildings, Industry, EV Fleets) | 800 MW | **Efficiency:** ~86%<br>**Total Loss:** ~112 MW | **Efficiency:** ~94%<br>**Total Loss:** ~48 MW | **64 MW** |
| **Grid-Scale Energy Storage** | 200 MW (Capacity) | **Round-Trip Efficiency:** ~88% (AC-DC->Battery->DC-AC)<br>**Loss per Cycle:** ~24 MW | **Round-Trip Efficiency:** ~97% (DC->Battery->DC)<br>**Loss per Cycle:** ~6 MW | **18 MW** |
| **Renewable Generation Integration** (Solar Farms) | 300 MW (Nameplate) | **Inverter Efficiency:** ~98%<br>**Loss:** ~6 MW | **DC-DC Boost Converter:** ~99%<br>**Loss:** ~3 MW | **3 MW** |

| System Component | Scale (MW) | AC System (Before DC) | DC System (After DC) | Power Loss Saving (MW) |
|---|---|---|---|---|
| **City Power Distribution** (MV/HV Lines & Substations) | 1,000 MW (Transmitted) | **Losses:** ~5% (50 MW)<br>• $I^2R$ Losses<br>• Transformer Losses<br>• Reactive Power & PF Correction Losses<br>• Skin Effect Losses | **Losses:** ~2.5% (25 MW)<br>• $I^2R$ Losses (Lower current for same power)<br>• Fewer Conversion Stages<br>• No Reactive Power / PF Issues<br>• No Skin Effect | **25 MW** |
| **Voltage Support & Stability** | 1-10 MW | **Losses:** ~1% (10 MW)<br>Requires massive capacitor banks, static VAR compensators (SVCs.etc) | **Losses:** ~0.1% (1 MW)<br>Voltage is maintained electronically by converters. No need for reactive power compensation. The concept does not exist in a DC grid. | **9 MW** |
| **GRAND TOTAL (City Scale)** | **1,000 MW** (Peak Load) | **Total System Loss: ~202 MW**<br>**Overall System Efficiency: ~79.8%** | **Total System Loss: ~83 MW**<br>**Overall System Efficiency: ~91.7%** | **~119 MW** |

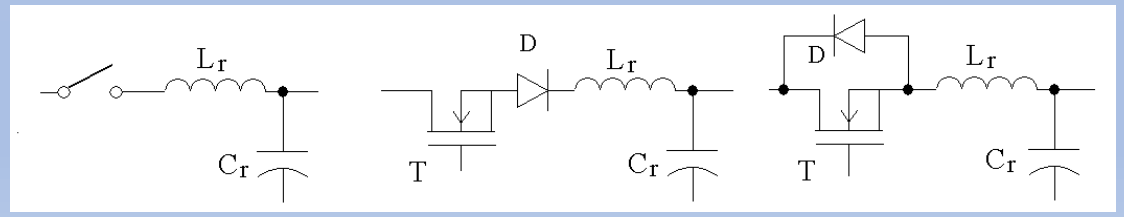
Improved: 11.9%

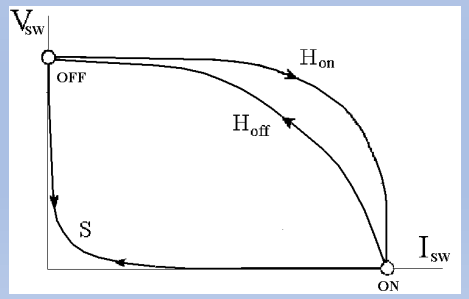
# The technology

- We use high frequency DC-DC power conversion for all types of voltage conversion to replace the conventional AC-AC transformer




- Install power breaker with zero-current switching:



# Final remarks

- In the next 10-20 years, the market will be dominated by electric vehicles, robots and data centers.
- No need to worry about the frequency, phase angle when adding DC sources and DC loads as in AC system
- No power factor issues
- No electrocution we use low voltage 20V layer
- Reduce materials and enhance efficiency
- New standard, new operation and new era of power for the future
- No need to worry about the frequency, phase angle when adding DC sources and DC loads as in AC system
- No power factor issues

# DC Power Distribution